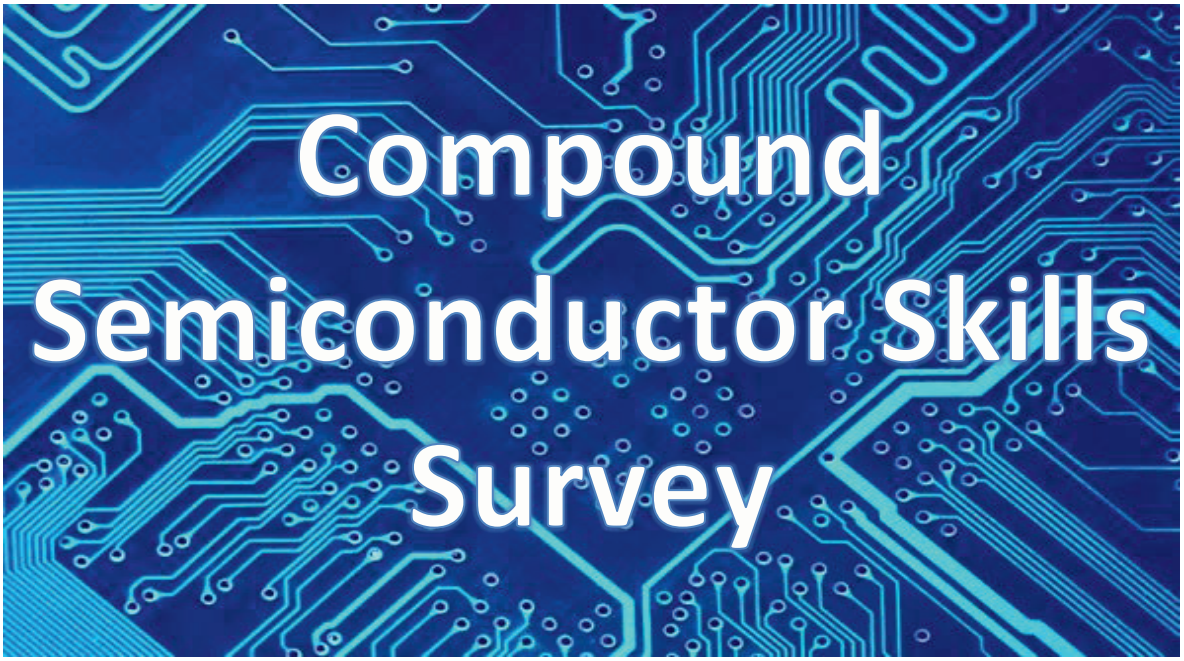

FINAL REPORT

July 2018

"Skills are a priority for businesses because they are central to adding value – in leadership, management, production processes and innovation, enabling the introduction of new technology and knowledge transfer. The best performing businesses are those which are highly innovative, quickly adopting new technology or innovating themselves – in their products and processes as well as in business and management practices."

Neil Carberry, Managing Director, CBI

"What we are trying to achieve here is South Wales will be unique. It's an opportunity, not only for Wales but for the UK and Europe"

Drew Nelson, CEO, IQE

UK Electronics
Skills Foundation

Contents

Introduction

As noted in a recent report by the CBI (CBI, 2017) skills are critical, yet we struggle to get provision right. They are central to an effective, national industrial strategy. For the UK to maintain its position as a leading global economy, investment in people's skills is essential.

There is a growing Compound Semiconductor (CS) Cluster in South Wales, which currently directly employs around 1,500 people and is set to see significant growth.[1] These are high value jobs at the start of the semiconductor supply chain and demand is expected to grow significantly over the next five or so years. There are expectations that the UK will be at the fore of a global compound semiconductor market predicted to be worth $140bn by 2023. However, it is a highly technical sector with some very specific skills sets.

In order that the Cluster can grow and flourish as an area of expertise in this global industry sector, it is essential to ensure that the appropriate educational and training capabilities are in place. These are required to support the anticipated growth and to attract more talent and inward investment.

Objective

The objective for the UKESF has been to produce an independent report that identifies the future education and skills requirements to support the success and growth of the Cluster. In order to produce the report, we have gathered evidence through an online survey and in-depth interviews with key stakeholders from industry, NGOs and academia.

[1] At the core of the Cluster is CS Connected. This consists of the Institute for CS, the CS Centre and the CS Applications Catapult. There are four principal business partners: IQE, MicroSemi, Newport Wafer Fab and SPTS. The supply chain partners are: Airbus, GD UK and GE Healthcare.

Context

In November 2017, the Government published a new Industrial Strategy. This long-term plan aims to boost productivity and earning power throughout the UK with investment in skills, industries and infrastructure of the future. The Strategy states:

> *"The world is undergoing a technological revolution. Artificial intelligence (AI) will transform the way we live and work … This fourth revolution [also known as Industry 4.0] is of a scale, speed and complexity that is unprecedented … blurring the lines between the physical, digital and biological worlds. It will disrupt nearly every sector … The UK is already a world leader in AI … UK innovators push boundaries in robotics and the internet of things*."

The Industrial Strategy also highlights the importance of improving intra-city transport and creating faster links between cities. AI, robotics and transportation are picked out in the strategy as key areas for focus and investment, and all are dependent on Electronics. As the strategy explains, its success will "depend on our ability to keep up with the pace with new sectors and emerging businesses". For this to happen, a higher number of young people will need to study Electronics at university.

The UK has a long heritage of technological innovation and has a world-class Electronics sector. However, there is a fundamental problem for the UK. Our participation in and leadership of these technological advances is being limited by a chronic skills shortage in Electronic Engineering. Over a number of years, too few students have been studying Electrical and Electronic Engineering. This, in combination with an ageing workforce, means that there are insufficient graduate engineers to drive forward innovation and progress. This situation is likely to worsen post-Brexit. The shortage is also exacerbated by a fragmented landscape across the sector. Ultimately, this will undermine the Electronics sector as a whole in the UK, which in turn, will adversely our economic prosperity.

The UK Electronics sector is a world-leader and one of the keys to the success of the UK economy. Engineering contributed £455.6 billion to the UK's economy in 2014. The Gross Value Added (GVA) of engineering businesses was more than retail, wholesale, financial and insurance sectors combined (Engineering UK, 2017). Within engineering, the Electronic and Electrical Engineering sub-sector contributed more than any other did (GVA £131 billion) and employed 1.5 million people (Engineering UK, 2016, p.23). The market for compound semiconductors has rapidly expanded and is estimated to be worth £66 billion; the UK has a current market share of around 9%.

Electronics is a sector that is continuing to grow and the demand for graduates is outstripping supply. Overall, only 3,330 UK students enrolled on first degrees in Electronic and Electrical Engineering in 2017, which is less than half the number enrolling on Mechanical Engineering degrees (UCAS, 2017). Approximately 22% of employers in this sector have reported problems in recruiting engineering graduates (The IET, 2016). A survey conducted by the CBI revealed that 46% of employers reported a shortage of STEM graduates (Engineering UK, 2016, p.262).

Findings

Preamble

This report provides some key themes from evidence gathered through a series of in-depth, structured, telephone interviews with some key stakeholders. A locally based, highly experienced, journalist has undertaken these interviews.[2]

As noted in the Introduction, the CS Cluster has only a small number of core partners and, as a whole, the CS sector is relatively small. Nevertheless, over 20 stakeholders and potential partner organisations were interviewed and their views are reflected in this report. As well as the core CS Cluster partners, they included a number of different commercial companies and Higher Education Institutions. This range reflects the disparate and wide nature of those involved with compound semiconductors through the Cluster. Transcripts from these interviews have been included at Appendix 2. In addition, we have augmented the evidence collected through the interview with data from an online survey of stakeholders (16) from the wider CS community who had not been interviewed. The full results from the online survey are included at Appendix 3.

Headlines

These are the main headlines from our research:

- There was a lot of positivity surrounding the potential for growth within the CS Cluster but there were significant concerns about sourcing sufficient additional, skilled, staff at all levels to meet the future demand.

- It was widely acknowledged that there are few, if any, 'ready-made' potential employees for the CS Cluster; upskilling and re-training are required for all new recruits.

- The likely retirement of older staff over the next decade means that sustainability is a genuine and immediate concern for companies; recruitment has to increase over the next five years just to maintain capability, let alone meet future growth plans.

- Furthermore, the future growth for high-value jobs within the CS Cluster core partners is forecasted to be high; almost a thousand (939) additional jobs are likely to be created by 2024.

- Therefore, there is a need to take a more strategic approach, across the CS Cluster, in order to create a 10–12 year pipeline of 'talent' to address both the skills shortages and skills gaps.

- Employers were positive about apprenticeship schemes. However, employers would encourage providers to offer a whole range of more flexible and modular-based training courses, not just for apprenticeships.

[2] Nick Flaherty. He is one of the UK's leading technology journalists with over 25 years in the business as a writer, editor, consultant and media trainer. In that time he has edited a wide range of magazines, blogs and newsletters across the spectrum of technology, from silicon to automotive, providing clear, detailed and informed content, from news to industry comment. He is currently power editor for *EEnews Europe* and Technology editor for *Unmanned Systems Technology* magazine.

- Employers have some specific skills gaps; these include wafer level testing, characterisation and software.

- Employers saw the future demand for engineering staff educated to Level 8 (PhD) as high; plans for the Centre for Doctoral Training were welcomed, particularly the collaboration with industry. However, some doubts remained that demand at both Level 7 and Level 8 may still exceed supply.

Future Growth & Skills Demand

Interviewees were optimistic about future growth prospects for the CS Cluster and identified a number of areas where they considered that there was the prospect of significant growth. These included a wide range of application areas, including power (consumer, automotive, industrial), RF (4G, 5G telecoms, radar, sensors) and optoelectronics (VCSEL, fibre, sensors), as well as across multiple substrates (Si, diamond, GaN, GaAs, SiC) and multiple materials (GaN, SiC, GaAs). Some interviewees also identified possible applications for compound semiconductors in the healthcare arena. This positive sentiment was echoed by the survey results; 14 out of 16 respondents said that their organisation had plans to recruit engineering staff in the next 12 months.

Therefore, we have attempted to quantify the potential for future jobs growth within the core partners of the CS Cluster. Our forecast for this future jobs growth is shown in full at Appendix 1. The methodology we used for making the forecast was to take the stated 3-year business projections from interviewees and then combine these with some longer terms forecasts. Clearly, beyond the 3-year business plan horizon, there is a degree of uncertainty. For instance, the figures for years 4–6 would depend upon the successes and deals achieved in years 1–3. Nevertheless, from this analysis, we are forecasting that almost a thousand (939) additional high-value jobs could be created within the core partners of CS Cluster by 2024.

Skills Shortages

Although growth is the driver of increased demand for skills; however, it is not the principal reason for recruitment, at least not in the short term. The principal reason is sustainability. The retirement of older staff means that recruitment has to increase over the next five years just to maintain capability, let alone support the forecasted growth. The consensus of interviewees is that at least half the employees of their organisations, if not more, are likely to retire in the next ten to 15 years. Moreover, it generally agreed that it would take at least five years to get the majority of new employees fully competent. Therefore, this is creating a real a sense of urgency about tackling the skills shortages.

> *"We are going to have to run fast to stay still and even faster to make any ground – we are not the only country in the world looking at CS through all the applications.*
>
> CSC, Cardiff

Overall, almost two thirds (10 out of 16) of survey respondents reported that they had already experienced a skills shortage[3] within the last 12 months. It is particularly noteworthy that the most serious problems companies experience when recruiting is for positions requiring higher degrees (post graduate degrees or PhDs); we found that 6 out of 16 respondents said that they 'very often' had

[3] A skills shortage is defined as 'an Engineering or Technology vacancy that has remained unfilled for at least 3 months due to the lack of a candidate with the required skill set' (Annual Skills and Demand Survey, The IET).

problems, whilst almost a fifth (3 out of 16) said that they 'always' had problems due to shortages when recruiting post graduates.

Skills Gaps

As well as a shortage of staff, there were significant concerns about particular skills gaps. In general, a substantial majority of survey respondents (12 out of 16) reported that 'lack of depth of technical knowledge' was the biggest problem when recruiting new staff. Indeed, 7 out of 16 reported that new starters lacked a knowledge of compound semiconductors, whilst over two thirds (11 out of 16) cited lack of practical experience of compound semiconductors as a concern.

In terms of specific technical gaps, interviewees identified wafer level testing as a key skill that is currently lacking. Testing is important for fabless companies but differs from silicon functional testing of large chips, as the compound semiconductor devices proposed are simpler and less integrated. Therefore, characterisation is more important but will become a bottleneck for high volume production. Whilst there are plans to expand the testing infrastructure with the Cluster, the absence of skills in this area is seen as a problem.

Another skills shortage associated with volume production of compound semiconductor chips is software. Interviewees considered that engineers with knowledge of software (for modelling, characterisation and test of CS devices) are in short supply and will become another bottleneck for manufacturers.

Skills Solutions

Those interviewed all recognised that there are no 'ready-made' employees for the CS Cluster, citing the relative newness of the sector as a specific recruitment challenge. New recruits either have silicon skills and, therefore, need specific compound semiconductor training, or have compound semiconductor skills but still need training in volume tools and processes (for instance, in the cleanroom environment or in packaging).

> *"We have got to train our own people and create a talent pool in Caldicott as looking outside there's nothing out there. It is quite scary the skills shortage – the average age is 46, 47 – there's a big void to the younger age group."*
>
> MicroSemi

In the short term, it was felt that some recruitment was possible from Scotland with the closure of fabs (e.g. TI/National Semiconductor, Motorola/Freescale/NXP); however, it was acknowledged that these silicon engineers would need re-training. This re-training would require a mixture of in-house and externally provided courses.

There had also been some limited success in addressing the skills shortages by recruiting engineers from overseas (e.g. from Singapore). However, respondents did not consider this to be a sustainable, long-term, solution for a number of economic and financial reasons. In terms of re-training, there was strong support for a flexible approach, with a mixture of short (day release) modules on specific tools and processes, rather than longer periods of off-the-job training.

> *"Cross training between the compound structures is a real skills gap"*
>
> Swansea

However, the overwhelming consensus was that these measures were merely short-term palliatives and that developing a strong talent 'pipeline' within the UK was a strategic priority.

All interviewees from companies thought that apprenticeships were an important part of the solution to skills shortages. They all currently operate apprenticeship programmes at Levels 3–5 and some were involved with degree apprenticeships (Level 6).

One barrier to the future expansion of apprenticeships was the availability of training providers and partners with sufficient specific technical focus and Electronics content within curricula. Another barrier was the lack of awareness about opportunities within the CS Cluster among school pupils.

In terms of degree apprenticeships (both Level 6 and Level 7), it was felt that more Higher Education institutions should be offering further programmes, as employers were attracted to the flexibility of these schemes. More widely, they wanted more students to have the opportunities for more industrial experience as part of their degrees. In the survey, around two thirds of respondents stated that they already offer work placements to students.

Looking ahead, demand for engineering staff educated to Level 8 (PhD) was expected to be high. In the survey, 9 out of 16 respondents identified doctorial research programmes as a future need in the next five years. In addition, 7 out of 16 respondents identified the need for specific modules in postgraduate degree courses, relating to compound semiconductors, to help them grow.

Interviewees welcomed the proposed Centre for Doctoral Training (CDT), particularly the envisaged prospect of 16–25 potential recruits per year in three years' time as the output from the CDT. They also supported the CDT intended approach combining research with industry and innovation. However, there was concern about the size of the potential student input into the CDT and some doubt that even with the CDT, demand may still exceed supply at Level 8.

Opportunities & Threats

During the interviews, we noted a number of potential opportunities and threats; these are summarised below:

Given the heterogeneous nature of compound semiconductor (compared to silicon, which can be considered as homogeneous) there is huge potential in the future. However, some saw the breadth of applications to be a possible negative. On the one hand, the potential growth for compound semiconductors was seen as an obvious positive. However, the wide range of technologies and the huge array of applications means that it is difficult to have a clear focus. Therefore, there were concerns that efforts to develop coherent strategies may by problematic.

Investment in CS Connect as the effective representative body for the Cluster by local and national government, academia, research and commercial companies would allow a single voice to be heard across technologies, processes, training and end applications. However, defining that single voice from the multitude of stakeholders would be a complex task and would need considerable coordination and 'buy in', which has sometimes been difficult to achieve in the past.

Potential external partners in the UK were concerned about how elements of the Cluster would compete with existing provision, especially in wafer epitaxy and device fabrication.

> *"There's a risk that if we only work with one or two companies we become too focused"*
>
> ICS

There are also concerns that the Cluster is not fully taking advantage of collaboration around end market applications.

> *"If Wales is serious about space and drones then it's here at Aberystwyth, with people and facilities, it's here with the radio, sensors, IT, big data, building cameras for space missions and modelling space craft."*
>
> Aberystwyth

> *"The worst possible outcome is to have two facilities in competition"*
>
> Sheffield

Appendices

1. Forecast of Future Growth in Jobs
2. Interview Transcripts
3. Survey Data

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About the UKESF

The purpose of the UKESF is to tackle the skills shortage in a coherent way. Our aim is to:

> "**Encourage more young people to study Electronics and to pursue engineering careers in the sector.**"

To achieve the aim, we have four strategic priorities:

- Ensure more schoolchildren are **aware** of Electronics. Show these children, their parents and teachers that there are exciting and worthwhile careers available as designers and engineers in the Electronics sector.
- With our partners, provide opportunities for them to develop their **interest** in Electronics and engineering, through to university study and/or apprenticeship.
- At university, ensure that undergraduates are encouraged to pursue careers in the Electronics sector and they are supported in their professional **development** so when they graduate they are equipped with work-ready skills and experience.
- After graduation from university, we will help create a community of Electronics engineers to secure the future pipeline. We will **build relationships** and act as the representative voice for the sector on skills.

We are an independent charitable foundation at the nexus of an extensive network of partners and collaborators. On behalf of the sector, we will build relationships, provide thought leadership and act as the representative voice on skills related matters.

Registered charity number: SC043940
www.ukesf.org

With Thanks To….

Neil Dickins and IC_Resources

Nick Flaherty

Respondents and Interviewees

Appendices

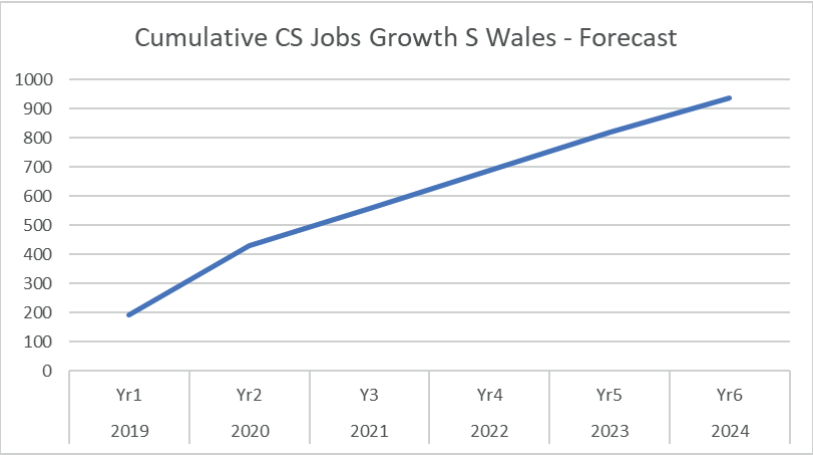
Appendix 1: Forecast of Future Growth in Jobs

We have attempted to quantify the optimism reported by interviewees about the potential for future jobs by predicting the future skills demand within the core partners of the CS Cluster.

The methodology for making the forecast was to take the 3-year business projections from interviewees (see transcripts at Appendix 2) and combine these with longer terms forecasts. Beyond the 3-year business plan horizon, we acknowledge that there is a degree of speculation. For instance, the figures for years 4–6 would depend upon the successes and deals achieved in years 1–3.

From this analysis, we are forecasting that almost a thousand (939) additional high-value jobs could be created within the core partners of CS Cluster by 2024.

Organisation	Role	2018	2019	2020	2021	2022	2023	2024
		Baseline	Yr1	Yr2	Y3	Yr4	Yr5	Yr6
IQE	Process engineers, Equipment engineers and Operations staff	600	50	50	50	50	50	50
Newport Wafer Fab	Process Engineers	200	20	20	20	20	20	20
Newport Wafer Fab	Cleanroom Technician	200	30	30	30	30	30	30
SPTS	Equipment engineers	55	30	30	10	10	10	10
	Technicians	55	30	30	10	10	10	10
Catapult	Power		6	20				
	Opto		6	20				
	RF		6	20				
	Support		5	6				
Swansea	Cleanroom	200	10	10	10	10	10	
Total		1310	193	236	130	130	130	120
Cumulative			193	429	559	689	819	939



Appendix 2: Interview Transcripts

Higher Education:

- Aberystwth
- Cardiff
- Sheffield
- Swansea
- Warwick

Epitaxy Wafer Suppliers:

- CSC
- ICS
- IQE
- Newport Wafer Fab
- Plessey Semiconductor

Catapult

Equipment Suppliers:

- Oxford Instruments
- SPTS

Packaging:

- Microsemi

End users:

- Compound Semiconductor Technologies, Scotland
- Huawei, Ipswich
- NPL, London
- Zeta Lighting, Oxford

Higher Education

University of Aberystwyth
Experienced record intake in 2018: 130 for Physics, 250 for Computer Science, 70 for Maths.

Prof Andrew Evans, Head of Physics at the Institute of Maths & Physics (includes Computer Science and Engineering)

We have an interest in working with all major industries in compound semiconductors. We tried to get some research work going in the past, but it has not led to any projects so we have no formal projects.

Mike Scott, the IQE founder, is a fellow at Aberystwyth, and through partnership with Bangor, we have explored many possible links. We still have some interest with the odd paper and areas of electronics and surface science and optics – network of photovoltaic cells, another on optoelectronic sensors.

We have engaged with the various forums, but it just felt an endless process of providing lists of what we do, duplicating over and over again.

I am telling graduates the CS investment is huge, and the UK is investing. If we could design our graduates to fit and there was a handful going down to S Wales I would be delighted. We have 70–80 graduates on CS each year; we are producing people that are being trained in Wales and more willing to stay in Wales than attracting people from elsewhere.

We are re-designing the course so that we can do one-day modules at a drop of a hat – Quioptic have done that for optical design. We had a student that did a summer project there.

I started out in III/V materials – we wanted flat substrates for organic electronics, using diamond, SiC, graphene, organic on epi substrates, instruments, nanodiamonds. If you really want to understand these interfaces, that is fundamental research. We are working with Swansea on II/VI materials on solar cells and sulphides, on GaN with Bristol, but the measurements are difficult.

Boron nitride (BN) is a good example. Diamond company De Beers is interested in how BN is chemically effected by drill bits; we model experiments to look at interactions at various temperatures and work with Johnson Matthey on oxidation state of alloys at temp. There are loads of really interesting physics in there. We have software tools to do that that most people don't. We have around six students on diamond and III/V making diodes and measuring how the atoms line up. I would like it to increase – but it is not an alternative to fundamental work. We will be looking for three or four post docs; a technician for one of our post docs.

We do not have spinout companies yet, our priority is teaching – our focus is very much on provision of graduates so in some ways Cardiff and Swansea are competitors. I prefer to be involved with things – many places prefer to do things themselves rather than collaborate – if we are up against that, we are wasting our time.

I am involved as a probable partner on two CDTs but that does not include CS. My assumption is there will be a PhD training bid and it will be Cardiff. There is a tendency for big places to do it themselves and the instinct is not to share unless there is something that they do not have.

It's the wider collaboration is always a challenge and there are obstacles – we have to get into people's minds. Geography is often stated as a block as we are closer to Manchester, Liverpool than Swansea. However, in drones and satellites we may well end up being the centre of things. If Wales is serious about space and drones then its here, with people and facilities, it's here with the radio, sensors, IT, big data, building cameras for space missions and modelling space craft.

Cardiff University

Prof Rudi Allemann, Pro Vice-Chancellor and Head of College of Physical Sciences & Engineering

One things that seems to be a real problem is the awareness of high school students on what we offer – there is a lack of understanding that these jobs exist, how does a kid know what to do when no one else does. There is a clear disconnect between the iPhone even though everyone uses it and the technology behind it. That is a big problem. There is also a certain lack of awareness of the opportunities in the career path – they are not aware of what the people do in the strange outfits.

There is also a lack in apprenticeships to get more technical people in who are trained. There are over qualified people doing some of these jobs. For us that matters.

If we had a CS degree I don't think there would be much interest. We need to strengthen material science – it is distributed all over the place – so we have a potential plan for an institute of material science combining physics, chemistry and engineering. There is a lot to be done; we've hardly begun.

Problem solving skills are important for everything but then there is a shift from specific knowledge – if you do a career apprenticeship you are trained on the job. To be just 100% skills focused is a bad move, wide knowledge – CS is a good example, from optoelectronics, through power and RF – industry can do the specifics much better than we can.

Software – we have a computer science programme but that is a wide field. We just started the National Software Academy to write software for specific problems. The first set of students graduate this year but we don't get enough students, they are not aware of the opportunities. There are so many opportunities but so few people. In the end we think that can be moved to degree apprenticeships.

This is a wide field where people can operate in many different places. It is a growth area for us – we are in the process of getting a CDT in epitaxy, which would have five intakes generating 20 graduates a year, so we would have a steady stream of PhDs in CS. We should know by the end of the year. That is a good place to start. Then we will probably follow with a Masters that's CS-related, especially for the international market if the market develops in the way we think it does.

As long as we use CS Connect – we are very keen at Cardiff – if we do that we might get somewhere.

University of Sheffield

Prof Peter Houston, Electronic and Electrical Engineering

Talking with colleagues there is very little coming out of Cardiff generally about how it links with the rest of the UK in particular. As part of the National Epitaxy Facility with Cambridge and UCL, we are in the enviable position of having a considerable technological expertise in-house in device

fabrication. Therefore, we do not feel at this stage that the CS Centre can help with the basic technology until they get up to a certain level and offer certain services. However, I'm sure there are other people that can provide the crystal growth as well.

The CSC and Catapult are looking at a TRL level above that of the EPSRC, so the main benefit that my group is helping bridging the gap between the research we do and companies that can use the technology that we develop. I think it would aid taking the ideas forward into industry.

My current work is on GaN power devices and innovations there – there is been a big surge in interest in these materials and devices, and we are looking at a few innovations that may or may not be of interest to companies. We would hand over to the Catapult to put us in touch with companies. For example, we are talking to Nexperia (former Philips Semiconductor silicon power fab at Hazel Grove, Manchester) – they have supported our programmes and are aware of what we are doing.

In the general semiconductor group at Sheffield in Physics, as well as Electrical Engineering, we do cover a wide range so I think the diversity is quite substantial. It goes back 40 years as one of the first universities to get involved in CS, but what it means is there is a lot of diversity generated in that time through the years, but I can only speak generally. There is a strong area in visible LEDs, different substrates; Tao Wang, prof in charge crystal growth, is a partner with Peter Smowton in that.

It's not clear how that fits with the Cluster – it could be split via TRL levels – the centre supplies novel materials into the community and has been around for 30 odd years; it's not clear whether the Cluster will be a certain TRL level.

The worst possible outcome is to have two facilities in competition – our view when I was running the facility was we applauded the funding going into S Wales so we did not see it as a threat but we must be careful – it's not inevitable but someone needs to keep an eye on things. EPSRC encourages applications in certain areas so that would probably be the best organisation to have an oversight.

We collaborate with Cardiff in a joint EPSRC project with Paul Tasker, but the expertise that we draw from Cardiff is in the RF and microwave characterisation, mixing switching with RF to integrate the two technologies. We make the devices, and we wouldn't tap into any device technology as I don't think its mature enough and we would want to retain our own capabilities.

Most universities have their own modelling capabilities and we have groups in the department that do RF modelling so I think that would be more beneficial to the companies and a lot of them do that.

The other project we are involved in is switching for power electronics – the University of Nottingham has packaging covered. There is good capability spread around the UK and the Catapult could tap into that and supplement it, but I think Nottingham with the packaging would want to retain that capability. For example, we have a need for prototype packaging from our project with Nottingham, which might be where it fits in with the Catapult.

The UK generally lacks sustainable funding over decades – the danger is that Catapults are the 'in thing' now, but if the funding stops or it has to be self-funding after three years then it can peter out.

There are two things missing – who knows how to make GaN power or RF devices? We can train PhD students no problem but there is a lack of funding and a lack of UK-based students. This is a persistent problem so we attract people from overseas but not all of them stay, which is a danger with public funding.

No one should underestimate the time it will take to acquire the technology. Building a new clean room is just the start; the operation of the clean room is two to three years away, but it is usually longer than you think – then you have to fill it with people who are experts – this is the problem I think.

At Sheffield, we have grown up over decades in a gradual way, but what they are trying to do in the CSC is a step change and that is very hard to cope with in terms of manpower. As an example, with the dotcom bubble, we lost a sizable proportion, the majority of staff, to Marconi at Caswell – at one point we had no skilled people to grow crystals (but then they came back). That is the danger of a Cluster like SW sucking experts from around the country – it has to be done in a controlled way and I'm not sure how that would be done.

Sheffield could have a role in training on device and it would be studentships to be placed on projects, and you can then be tapping into the expertise at different universities and it has to be done in a responsible way.

It's quite difficult for a university at the moment, with expertise to train them for six months or a year and send them back – a better route is to have someone stay in the institution for three to four years and contribute, and then move on.

I think the Cluster is a positive thing – I just worry about the sustainability. I am not sure there is enough funding routes available in the future to keep it sustainable and the loss of European funding would be an issue. Five years to judge whether it is successful is also too short – it takes two to three years for the infrastructure to be put in place and then you have to build up the technology and that takes years.

Swansea University

Prof Paul Meredith [PM], Physics (fabs, device, process development) and Dr Matt Elwin [ME], Director of NanoHealth (lots of semiconductor work)

We are heavily involved in the proposal for the Centre for Integrative Semiconductor Materials (which will be April 2019 to find out).

In NanoHealth we have had four innovate UK projects with partners in the Cluster over the last two years, both industrial and the University of Cardiff, mainly around process development – nanoimprint lithography for the definition of gratings, dielectrics for passive optical waveguides, for stress tuning (CVD kits to tune the stress), photo lithography, photo etch deep oxide etch, deep CS (with SPTS). We have a long-standing collaboration with SPTS on process development programmes.

In power semiconductors we have projects with industry including Xfab and Zetex designing in CS material and are able to make those locally, with the capability to do all the bits of the process that are missing. We see an opportunity for the Cluster in power devices:

- Power RF is already covered by partners (NWF has a strong track record in this), developing new devices, new processes and make them available to the fab;
- Sensor programmes – medical (magnetic GaN device, seems a good opportunity);
- More niche – organics – join aspects of silion and CS and combine sensors, on board chips;
- High power GaN is pivotal for drivetrains.

Cross training for growers between the compound structures is a real skills gap – because if you need high yields you have to do the same thing every time and not keep changing. We need to upskill the growers and the test and analysis – testing chip or wafer level GaAs diodes or transistors is very different from high power GaN. Testing is a key challenge, as industry can't outsource the level of measurement and analysis at the current level, with surface analysis and microscopy. We are talking to SPTS, NWF and IQE about how we help them with that.

We are lacking the design capabilities for clean rooms, etc. There continues to be a real problem in finding design engineers that are capable of facilities design that can accommodate silicon processing but also manufacturing grade clean rooms for mixed material systems.

We will need 30–50 highly skilled engineers in the next three to five years, upscaling standard engineering graduates, fabrication engineers with additional skills for materials, liquid coating dielectrics, line printing of contacts; all skills that will move across.

ME: Grant proposal – £90m/£30m from funding council, dedicated facility, 30 to 50 engineers. Training that number of students.

PM: We have a lot of good analytical equipment in the region but there is a gap in funding the projects to skill up the staff to run the kit for the industrial needs (microscopists trained up, that's what you need for a good characterisation service).

We are lacking funding for training to run as a service. Even if the integrated semiconductor centre is not successful, we can see that the semiconductor industry will need something like this – it's been a long discussion with IQE and SPTS from both directions, for university and to support local industry.

University of Warwick

Dr Richard Beanland, Reader in Physics and consultant and director of Integrity Scientific Ltd (working on electron microscopy)

We have lots of kit and will start growing lots of stuff in the near future, but I've moved away from semis as an academic.

The problem that you have in terms of growth and epitaxy is that there are so many different groups with their own growth facilities. The EPSRC centre of excellence in Sheffield, for example.

We have nanosilicon doing SiGe and SiC; we also have MBE (molecular beam epitaxy, low volume, high resolution) kit in Physics looking at the antimonides.

There is definitely interest in narrow and wide bandgap semiconductors. That kind of thing is replicated all over the country in variable quality – it is not a very effective way of doing things but it has proved difficult to centralise it.

Our interest would depends what is being offered:

- Tthe SiC guys (Phil Moreby) are working more on the device side than the substrate side, so if there are sources of materials and devices for him, he would be interested;
- Antimonides – I think (Richard Jeffries) on a grant (Phil Buckle at Cardiff);
- Nanosilicon is not what it was – most of the academics have retired;

- There is a lot of interest in the technology at undergraduate level, for example in semiconductor nanowires. One of the attractions is Photovoltaics as a green technology, that is always really popular.

My expertise is electron microscopy of semis (at Caswell for 13 years, to Bookham, Oclaro) – how much of those characterisation facilities are being put into place? That's exactly where TEM fits in for preproduction – all of our useful and value added work was on the development of material – controlling epi parameters, on production errors – identify and fix, and failure analysis. The bulk of the work was actually developing material, making sure the composition and defect density is within specification.

SIMS is a huge thing (secondary in mass spectroscopy) for measuring the dopant levels – where you get that done nowadays is not simple.

Epitaxy Wafer Suppliers

Compound Semiconductor Centre (CSC) Cardiff

Dr Wyn Meredith, Director

The CSC is a joint venture with IQE to provide medium volume CS wafers on a commercial basis.

The whole enterprise has been getting momentum for the last year or so. The CSC is probably one of the first initiatives to get started quickly as a 50% joint venture between IQE and the University of Cardiff. The whole model was co-location with IQE and a staged transfer of capacity. The aim is to promote new applications in the regional and national supply chains and scale up R&D out of other universities.

The current head count is 77; the majority are operational staff, operating reactors, with 15% in engineering and programme management. As the business grows, we will be increasing the capacity for R&D and commercialisation. The view is that there is a very clear handover – we are not taking on volume activities that would be handled by IQE.

The Catapult is a different beast – that will handle T&M (test and measurement) and packaging, open remit for UK.

Skills need – we have been very much looking at the gaps in the innovation supply chain and manufacturing

Innovation supply chain – increasingly this is Cardiff and Swansea (power, sensing, integrated semis, healthcare) and Cardiff for RF, opto, nanomaterials

Gaps – both Cardiff and Swansea tend to be focused on device end, lacking pull through into systems. For a 10-year prediction we need to expand the remit to exploit materials at the system level, for example communications, sensing, healthcare, power – that's very much in line in co-creation and system level approach.

The local thing is the sheer industrial pressure – we have the full supply chain in the region with companies such as Renishaw for the automotive supply chain, so there is the critical mass. However, we need to build intelligence into the supply chain rather than re-inventing the wheel.

The national view of austerity means institutionally, morally and financially there is more pressure on delivering the impact of research. It is now about not just SMEs and spinouts but strategic relationships and balancing the demands of challenge-led research vs blue sky research – that's starting to be embedded in the way research bids are written. All those things are working in our favour.

There is a need for more coherent national strategy in the face of Brexit and cluster development. What the CS initiative does is give the conditions for innovation to thrive and the ability to measure it.

We will see over £500m of investment over the next 10 years with the Institute, Catapult, Cardiff City Deal, Newport Wafer Fab foundry, IQE and the EPSRC manufacturing hub.

Jobs:

- 480 NWF
- 200 SPTS
- 110 Microsemi
- 130 IQE inc. CSC

The new plant will be 8–10x capacity of the current one, with 90 to 100 reactors with the target of 300–500 jobs; 100 will be recruited in the next 18 months and we are talking about double digit expansion. These will be an equal balance post graduate and apprentice skills.

One key issue is the current age of workforce (these are from the last semiconductor industry boom in the '80s and '90s) and we have had 10 years without apprentices; that is a problem that's not going to go away.

The average GVA of these jobs is £86,000 GVA in 2013, 2.2x GVA. Three to four jobs at the wafer level for the supply chain is equivalent to eight call centre jobs, and that is an attractive pitch to Cardiff City deal. There is an angle to re-visit on 1,200 jobs and GVA footprints for three year predictions.

A CDT will have an output of 60, but that leads to 300 over five years and that's not going to solve the skills problem. The interesting bit is the NVQ with the Welsh Semiconductor Skills Centre – Semiconductor Engineering, which needs to be done again as a course. We cannot ignore this as it is the quickest route to upskilling the existing workforce across the UK for continuing professional development (CPD), as well as school leavers.

The narrative of the Cluster is beginning to change – we are starting to see a movement between NWF, IQE and SPTS to de-risk the activities, and that makes South Wales investing in semiconductor more attractive. We need a recognised training infrastructure with the logos of all those companies with the collective brand to give people confidence.

Once the infrastructure spins up we need to foster value added start-ups with an open access model. With the Cardiff facility when it opens in 2020, there is not long-term incubation space included in the foundry. Swansea has a model that could work; there is lots of spare ground behind the foundry that could be a Skills Academy or the HQ of CS Connected with incubation space.

This highlights the importance of the Cardiff City deal with income from rates. We only have five years to demonstrate the economic returns so we have to force the pace.

Test – we have been surprised in engaging with automotive component supplier KSR in Swansea for sensors as well as Sumitomo wiring, and they want modules and sub-modules test capability. They want to engage – gives an opportunity for value add services to US or Japan to justify investment.

There is been confusion that CS goes the way of silicon with standard product development kits (PDKs), which includes software modelling and test – that underestimates the fact that the CS has grown up without standardisation in equipment sets and with optoelectronics and optoelectronics where the key is the etching and that is very different.

On the software side, we have the National Software Academy in Cardiff so we think it is well served. There's been a feeling that there is a generic focus on software and CS will become a sub-sector of that, and I suspect at some point it will be, for example a CS Academy with an NVQ on materials and equipment. But the whole semiconductor skills definition needs more work.

CSC is currently engaged with over a dozen high profile partners with projects to the total value of over £5 million over the last 18 months. As an example it is working on a new product line of high speed InGaAs-InAlAs PIN and APD detectors with Integrated Compound Semiconductors Ltd (ICS) (not the Institute of Compound Semiconductors), who will use IQE as its key wafer supplier for high volume production.

Rob Harper, Programme Manager

I am familiar with the silicon clusters elsewhere, then they have all been highly successful but silicon based, and this is the first time that someone has tried to do it for CS – I think it's very timely. There are opportunities in data centre power, 5G, autonomous vehicles and the Internet of Things (IoT).

Most of these trends will be addressed not by silicon but CS so the timing is exceptionally good. The ambition is the correct one to have – to work across the material systems, different substrates, InP, GaAs, GaN and anything else such as antimonides.

The fact that we are focused on a few key technologies is a good thing. The market trends are for VCSELs, autonomous vehicles and wireless, so we are focused on the right technologies. This includes silicon carbide which can't be ignored, its IV/IV rather than III/V but it's still a compound semiconductor. They both take certain parts of the market depending on the application. The important thing is to focus on the III/V products that are close to market with large market size, such as VCSEL, power and RF, to grow the business profitably in the first few years to see the tangible benefits delivered early on, and once you have the momentum it's easier to bring the other technologies along.

In S Wales there is growth already at the epi factory in Newport – jobs are being created. CS activity in Welsh universities is taking a step function upwards as well as the rest of the UK; it was going up anyway but the engagement through InnovateUK CS calls and targeting the types of application where CS will be needed is accelerating research.

We are going to have to run fast to stay still and even faster to make any ground – we are not the only country in the world looking at CS through all the applications. The expertise is already here – we are not at the starting point, we are a long way along the curve. Roborough (Plessey at Plymouth), for example, is just one type of technology – there are a lot of other technologies that are TRL level 4 or 5, not quite at market but the basic research has been done and there are routes for markets, e.g. VCSEL, using materials developed elsewhere that are now being made in the UK.

It is about having the infrastructure to deliver what is needed and you can't grow that overnight, that's why the development of new skills is essential. We need to bring people through at all levels. With silicon developing that skill set was more straightforward but optoelectronics is very different from electronics and silicon electronics. If you look at the skills at the technician level, running an MOVCD reactor and understand the complex tools, that is a portable skill whether its power or opto.

Regarding test, the silicon foundry model is well understood and the fabless design houses understand how the system works as well, and there are good practices that can be adopted into CS.

You do have a lot of CS where you would not allow through a silicon line but are essential for, e.g. GaAs processes, so there will have to be some dedicated III/V foundries alongside the silicon foundries.

The volume demand for CS is not going to be like silicon – for example, UMS in France runs 1,000 GaN wafers a year. However, the amount of silicon in cars will diminish over the years as the material systems become more mature, moving to CS. For example, the UK Automotive Centre roadmap targets cannot be reached with silicon but require new III/V materials and that is what they expect to happen. It is challenging and a lot of work. Automotive qualification requires stringent testing.

I think we need to focus on the skills for the current roadmap – you will always need a few product experts, device physicists, they make good product engineers, but also the manufacturing skills at a very high level – 0.18um at NWF, process integration skills, software skills for building tools.

Alot of the skills are out there but the challenge is attracting them here. There have been many new recruits at IQE and I have been very impressed with their knowledge levels – the other important thing is the experience – there is a skill shortage

We will be creating more technician jobs than engineering jobs, and we have nvt seen much evidence of activity at technician level with course availability.

Institute for Compound Semiconductors (ICS)

Steve Sutton, Business Development Manager

ICS is intended to be a facility to be used by academics and we offer the use of the facility to industry. I am engaging the academic side in the wider UK who are active in CS area but need access to fab facilities. There's a certain amount of equipment sharing (for example, with the GW4 universities); we work together to plug any gaps to move projects along

We are also looking to set up spin-out entities in this area so they are near to the ICS as a facility to use. We need to be industry facing, raising awareness of what CS can do for the industry and engaging with industry in collaborative R&D, developing prototype devices, developing new processes. The main areas we focus on are GaN, RF and power, immediate focus on RF, and VCSEL technologies.

The aim is to address areas of weakness – capability gaps in the UK where we can make a difference, such as GaN on Si, GaN on SiC – there are some technological challenges to GaN on Si for cost sensitive applications that have led to companies moving away from that.

We want to identify exactly what those technical challenges are. A lot of activity is identifying the challenges and then finding the solutions, scaling up the CS technology and GaN on Si as ideal for that. We have initially invested in 6in capability and will transfer to 8in, scale up to silicon-like economies of scale.

From our perspective in the core ICS team we focus on fabrication for process engineers and building. What skills are lacking now has yet to be seen – internal strategy in development for process and device platforms. For example, NWF would require a product development kit (PDK) but we don't have the people to put that together. That could be done with research groups such as a modelling project with Swansea that could lead to PDKs.

Test? What is device characterisation and what is test – wafer level characterisation in front end, but vast majority on packaged devices is go/no go tests (although the same person writing the tests). ICS is certainly focused on wafer characterisation and metrology so we are looking at investing in equipment for broader characterisation for final test but not in volume, in small lots.

Prof Peter Smowton, Managing Director

We are involved in a major fabrication facility, ICS, which I look after but we also have research activities across semiconductor – on demand fab service, growth, fab, characterisation, even into systems development. We are definitely underpinning the Cluster.

CSC handles the epi growth but requires partners for fabrication, so we do that from small scale to intermediate scale, up to 10,000 devices – beyond that the next scale is NWF, that gets up to 7700 wafer starts a week each with 50,000 device on a wafer.

Test – we are looking to scale up as quickly as possible and it is something we are struggling to find the skills. We have eight post doc staff on characterisation; we have recruited six over the last 12 months. We are upscaling at a fairly fast rate and limited by the potential to recruit people - it is a slow process and it is limiting us quite a lot and probably where gating factor. The response to adverts are not picking up application as well as other R&D areas.

We do a lot of design work with software and the characterisation links into the design software so the activity is at that level. The aim is to have full wafer mapping with automated test and we are certainly pushing that, but even five years is insufficient to train up the number of people required.

We took a strategic decision to focus on two of the strongest growing areas – the first is RF devices for wireless comms and other applications and that is on GaN, probably on silicon. However, there are some alternatives and pros and cos to the different options – that will be a big area but might also be GaN on SiC, and that may get there first for the smaller applications with even higher performance such as radar. Then there is GaN on silicon for power electronics and that will be a huge area.

Photonic applications are also huge – there is massive interest in short reach comms, underpinning IoT, sensors, particularly in automotive with LIDAR sensors, the probability is that a lot of that will be in the GaAs devices that you can grow on silicon and I believe that will a huge area. These will be on 12in wafers in five to 10 years – we are intending to be 8in by 2020.

ICS is recruiting PhD level engineers; most people out there are limited by not having hands-on experience – they have seen someone else do it but not done it themselves – that is a big training thing.

What we have also been looking for is appreciation of manufacturing rather than small batch processing – that skill is not there unless you go to people who have been in the silicon industry and they don't have the CS skills so it requires a lot of training. People will always go back to their original way of thinking under pressure.

At the apprentice and technician level where we have recruited again, there is less of the hands-on capability and the appreciation of the working environments. There is a need for concentration throughout the process, understanding what is sensitive and when you can relax. Therefore, you need technical skills and manufacturing ethos with hands-on experience. Not finding people is a real problem.

We have got to train sufficient people and encourage the best people into the industry from an early age. The silicon industry people are of a certain age and will not be with us for much longer, and Asia has a skills shortage as well.

A CDT would produce 16 people a year. That's a relatively small number – what I hope is the publicity will pull in extra students who will also go through the same process, maybe 24 a year, and these would either be self-funded or by other governments, on the basis that the skill set gives you access to higher level jobs beyond process engineer, it's a route into industry.

Chris Matthews, Project Manager

Within CS Connected there iare CSC, IQE, InnovateUK Catapult and Institute of Compound Semiconductors at Cardiff (Univ EPSRC, Wefo funding)

We are an integral part of the Cluster (aware of logo and webpage but not anything else), already engaged in projects in the Cluster with SPTS and CSC, but we at a start-up stage, purchasing equipment and commissioning.

The philosophy is that it should be industry facing. With the process we need specific skill sets – recruited four process engineers, all new employees to Cardiff, one from a university background and two from industry, which is the balance we were looking for. That was through laborious advertising – we had to re-advertise several times with three rounds of advertising jobs, and we identified equipment requirements in those adverts. The equipment drives the job spec.

Clean room manager and Ops Manager recruiting: we wanted them to become experts in one or two elements of the process – we want specialism. We are trying to build on that and put in place a physical facility to enable them to demonstrate that their research can be rolled out to industry. It is a result of an EPSRC 2012 III/V report that identified a gap to 6in, 8in wafer. We are currently in an adapted clean room to 6in – new building in 2020 with purpose clean room will allow the move to 8in.

We will recruit one or two more process engineers – we only thought we would recruit three but the demand from the new equipment is that we will start a fourth. We definitely plan to have another clean room technician.

Looking ahead, I don't know. Our survey says the industry is fast growing, but industry has to trust that we are not an 'airy fairy' research centre and we will deliver, and that requires breaking down barriers of perceptions.

The more the merrier – the Cluster is important. There is a risk that if we only work with one or two companies we become too focused, but we will be restricted for the first couple of years with current clean room until we get into the new building.

We will focus on GaN VCSELs for the next couple of years and then we will look at what the industry wants.

In terms of recruiting we take above PhD, i.e. PhD plus some experience, or no academic quals from industry – equipment supplier with technical knowledge. We already skilled up another technician. We do not have the luxury of time to train up; they have to be mastering processes.

In terms of growth plans for the CSC and the Catapult, we are still waiting to see what shape that will take. We are at stage one for the next couple of years with processes that are characterised and available for industry, that is where the workforce kicks in. Therefore, we will work with Cardiff on the Masters programme for CS Process Technology and CS Electronics.

When we move the production equipment to the new building the old clean room will be the training clean room – training on the procedures in the actual clean room and standard operating procedures (SOP).

We will also have benches available for training on equipment so that companies could use clean room, renting space for training.

IQE

Matt Green, Engineering & Operations Director

My understanding of the Cluster is that it is an initiative to bring together academia and industry to build a cluster of appropriate skills, networking and infrastructure to bolster the CS manufacture and development. From what I am seeing it is still in its infancy (I'm at the volume manufacturing end). I am not getting much visibility on what projects are moving forwards or the initiatives that are in place.

Requirements are networking, working groups, communication of what is available (i.e. the capabilities), getting the industrial and academic areas together to have those discussions and disseminating the information to the whole wide groups. For example, at IQE we have a team that deals with conference and outward looking, and I only pick up little snippets from them so I'm sure there's lots of activity going on.

I am seeing huge growth in consumer optoelectronics – VCSELs are going into a wide range of phones and tablets. Can see that continuing to grow but with falling prices for applications such as 3D gesture recognition, proximity detection (where you put your phone to your ear and it switches off other applications), then there is automotive LIDAR sensors and medical 3D modelling (that is a bit further out). Beyond that, I am not really seeing what the growth drivers will be.

Right now, we are actively recruiting process engineers, equipment engineers and operations staff at IQE Cardiff and Newport. We have 60+ job openings immediately, and then we have to get them trained.

There is an immediate need for a handful at Cardiff as we have 10–15 already, and at Newport there's a roadmap to increase to several hundred in five years' time.

It is the classic foundry model with:

- Module specialists
- Operators
- Engineering
- Equipment engineers
- Process engineers

I do not worry about test at all – an epi foundry supplies the epi wafer and guarantee the specs and then the device test and customer carries out life test, so it's not part of the contract. However, as we move to larger volumes and established products then in-house in-line testing is desirable rather than mandatory.

Looking for all categories of applicant but we are more biased to PhD and degree level rather than college leaver. It is also about experience – you will have people who are competent in the technology but not in volume manufacturing as no one has done CS in volume (Motorola, Seagate and IR do volume production of epi or something else but not CS).

At Cardiff we can take someone with CS experience as its 50/50 pilot volume and R&D; for Newport we are biased to volume experience. It is a given process that's well controlled so it's a process with experts that can assist.

We can get people that understand the technology and the products coming from university or small manufacturing R&D sites, but it's about making the leap into high pressure, high volume production 24/7. Its running a production process with analysis tools, analysis software, stats software, process control, manufacturability, process variants and then how that interacts with the process on a particular tool.

Those moving from academia to industry are not workforce ready at all and a big risk – the individual may not be able to cope with that jump – it's a change in pace or mind-set, for example spending an extra day looking at something that might be very interesting versus getting the process back on track as quickly as possible.

There is a big disparity in relative timescales; dealing with academic customers, they may want a handful of wafers and spend a week discussing that and that does not fit with our available bandwidth and resources.

Training: we need a training academy – a German equipment supplier from Aachen uses Cardiff University as a seed ground for people to come across, which is a good idea. It provides the right technical skills but I would want to make sure that those individuals have been exposed to more relevant manufacturing technologies.

A toolbox for a production engineer is different from a CS process engineer but you don't get those in the degrees that people study today. I can see that right through a company a modular approach

on MOCVD, X-ray topography, statistical analysis would work – all of those become part of a tool kit and each company has a career progression, and to progress you need to achieve these modules.

The other side is when you bring people in a certain level there is the expectation of learning on the job, you cannot just put them through a course and they will be production ready.

The more junior levels you can more readily train for, such as technician level. Higher-level apprenticeships would certainly work for shift technician or shift engineer, and with career progression, chartered status would be further down the line, or other qualifications, which is more personal development than company development.

We have used apprenticeships in the past and we should in the future (there has been a lull in the industry).

I think there is a skills shortage only by virtue by having the right CS skill set, as there are not that many places in Northern Europe that do it in meaningful volume, specifically for InP and GaAs. We are looking further afield to attract skills; many engineers were homegrown, brought in at junior level, learning processes in house. However, as a bigger organisation if you don't have a more formal training scheme method it becomes harder to do, so you are looking for semiconductor skills or other III/V manufacturers around the world and there's not many of those.

I would like to see more of a formal interaction with the universities and colleges on modules, training courses and structure that IQE needs.

You cannot write off the human aspect. They might do a two-year Master's degree and may think they are ready but then find they are not; with an apprenticeship you get to that point earlier and when they are released they really are ready.

Eliot Parkinson, General Manager, Cardiff and Newport

Optoelectronics has grown at 25–30% CAGR over the last three to four years, and we see that accelerating in the next three to five years to 30–50%. Optoelectronics has finally matured into more consumer applications; before it was niche, scientific applications. Now LiDAR and mobile phones are the growth drivers.

Internet infrastructure in China – Fibre to the home (FTTH) – basestations for 5G with InP, all of that connectivity. VCSEL growth is expected to be huge for time of flight (ToF) 3D sensing and automotive sensing. That is where we see the growth.

Cardiff is focused on silicon optoelectronics – integration of optoelectronics onto a silicon base for higher performance. We have a site here that is full in St Mellons with 120 staff.

The growth driver is the Newport site. That facility has the capability hold 100 reactors in one site (we currently have 100 reactors across the world across 10 production sites). The site in Newport has IQE staff currently 600, 620; could have a factory at NP with 300, 350 staff.

The challenge is that a lot of the reasons the Cluster is starting to exist, as the partners grow they will need similar skills and that's a massive challenge to get the right skills and we've been talking about the pipeline for people studying III/V and even epitaxy to join the companies in the Cluster. We are looking for 100 a year for the next three to five years – the market will go up and down, split between very science-based chemistry/physics skill set for epitaxy and engineering, with mechanical

and electrical engineering for the maintenance. We want to hire a higher proportion (60/40) of engineering talent with good theory knowledge so we have the capability to absorb new technologies, but there will always be room for technicians.

I see the process is obviously going to be college-based and there is not the bandwidth in South Wales. We have gone international, for example active in Singapore recruiting. For equipment engineers, ex-REME, ex-Marine engineers have turned out to be really good.

We have pulled in really good engineers with electrical experience in complex equipment, but not with university qualifications. We have pulled in people with specific epitaxy growth experience – these are more senior people, but we have also had several process engineers from Infineon/IR; they know SPC, data management. If we had a choice, I do not think we would want 100% epi growers – the mix is proving interesting, people are bouncing ideas off each other.

As IQE has grown explosively, we have not yet settled on an agreed framework and organisation – that is still in the process of being agreed. We have hired a new HR and we are doing a full company skills analysis. We have been partners with Cardiff, but I don't see any movement on partnering on skills and qualifications so that we can send staff on day release or part-time education to get the skills they need, or the university creating degree courses as a qualified equipment engineer or an epi grower.

We have hired people from Sheffield who have the epi qualification and they have proven excellent. Initially we have been looking at a baseline engineering apprenticeship and HR are working on what those requirements will be – mulling it over, it is on the development list (we stopped being involved in that 2012).

We are desperately short of people that understand the epi growth technology – our second choice is people from the silicon industry. We have been hiring ex-silicon engineers with data analysis and process skills and they hit the ground running. We need that kind of skill – e.g. from Seagate in Ireland, production engineers, looking at trends and looking at SPC, that will be more important, that will be less than 10 for 100 reactors. Process engineers and technicians make up the bulk.

Test: IQE do not get involved in the processing aspect as we do not compete with our customers – our intellectual property is in the epi structure. Characterisation is a very specialised skill and we have been bringing in new people for new capabilities in characterisation. It is understanding what the tools are telling you that the skill, but that will be one to two people a year, a maximum of 10 for 100 reactors.

A training academy coupled with a mechanical engineering HND would mean people could work on the reactors in the courses and come out ready. We would want to look at the full suite of skills, hoovering up good relevant people from all over – as the partners grow, they will need things like test, but it is so varied. As the Cluster grows over the years, it will encompass the full suite of skills.

We have been trying to hire for eight months at Newport and we are making progress but it's not just technical staff but also Health & Safety with COSHH, facilities management, global supply managers, as the site gets bigger the challenges get bigger.

Newport Wafer Fab

Newport Wafer Fab focuses on wafer processing in silicon and compound semiconductors. It bought the silicon operation of the wafer fab in Newport from Infineon (International Rectifier).

Simon Argent, HR Director

Our raison d'etre is to be part of the CS Cluster so we know the challenges that may give us in the move from silicon, but the aspiration is to get into CS space. Some of it is the transition – we don't see ourselves moving out of silicon, we will populate the wafers that other people will produce.

When we were part of a larger group we did have some GaN, which went to Infineon. The transition to CS will be by skill and experience – we are in discussion with Cardiff on various modules to train existing staff. Some of the challenge is resource, finding staff with that skill set, then there is investment in new equipment. We know that some areas that need to be isolated and some investment is needed.

We currently employ 500 people including contractors – we could see that moving to 600 to 700 if things go the way we expect them to grow, as we have the space to expand into the old empty 6in fab that could be used for these other fields. We still use one part for final operations and test, but it is more cost effective than building a new fab from a standing start.

The people we need are not here now. We have a host of engineers on site – we need to get people in place with more technology specialist, translating customer requirements into something that you can make, practical R&D, so we will need tech transfer engineers.

We know in S Wales there are not those people so we will have to grow new, perhaps through the universities, nationally from the north of England, Scotland, such as the TI plant in Greenock (the old Nat Semi fab) or Motorola.

For short-term skill gain you are talking about the Far East, Singapore, we are going to have to look there. We did the same in 2007 for the site and gained 15 engineers from Singapore and Thailand, but the better way is to do that as a cluster as we have more to offer. We have had a good response on LinkedIn to flyers in Far East.

Looking from the bottom up, we have internally recruited technicians to move up to engineer position, with training and development. We need a graduate flow, we need a graduate scheme, more Masters and PhD students working on the more technology transfer activities, more females and reaching out to schools and tap into that network through Career Wales, VR 3D simulation. For example, there is the SEREN network across Wales that take the top students in GCSE with programmes for Russell Group universities.

Colleges locally are quite well equipped for electrical and mechanical route that keep our machines running 24/7 – what we have found is we can convert people from other sectors, we are more confident in that as there are some existing routes we can use.

The bit that is not very well developed is the degree apprenticeship framework – the universities are half-hearted about it in detail – they all fight over student numbers, and this is a way to get the numbers up.

Cardiff, Swansea have the reputation to attract students, whereas Cardiff Met, USW, if they can offer a more flexible approach to learning, there is some market for that certainly from an industry point.

We have some people with exposure to CS but it is not widespread. We are looking for overview training on CS and optoelectronics that we can share with all our employees, along with advanced level that might be delivered through the Masters. The challenge for us is they cannot have them for five days a week it needs to be flexible.

I would see a great opportunity for the Cluster to have something that is relevant and we all have an input into that suits our needs, such as a graduate cluster programme. We all have our own requirements and setting up the governance will be very important to make it successful on what it does and does not do.

From an HR perspective there is some mind-set changing. Now we are going for people already working in an industry setting. What we have not done is go for fresh graduates and have experienced a problem in the past as they were not workforce ready as that hasn't been part of their education – that's why a graduate programme or scheme that gives them experience is valuable.

I think that is one of the challenges is that the next generation coming through has a different expectation of a job and career. We have hardly any turnover at NWF and there is an expectation for long-term employment, the trick is getting them in and getting a great contribution from them while they are in.

Test is an area we know we need to invest in in both equipment and people. There is going to have to be development internally – I honestly don't know – that will be a challenge – not necessarily from overseas – it could end up being a limiting factor

I do see us having the software and infrastructure has been in place for some time and that will be a challenge as we move forward – the people who set it up may not be here anymore.
Universities with facilities could we engage with them overcome some short term shortfalls
That may be a route to help us in the short term

Plessey Semiconductors
Plessey makes GaN devices at its fab in Plymouth.

Dr Keith Strickland [KS], Chief Technology Officer, and Pippa James [PJ], HR Director

I have contacts within IQE and NWF so I am fairly familiar with what's going on. On recruitment, we have a number of scenarios now. We envisage doubling in size in the next five years but looking for partners in such places. In terms of jobs there are two aspects – more low- and medium-skilled operator jobs and shift work within the operational facility. I would image that is the same with the Cluster with IQE and NWF.

It is very difficult to say over the period but half would be that type, the other half at degree level and above in various sectors in optoelectronics and electronics. It would be 100 to 150 people over five years, it all depends how things go forwards.

Skills: at the specialist level such as optics, physics and optoelectronics we do like to find people with some relevant experience, e.g. specialist post grad, and they are the skills that are quite scarce.

There are specialist areas in semi processing that are quite rare and we have had to go outside Europe to find those skills and they tend to be specialist process engineers in CS. We have the same principal tooling as IQE so we are potentially competing within the Cluster for MOCVD reactor and

growth engineers. However, we have general semi processing engineers and process engineers, and many of our engineers have transitioned to CS from silicon – we don't see that as an issue as they are highly transferable skills such as photolithography.

PJ: For technicians and operators we do not ask for specific qualifications but like HND in Electronics but we do train people – they have a minimum of five GCSEs and come in at entry level and work their way up through manufacturing to technician and equipment engineers with HNC, HND qualifications.

Straight from school they do a five-year advanced engineering apprenticeship from A-level and AS – at college full time, then one day a week – HNC, HND sometimes foundation degree – we have two or three per year of these.

We also take graduates in Physics, Material Science and Electronics, with Physics most prevalent. On the graduate programme they come straight from university with rotations for the first 12–18 months then they join a specific team, e.g. MOCVD or characterisation, then progress from there, three to five per year; these are not degree apprenticeships. However, they need a lot of support – an issue we have is we can't increase those numbers too much as they need mentoring support. We struggle with the bandwidth (mentoring would need a higher level of skills and that would stretch us too far).

Not looking at degree-level apprenticeships – using the apprenticeship levy with equipment and facilities apprenticeships.

The big problem we have is the buying power – in the Plymouth area we are the only semi company so we are competing with engineering companies such as Babcock, so the courses are tailored to their needs, which is why the bespoke training is done in house. That is where we would be working with a cluster but in practice it is very difficult.

KS: Bringing training together this is something the Cluster could do. If it were modular out of Cardiff or Bristol, could that be linked with activities in a college in Plymouth?

Our specialist software tends to be tools of the trade such as optical software tools but in optoelectronics it's more highly specialised. We have maybe two embedded software engineers and may hire one more for particular support functions.

Catapult

Catapult

Andy Sellars, Business Development Manager

From the Catapult point of view, the Cluster gives us a strategic base to build on; it spans TRL levels 1–9, from pure materials up to systems, so from that respect it is unique globally. CS Connected spans the whole spectrum.

We are late stage TRL and in the supply chain at the end of the processes. Early stages are cutting edge work but find it difficult to get it to the end markets, for example ask them to develop specific chips to find end applications for them. The chip industry is dependent on volume – needs to be in

the millions per year. We sit at the end – we cannot do everything and we do not want to duplicate what other organisations are doing.

We have seen market forecasts that say CS will be a $60bn market with 9%, that is $6bn, in UK – expected to grow to $13bn in 2023 – the UK has a large percentage of the CS market rather than silicon, it is a healthy market.

Wales is early in supply chain with key suppliers needing volume. A lot of the capital investment has been made on existing capacity. Other foundries in UK, approx. 10 seeing uplift – making them more sustainable. Migrating from Si to CS on Si in different ways. Is there enough capacity? Possibly not at the moment – we have the clean rooms and the fabs – it is the capital investment to scale up to CS lines. Existing power is silicon but we are now looking at GaN on Si for the future

We are not designing devices – we are looking at the needs of end applications, open call for performance for die. Add packaging, evaluation, development kits reference designs. We do have EDA and simulation – companies that do RF, photonic, power device; small companies, academics. We will have some of our own design.

Catapult recruitment: 5 section heads, plus 15 staff, plus five admin/support roles. The section heads are already in place, recruiting from universities. We need a mixture of grey hair and young – there are many design rules that are not written down, rules of thumb, for example, and if we can bring the new blood along that will be great.

Now, the head of power has started (see below), and RF and optoelectronics should be filled by April 2018. We have been recruiting since May 2017 and had a 'hit list' of 150 so there is a massive pool of talent.

The next part of the process is that the team leaders will populate the teams. We do not have a sense of how easy or difficult that might be. Location may be an issue, asking people to relocate. We are open to secondments, flexible working; also bringing people postgraduates from university.

We could look at a CDT and feed into that for our skills requirements. We are complementary as they are earlier in the supply chain with the devices, we are more applications based. Our target is to have 70 staff by the end of year – 70% of these will be directly involved in projects with a small number of overhead sales and business development.

We are looking for technical skills, design, modelling, reliability, testing, modelling device or systems, failure analysis, thermal management. There's a question on in house versus outsource to independent consultants, it depends on how critical the skill is.

We have talked about high performance computing (HPC) access for multi-parameter modelling, working perhaps with the HPC Wales facility and CFMS in Bristol.

Catapults do not have a remit for training – they are delivering intervention (training can set up separately). We might have some apprenticeships for power electronics lab technicians. We are ramping to steady state – we have been advised after five years to expand by 50%, so by 2022 that is approximately 1,000 new jobs.

Ingo Ludtke, Power Manager

We have managed to make an offer to a power electronics lead. We will probably only have two people to start with but ultimately around six – we are looking at a large number of technical people between RF, optoelectronics and packaging with around 15 in total, but that would be a high share for power. We need to attract the right projects with visible timing for me to start recruiting.

We have come across a couple of start-up projects that cover a wide area of power electronics skills, from micro-energy harvesting to MW grid connections. Therefore, it is really hard to pinpoint the exact skills we need each time, so we need experienced engineers that can take on a range of projects – we appointed one out of only three CVs received in total. The other two were good and not totally out of the question – one had a working in the UK issue and the other was close and could be considered in the future; two were from England. The process took about four weeks with two agencies, so quick and successful.

One of the possible streams of projects will come from Power Electronics UK, and connected with InnovateUK that direct the research for power electronics in the UK, and out of that the automotive electric vehicle area is very prominent, so we could have projects to do with power train inverters, power conversions for solar and grid connect. They would be the projects with the selection, characterisation and packaging of GaN and SiC, as well as the topology and control algorithms for converters.

We already see lots of interest in power device characterisation and, as a result, we have invested in kit that SMEs can use and companies are keen for us to characterise their products. This can be done in two different ways, either through collaborative R&D in bigger projects or we can offer access to the equipment as a commercial service, and on both sides we have had interest.

We have a power device analysis/curve tracer – you put a semiconductor device in and press a button and get a datasheet characteristic curves, and then be further processed for modelling the device so that the model can be used in a power converter simulation.

We have also invested in a simulation environment already – Pspice ADS and ICcap for characterisation and modelling. One customer has already requested output in Spice.

The Catapult is planning to build an innovation centre but we are looking at the timing of possible projects and may be this needs a temporary lab until the final destination is ready – that depends on the projects that we are winning, and that means going through the InnovateUK bids.

Equipment Partners

Oxford Instruments
Oxford Instruments develops semiconductor production equipment.

Mark Dineen, Technical Marketing Manager, Yatton

CS is pretty much our core strength. I joined from Cardiff having done a PhD in GaN – we are not mainstream silicon, we do MEMS but with InP, GaAs and other. It is a huge areas with Gan RF, SiC power, VCSEL, InP, and further out microLEDs maybe, depends if the tech takes off then out into bio sensors.

We are looking around the sensor market and a lot of that is less CS and more MEMS, but may be more related to the light emission. Until I went to the CS Connect event in Cardiff I was very

confused. There are the various bodies and lots of money but how they work together was a blank to me to be honest. Having spoken to various people there it makes a lot more sense. I can see that the CS Hub is IQE-based driving. The Centre is the research, the fab is the pilot production, with the Catapult connecting end users together. That makes a lot more sense now.

There are definitely opportunities. We have equipment in the Cardiff clean room and getting more involved in the projects there and we would like to be more involved in the pilot line.

This is a huge CS investment right now. We have aggressive plans to grow by following the research in CS and the applications into production – we want to be in production systems – probably 60/40 in favour of production – from small scale to full scale.

We have employed PhDs direct from universities – there is a dearth of people with experience, absolutely. There is exchange between SPTS and us, but when we recruit, we look for more of an attitude of problem solving and capable of being customer facing. There is lots of work where you end up talking to the customer, you have to be friendly and be able to carry on a conversation.

We have gone down the PhD route as they are the ones that specialise. We do not employ them at the technician level as they don't tend to run the tools but look after the hardware, but we have the technology side with more PhDs on hardware. We have people for example in production who came from Intel Ireland. We have a very multinational team – we look far and wide for people.

We do have apprentices in the company but we struggle to find people. We want hands-on time the lab and time out for learning, and they need to be work ready – it can take maybe six months to get them up to speed across the whole range. We really would engage on course development – we could we do one ourselves on plasma processing.

Bristol and Bath have good CS work and Cardiff, so they will come in with a very focused view on a certain device, e.g. InP photodiodes, so they are very specialised. You can have people that are very switched on, even with experience, but in a commercial environment and delivering what is needed rather than exploring the solution space is a challenge.

SPTS

SPTS in Newport is currently part of Israeli firm Orbotech. SPTS makes a range of semiconductor processing equipment.

Andrew Evans, Director - Commercial Services

I think it's a real opportunity with the Cluster as it identifies something that Welsh companies are very poor at promoting themselves – there has been the same presence in Wales as the South West for thirty years (that's long overdue), it could have been a silicon cluster a few years ago.

With the development of the Cluster I've seen more of Chris Meadows in the last six months than I have of my wife. We all have similar customers, similar supply chains, there is many benefits to be had. We are not starting from scratch – it is here already.

This year CS is 25% of our business and 33% next year, so it is a significant part of our business. It covers such as broad range: we see growth 8% in some areas, 25% in others; power, 4G/5G, automotive – this ties into the industry megatrends that are growing 15–30%.

We spend a lot of money on market analytics – we bounce a lot back and forwards and could be sharing that in the Cluster.

Growth plans: In the last 18 months, we have taken on 60 people. We do not think five years out – we look out a maximum of 18–24 months and we can see the same growth again. As a result of this growth we have changed the way the business operates and moved to a shift system as a trial – if that is permanent we will need more structure around that: more support in the teams, supply chain and R&D departments to support those longer operating hours. For every £1m we spend in our supply chain it generates five to eight jobs, so if we increase revenue by £50–60m that is 50–60 jobs in the supply chain.

There is general growth in all areas so we are doing more graduate and apprentice recruitment, experienced engineer and management. We rarely hire anyone without HND or degree – it is not a typical shop floor. The only non-degree apprenticeships are the build technicians – most have mechanical qualifications.

We tend to take on 25% with a Masters qualification in specialist roles such as Physics or Chemistry for process development and materials. Even at the graduate level from Cardiff, Swansea or Bristol, 1st 2:1 in Physics, Chemistry or Maths, and we take on eight to ten new graduates.

We take on others with experience, for example from Newport Wafer fab or our supply chain, for example Edwards. We have very few opportunities for mechanical engineers. We are looking for the ability to work in an environment to be creative and solve problems, and engineers with a commercial focus, for example running processes for customers.

Regarding new employees being workforce ready, we have a robust recruitment process where recruits demonstrate technical skills, presentation skills, are observed in tasks and on our leadership programme. Some of our graduates are up and running in front of customers in six to nine months, others it takes 24 months. For apprentices, it is an average 24 months before we let them out on their own. For our deposition equipment a graduate can be demonstrating systems in six months – it varies by department and engineer. We are getting our managers to think beyond technical skills for recruitment.

We work with University of South Wales for the apprenticeship scheme. This is five years, with three days a week in factory, and we pay the fees and small salary. We have 11 students – 99% of graduates get a role in the company – seems to be undersold (just celebrated 100th graduate with GE and other sponsors but there's not a lot of employers engaging). This is the type of training programme we need to look at, and we would take more if they could offer more – in marketing, finance, manufacturing, engineering,

We put all the potential applicants through a recruitment process with interviews, and we take the students on in the subjects they have chosen. The next level is a specific semiconductor course, e.g. how to work in a clean room, wafer handling, as well as the commercial angle – how to translate a scientific solution to a problem and explain to a customer. Half of our business is in Asia so core communication skills are essential.

Whether there is a follow on for new graduates or Masters courses – that is open for debate. That is a fundamental shift in degrees that is harder to do (we do that with Swansea, involved with first degree projects, and Swansea is the strongest university we work). Commercial experience is needed to make applicants more employable.

Software engineers – we have permanent open requirements for software and test – we interviewed a whole load of software engineers and it was quite clear their experience was very different. They all wanted to be games or apps producers; no one thought of semiconductors.

That is a challenge for us: we find it almost impossible to recruit in Wales, we recruit from Bristol or the South East. We are encouraging more women, and our R&D manager is leading this – it needs to be a focus. In Q1 we took in more women than men, including engineers, but it's about altering the perception of the industry – it's making the industry look more like pharmaceutical industry.

In Newport, Cardiff, South Wales, there is an issue with work experience and getting kids into the companies is a challenge. For example, Newport has withdrawn funding for a health and safety analysis and inspector, so schools cannot send kids into industry any more. This means a lot of work experience is through employees as a private arrangement under our own insurance – it is simply a case of an HSE officer and we would be willing to cover the costs – it is not very onerous, it's invaluable and could change someone's whole life.

Packaging

Microsemi

The Microsemi plant at Caldicott outside Chepstow comes from the heritage of Mitel and Zarlink and focuses on packaging..

Martin McHugh, Head of Technology & Business

Our expectation is to really benefit from the economic growth that may happen in the supply chain, taking die from Newport Wafer Fab, binning (selecting the performance grade), wire bond, flip chip, small packages, modules, sold onto end system developers. We build and supply RF up to 2.4GHz in silicon, high speed analogue amplifiers up to 30GHz in SiGe, GaN GaAs with multi-die system in package. Our main mantra is miniaturisation and high temp electronics.

We have research programmes around better performance, packaging of devices, quantum dots using CS substrates and we are half expecting a spinout welsh cluster of quantum technologies as well.

We do very little off the shelf packaging, such as SOIC or QFN – all of it is bespoke custom packaging to JEDEC footprint or JEDEC reflow specifications with moisture sensitivity level 1–5, so that the end user can use standard assembly profiles. Mostly we use FR4 or LCP, PTFE ceramic substrates for mounting discrete active and non-active components, adding a lid and encapsulating.

We need RF specialists up to 20, 30GHz and materials specialists – as we move more into this RF area we are dealing with exotic materials that we need to understand. The skills sets are double edged – a combination of electromechanical and mechatronics for the packaging challenges, yet with an innate understanding of electronics

We are looking for another graduate at the moment as an integrated systems engineer. We need access to simulation tools, people with knowledge of high end optical, RF and thermal simulation tools, and it can be difficult to estimate whether we need it in house or whether it sits in the Catapult.

The engineers we need have to have an understanding on the background of the foundry process and a little bit of the product electronics product, which is why the need for an integrated engineer.

Test development engineers are difficult to find the right side of 50. Test for us falls into two camps: maintenance and support of test equipment, analysing results, looking for cost improvements; for me, it is test development engineers – modules need a rack and stack system based around a PC with Labview software. Ten years ago we were writing a lot of the subroutines ourselves, now we write the scripts to fetch parameters. Producing 100,000 modules a year at $100 is good value business but does not warrant buying a $1m sophisticated wafer probe tester.

Another technology we have developed here is silicon on wafer hybridisation, which gives us the ability to surface mount components onto wafers with the distribution on – that adds to the complexity of the test solution. The test strategy to work out how to know the circuit is working, e.g. using sacrificial traces from the module

One area that will be quite interesting is combining a 8in wafer and surface mount line, so instead of having a chip on a board with connectors, we put the RF devices on top of the wafers and the customer wants to put the miniature RF connector onto the wafer itself – we can do that now. For miniaturisation we embed silicon die in PCBs, or use wafer substrates with RF devices on top. For high temperature modules we use SiGe MOSFETs at 200degC ambient temperatures.

We are trying to recruit integrated engineering graduates from Cardiff – we may have an opportunity there. At the moment I have to have packaging, material (chemist) and RF engineers, but they are all over 50 – they are here for another 15 years, so it's not an immediate problem, but I don't have those at 35 to replace them.

We have 110 people – we will grow the business with ten to 15 engineers over the next five years as we aim for medium volume, high value devices such as radio modules for medical that are $100 each. Ideal for me would be a luxury car needing a high-end radar needing a 77GHz module for $40 at 250,000 a year. We are already talking about engine systems for a 30mm^2 module, built on a 400mm x 200 mm process panel this is 1000 panels a year. We are used to products up to 500,000 devices a year, costing from $20 to $30 to $100.

Most of our recruitment will be in technical staff – more emphasis on apprentices, supporting them doing degrees, ending up as senior engineers. We see developing graduates, through our own training, and we may well take some space at the Catapult for that.

The tunnel (between Newport and Cardiff) is an issue. We have engineers in Bristol coming to Chepstow but who not go to Cardiff through the tunnels – so the Catapult needs the proposed relief road.

Colin Guest, Senior Manager for Assembly & Test Engineering

Backend assembly of wafers and die, mostly medical (our own), hearing aids, pace makers, camera pills, surge protection, more in optoelectronics – they tend to be other people's designs. Current business doing well, most exported – sensors are a short-term opportunity that has grown rapidly. If it takes off as it is likely to we will start recruiting technical staff: degree, HNC level. We have a huge amount of training going on, taking on operators doing modern apprenticeships (we have taken on two this year), doing BTECs and going on to degrees.

It is very difficult to find people; in general in engineering there's a shortage but particularly in test support and quality. Over the last few years we have struggled, for example finding a quality engineer. With manufacturing technicians the average age is 40+ with hardly anyone younger. We are not getting the people applying, and those that do lack general experience and qualification in electronics. Electronics experience is few and far between – part of the problem is on the BTEC side of things where there is a choice of mechanical or electrical engineering with an electronics bolt on (years ago you could do an electronics-specific course).

Everyone has said the same thing over the years but nothing changes – the trouble is there is essential skills expecting GCSE Maths, Physics, and then go to essential skills in BTEC – that is a wasted resource. The BTEC is not giving us what we need, as it is too general especially in quality systems.

We had a bad experience with Gwent College so we are using Newport training school in Cwmbran – still only add-ons for electronics – they would be ideal to take on the extra courses, perhaps with Newport District Group Training Association. BEC and HNC are the vast majority – to be a technician you need HNC or HND level, but some doing some open university.
We have got to train our own people and create a talent pool in Caldicott, as looking outside there's nothing out there. It is quite scary the skills shortage – the average age is 46, 47 – there is a big void to the younger age group.

It is not about just growth, it's getting people to cover the skills we've got now, its replacement. Everyone in the area, not just electronics, saying the same thing. We have to move quickly on skills as it will take years to get people to a reasonable standard – a school leaver will take three to four years of apprenticeships. The only way is to invest in the colleges, we canot buy people in, got to get a pipeline, which means we have to start now, added into my role going forwards – things like test take even longer, where you have to understand the technologies and the test systems.

End Users

Compound Semiconductor Technologies, Scotland

Neil Martin, CEO

It's a very bottoms up view of the Cluster they have got some level of materials knowledge in Cardiff, an outstanding world-class company exploiting the materials in the marketplace and the rest is aspirational, so from that perspective it has the kernel of a cluster.

When I look at it for the next levels up there are very few companies that deal with the applications. I don't know that this is going to change that much – 90% of my customers are outside the UK and we are one step up the supply chain from IQE, so I'm not sure the base material on its own is going to foster the applications development.

I do not see it as competition – we buy a lot from IQE and don't see any reason for that to change. We have people placed at Imperial, Southampton, Sheffield, so we would be happy placing activity in the Cardiff area and we have done some work with Swansea. I see many of the things that we do as feeding into that core market with new products, new devices – that we can do IQE or with CSC on new materials and structures. It is really a matter of keeping pace with the market.

The CSC is allegedly available for companies to get materials grown and try some stuff, and it is very difficult to get capacity in that, as IQE has taken a lot of that so the rules of engagement are hazy and discomforting but that might be my lack of awareness.

We are a little bit in limbo as to where the direct access to CSC is currently. From the Institute perspective, I do not know how it dovetails with Sheffield and it would be good to have a map or signpost of where to go.

There is growth in all the sectors, particularly sensors and data centres, but those are massively broad areas with all sorts of new deployments of new technology. However, in very large part, it will be incumbent markets that will discover the advantages and change their product development to encompass CS, rather than a whole plethora of new CS companies. An automotive guy is not going to go to a start-up when he has a sensor supplier that just needs to change its technology mix.

There will be completely new areas that need new technologies and they can emerge anywhere – from universities or someone taking a jump from a company, but location wise there is no particular benefits to being close to the materials. It is always incredibly difficult to move the core guys to where you want them to be, but they will move to where they want to be – that's less than 15% of the reason for location.

What is good about the Cluster is IQE will attract some investment activities to the area because of the commercial success and that will be a good leverage for developing that cluster identity. Guys at Glasgow won't relocate but would be happy to be part of the Cluster if they can get hold of new materials, I can imagine them wanting to look at new applications, similar the automotive guys from the West Midlands.

One of the dangers is IQE being dominant. If you look at silicon fabs in Scotland they were driven by European manufacturing sites for global companies, and it's the same kind of argument on IQE, that their focus will drive a certain type of behaviour and if that becomes more dominant that can be an issue.

We doubled last year and will double or treble this year – that will double our staff to about 120, 130. We are just under 70 people now. We are trying to employ every conceivable strategy – we have been placing people inside academic institutions every semester for six months so we have been pipelining this since 2009. Many of the skills we need are manufacturing related and there are still remnants of Motorola, NEC, TI in Scotland, and people that have lived abroad are coming back, that certainly helps. We try to get hybrid skills – within silicon there are a lot of people doing high value RF, for example.

We have modern apprentices – that is working – trying to pick the right level of apprenticeship is difficult at times up to degree level. The sooner it can be shaped by the market rather than academic or economic development or a single company the better for everyone. However, that is not easy at all.

Huawei, Ipswich

Michael Robertson, Research & Collaboration Manager

We have some engagement with the Catapult in the setting up phase and discussion on what sort of topics it should look at. Our own interest in Ipswich is InP optoelectronic devices – lasers,

modulators, detectors for optical systems. We are interested in more efficient, lower cost devices as the main drivers.

Our model would be we would work by contract with the Cluster and look to develop things with the Cluster that are too high risk for us to do ourselves and, if feasible, would then bring them in-house and use the Cluster to develop the ideas further. The advantage of doing it in-house is faster access to new ideas, new designs.

We have our own epitaxy but nowhere near the number that IQE have, so we would use IQE where made sense and in-house otherwise – we would probably use IQE for the higher volume, more routine things. IQE is so busy that their turnaround time is very slow, victims of their own success.

I am not sure now how far the CSC has got; it may be changing but my perception is IQE is using all the epi they can get so the CSC hasn't really started to supply a service. I think now CS is quite high growth, perhaps 20% pa – it is not something we look at, we look at the devices themselves.

I think there is an opportunity here in optoelectronics that maybe they can look at some new materials – they will have a number of systems that allow them to look at a whole range of materials, things that lead to lasers that are more efficient over a wider temperature range. Antimonide materials are possible to get the correct wavelength but much less well developed, for example. We have to get away from the need for cooling in optoelectronics as that makes the package large, the efficiency low and we are trying to move to more devices on a single chip.

Blue lasers are no use to us. GaN can in principle can be used for intra sub band modulators as it has a much wider band gap, so just using the conductions band you can create a modulator so that is a possibility.

I do not understand how the Catapult will work – the problem is that there is such a diverse range of what you can do. It canot specialise in everything and it's very difficult to decide what the focus will be.

From our point of view we know what the applications are so we do not need that – we are very clear on the applications already. What for us is interesting is being able to look at different materials in a structured way and know we are getting good quality materials. You can go to various universities and set up a project for a different material but you have no certainty that the quality of the material is useful or realistic. However, if you get a mediocre result, you do not know whether the material is poor or the approach is poor; we would expect to get good quality material out of CSC.

I do not know how them producing the material is connected to it being processed into something. The ICS is supposed to do that. It is difficult to know what to do by way of demonstrators as the field is very broad – for example, with sensors, there's such a big range and trying to get some decent commonality is extremely difficult.

It will be OK as long as they are able to choose a few applications and develop something in those and then widen that – it needs sufficient synergy and engagement for a small number of applications and I'm not sure the telecom devices will fit because we know our applications.

One thing we did think of was reliability; even that is a bit specific. Reliability of devices is not something that many universities look at but is important from an industrial perspective. Finding a university that can help us on reliability work is a real challenge as it's not sexy for the universities.

It is also quite expensive to set up, and sharing [the results] is difficult as it's not terribly generic [i.e. the reliability results are specific to a family of devices].

There are also some very specialised measurements that the Catapult could do, such as very high frequency or low temperature, where enough companies would want that, but not want to buy the equipment – there Catapult could offer that sort of service. Modelling and simulation: offering services in that area is one possibility but the universities are better at doing that already and we have some university projects on advanced modelling topics.

What I would say is the Cluster and catapult should be thinking about open days and visits and encouraging people to engage and see what they are up to. The danger is that internally they are so focused on moving forwards they forget to engage with the people outside.

National Physical Laboratory (NPL), London

Mohsin Haji, Senior Research Scientist, Quantum Metrology Institute

I am not too sure about the Cluster as a whole but we've been working with CSC, as well as Cardiff, to develop VCSEL lasers as sources for miniature atomic clocks – we are about half way through a two-year InnovateUK programme with CST in Glasgow.

The design is coming together from ideas:

- The wafer designs are mainly coming from CSC and CST.
- The device designs come from CST with some involvements from NPL.

Right now we are very interested in a whole host of semiconductor lasers targeting the various quantum transitions in our various atomic clock systems, however there are other semiconductor applications, such as a quantum current standard is based on semiconductor strip lines.

We are really interested in blue lasers on a GaN substrate. The problem with GaN is finding very good quality substrate to produce reliable laser with good performance, and it is a tricky material to work with so its early days research in this area; current products are not suitable for atomic clock applications. Other wavelengths such as 600–800nm are quite difficult to get hold of – the ones that are available using GaAs-based devices are not very reliable.

The other problem we are having with off-the-shelf devices is the line width. We use single longitudinal lasers but the line width is too broad and that degrades the clock performance. Therefore, we are having to rely on much bulkier laser systems to mitigate that and that translates into a more costly clock system that is more difficult to manufacture on a commercial scale.

We are not interested in just R&D but in taking things to market – we have our own reference clocks in the lab but we are interested in producing clocks for industry. There is a real demand for compact atomic clocks right now but we are finding it tricky to develop such systems because of the lack of high quality semiconductors.

We are seeing a huge investment in InnovateUK and the Quantum hubs, which are focused on making atomic clocks. The other thing is one of the main drivers for these compact clocks is the vulnerability of GNSS systems, that is generally the reference for financial trading platforms, etc. but they are susceptible to jamming, spoofing, so there's been more of a push for localised atomic clocks. The Blackett Review (Nov 2016) can give some data.

There is been a number of issues with chipscale atomic clocks in that the performance degrades over time and people haven't tolerated that so they are looking at more reliable options. These depend on the application – in some cases they can sacrifice performance with low power, e.g. on the seabed you can get $1:10^{-11}$ accuracy at 100s stability. Also in Defence, there are a number of applications but the numbers we are hearing are$1:10^{-11}$, $1:10^{-12}$ level of performance.

We also need CS substrates for:

- Chip gratings – used for cold magneto-optic trapping of atoms for clock and other sensors, e.g. gyroscopes.
- Interferometry – still emerging.
- Chip scale linear atom trap on a semi substrate.
- Micro ring resonators – biosensing, when the resonant frequency changes in proximity to various molecules.

Zeta Specialist Lighting, Oxford
Provides LED solar powered and automotive lighting within the group.

Phil Shadbolt, CEO

We had a significant grant with Plessey under supply chain to develop high power LED diodes on silicon – that is the closest we got to compound semiconductors – we don't get very close to the die, we are users of processed and packaged.

The Holy Grail for me is to engage with a semiconductor developer on a die with a tunable CCT colour temperature so I can use one die and tune the colour temperature to the application or even change during operation. That would have 250lumens/W with mega efficiency. I want built in controls so I can dim it during operation and it does not need a heat sink (but that's ridiculous) and 1W to 80W.

We provide commercial lighting, street lighting, solar lighting, e.g. one contract was to replace 18,000 streetlights in Maidenhead to LED, platform lighting for Chiltern railways and solar powered lights in all Sainsbury stores across the country.

We are predominantly using GaN from Cree although we do use other suppliers. If the reliability was proven then we would use a start-up. We would have to engage early to test and validate along the way. One customers wanted 22-year warranty on products that is why we used Cree, as we had confidence that they could stand by the product. Now all end customers expect a warranty of five years on LEDs, I am very confident on that. Issues such as moisture and temperature kill an LED so with hermetic sealing and correct heatsink calculations I am confident we could use them.

I am a big fan of Chip on Board (CoB) – we tend to use phase change materials for heat sinks so while CoB may have a high power density the design of the heat sinking and control of the thermals is down to us. We are finding some substrates in ceramic and aluminium, now for higher power applications.

Because an LED is a semiconductor, the theory is that you can deposit a control technology on the same substrate with a pulse width modulator (PWM) or power supply interface on the same die. No one is really doing at the moment but in a few years' time you will buy an LED with control and power supply in the same package, not necessarily on the same die.

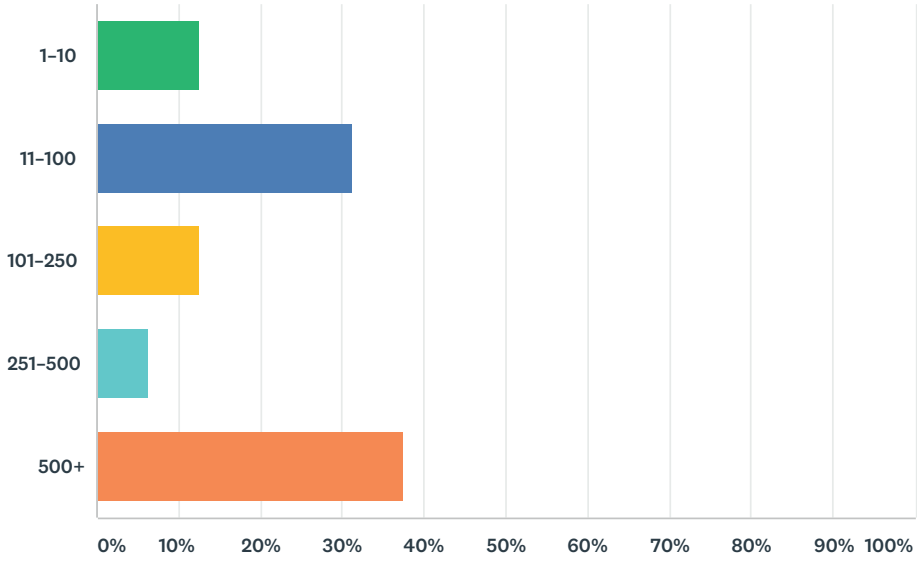
We were part of the Advanced Manufacturing Supply Chain project with Plessey – that worked beautifully, so we are experienced in working in collaboration. More than happy to put Zeta forward as a tester and user.

My frustration is I keep seeing the meetings coming up in Sheffield – would like webinars because of diary and distance. Newport or Cardiff are just as difficult for me; London would be great.

Appendix 3: Survey Data

Q1 How many staff does your company/organisation employ at your location (please include temporary as well as permanent staff)?

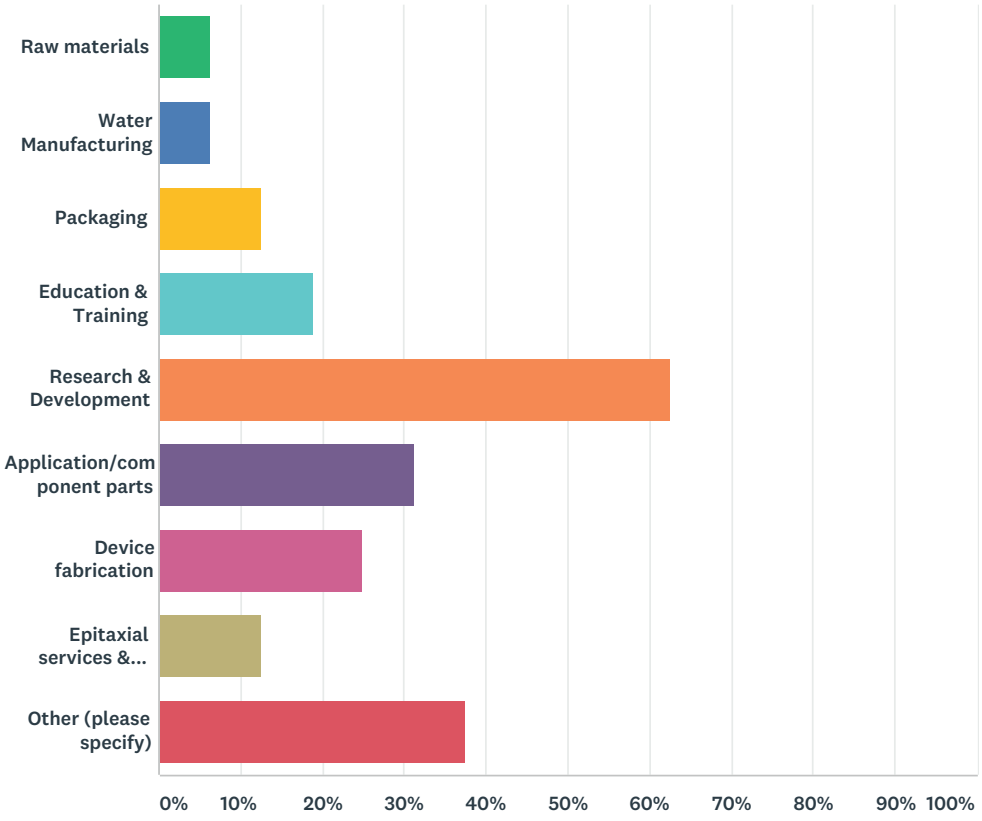
Answered: 16 Skipped: 0



ANSWER CHOICES	RESPONSES	
1–10	12.50%	2
11–100	31.25%	5
101–250	12.50%	2
251–500	6.25%	1
500+	37.50%	6
TOTAL		16

Q2 Please indicate which represents your company/organisation's involvement or interest with compound semiconductors (select all that apply):

Answered: 16 Skipped: 0

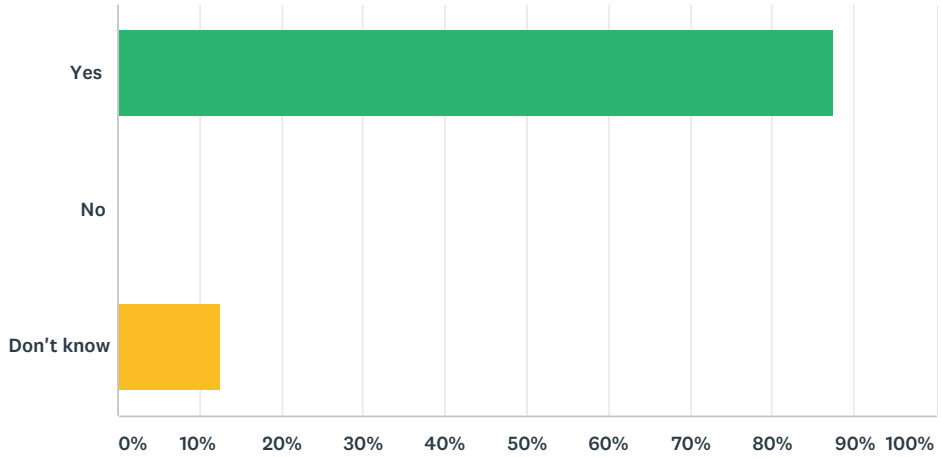


ANSWER CHOICES	RESPONSES	
Raw materials	6.25%	1
Water Manufacturing	6.25%	1
Packaging	12.50%	2
Education & Training	18.75%	3
Research & Development	62.50%	10
Application/component parts	31.25%	5
Device fabrication	25.00%	4
Epitaxial services & equipment manufacture	12.50%	2
Other (please specify)	37.50%	6
Total Respondents: 16		

#	OTHER (PLEASE SPECIFY)	DATE
1	Complementary Technology	4/8/2018 7:10 AM
2	Wafer Manufacturing	3/22/2018 5:53 PM
3	Incorporate power electronic switches into complete electrical drive systems.	2/17/2018 12:06 PM
4	Obsolescence	2/16/2018 1:46 PM
5	Ip	2/16/2018 11:32 AM
6	Testing and Compliance of Devices and End Products	2/16/2018 10:50 AM

Q3 Does your organisation have plans to recruit engineering and technology staff in the next 12 months?

Answered: 16 Skipped: 0

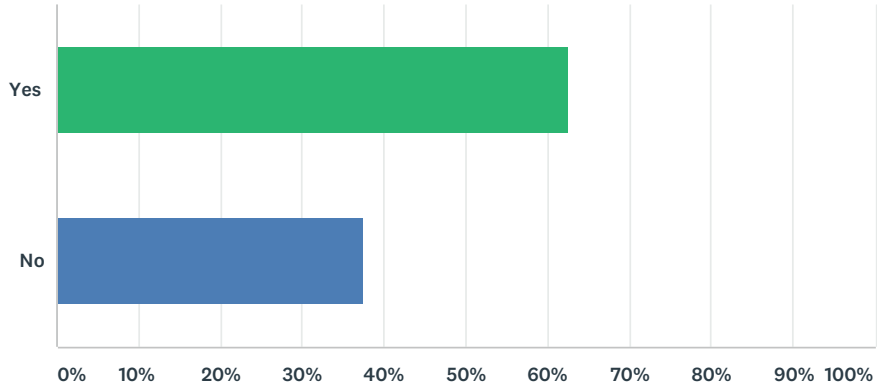


ANSWER CHOICES	RESPONSES	
Yes	87.50%	14
No	0.00%	0
Don't know	12.50%	2
TOTAL		16

#	IF YOU ANSWERED 'YES' OR 'NO', PLEASE EXPLAIN WHY AND PROVIDE APPROX. NUMBERS IF 'YES'.	DATE
1	10 staff over the next 5 years	3/26/2018 12:03 PM
2	TBC - minimum 10 however expectations are significantly higher	3/22/2018 5:53 PM
3	5+ due to ongoing expansion	3/22/2018 11:36 AM
4	Unsure of numbers at the moment	3/21/2018 11:31 AM
5	More student interns (approx 8)	3/6/2018 5:00 PM
6	A few	2/22/2018 4:30 PM
7	4-5 people, as part of natural turn-over	2/21/2018 5:18 PM
8	Currently lookign to grow by 50 heads	2/19/2018 9:33 AM
9	Electrification of propulsion for aircraft.	2/17/2018 12:06 PM
10	5	2/16/2018 11:32 AM

Q4 Has your company/organisation experienced a skills shortage in the last 12 months? That is, an Engineering or Technology vacancy that has remained unfilled for at least 3 months due to the lack of a candidate with the required skill set.

Answered: 16 Skipped: 0

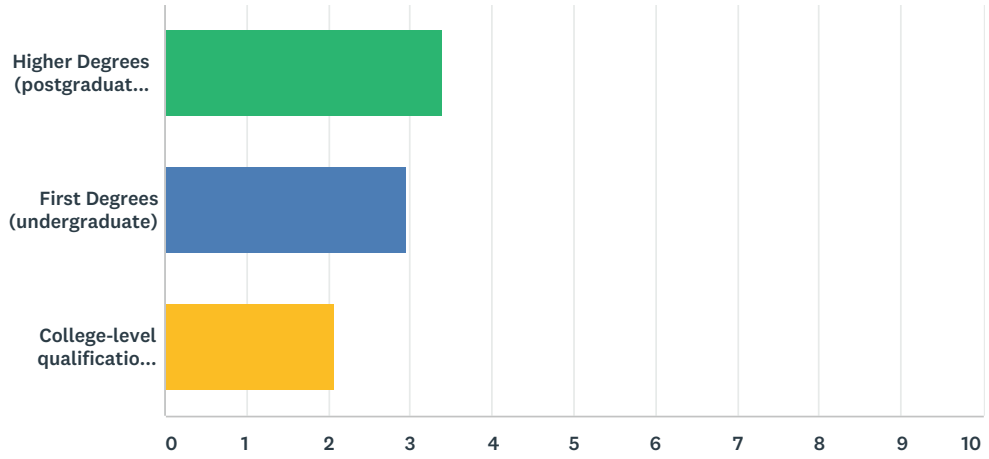


ANSWER CHOICES	RESPONSES	
Yes	62.50%	10
No	37.50%	6
TOTAL		16

#	IF 'YES', WHAT SKILLS SETS WERE LACKING IN JOB APPLICANTS?	DATE
1	This is too general a question. We have had skills shortages in different engineering-related departments fom Sales and Marketing, through IC and Software design, Training, Customer Services and Research. Each requires a different mix of technology and inter-personal skills. The term 'lack of experience' is often used, but is a non-helpful catch-all for educational forward planning purposes.	4/8/2018 7:10 AM
2	Technical research skills	3/26/2018 12:03 PM
3	Process Engineering Shift Engineering Technical Engineering etc	3/22/2018 5:53 PM
4	Mix of commercial programme management with technical understanding.	3/22/2018 11:36 AM
5	Appropriate experience	3/21/2018 11:31 AM
6	Industry experience, specialist technical skills in high level programming languages	3/6/2018 5:00 PM
7	MOCVD crystal growth	2/22/2018 4:30 PM
8	Optics and optical systems design	2/21/2018 5:18 PM
9	Electronics engineers (analogue, digital, power supplies not FPGA/ASIC design).	2/19/2018 9:33 AM

Q5 To what extent do you currently have problems recruiting at:

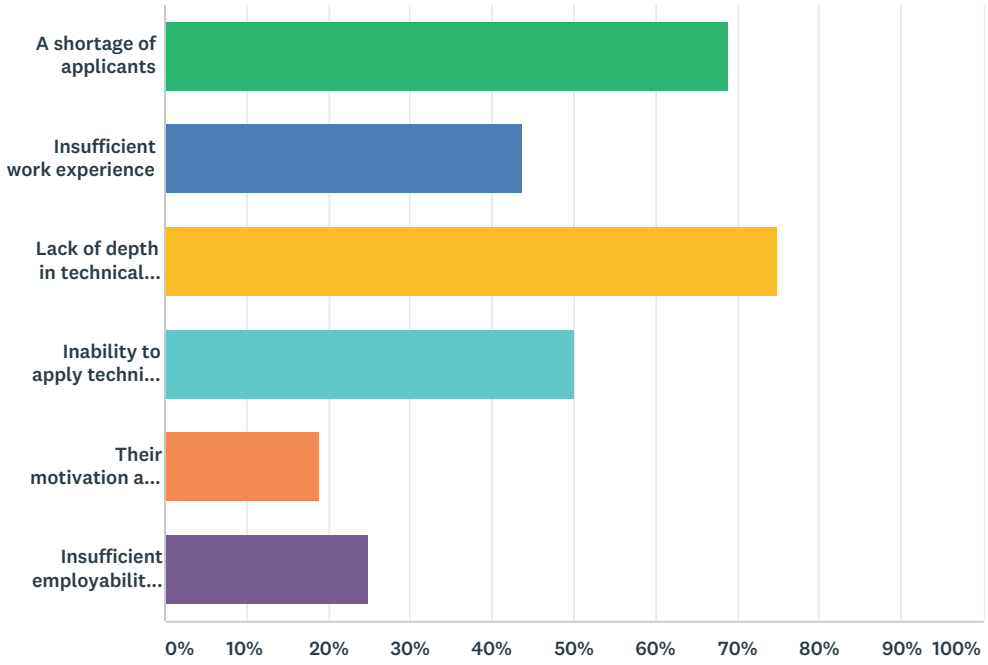
Answered: 16 Skipped: 0



	NEVER	SOMETIMES	OFTEN	VERY OFTEN	ALWAYS	TOTAL	WEIGHTED AVERAGE
Higher Degrees (postgraduate masters, Level 7 and PhDs)	6.25% 1	25.00% 4	12.50% 2	37.50% 6	18.75% 3	16	3.38
First Degrees (undergraduate)	0.00% 0	50.00% 8	18.75% 3	18.75% 3	12.50% 2	16	2.94
College-level qualifications (Levels 3–5)	20.00% 3	60.00% 9	13.33% 2	6.67% 1	0.00% 0	15	2.07

Q6 What problems do you face when recruiting technical staff (select all that apply)?

Answered: 16 Skipped: 0



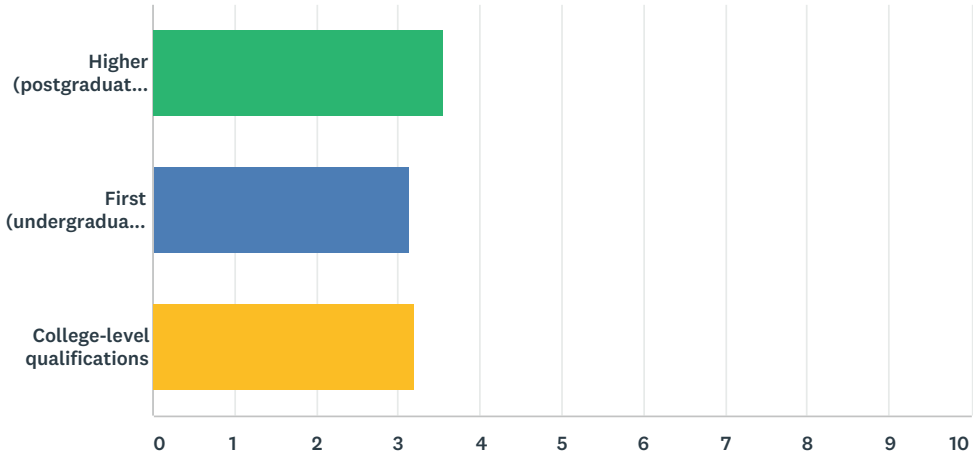
ANSWER CHOICES	RESPONSES	
A shortage of applicants	68.75%	11
Insufficient work experience	43.75%	7
Lack of depth in technical knowledge	75.00%	12
Inability to apply technical knowledge practically	50.00%	8
Their motivation and enthusiasm	18.75%	3
Insufficient employability/non-technical skills	25.00%	4
Total Respondents: 16		

#	IF YOU ANSWERED 'LACK OF DEPTH IN TECHNICAL KNOWLEDGE' OR 'INSUFFICIENT EMPLOYABILITY/NON-TECHNICAL SKILLS', PLEASE SPECIFY/EXPLAIN WHICH KEY SKILLS WERE LACKING.	DATE
1	A highly skilled technical person, may have insufficient skills in the particular area where the job opening is. Form outside the profession it is not obvious that there are so many micro-disciplines within Engineering, each holding its own specialisms, and very few have wide-ranging skills at the expert level. Even if they have a basic profile, in-house training is *always* required to match a person to a new role.	4/8/2018 7:10 AM
2	Existing knowledge in industry the application of the degrees, in relation to semiconductors, compound on silicon semiconductors, photonics. Process knowledge is limited and therefore top up training is required for this industry sector. To enable technical staff to reach the required standard.	3/22/2018 5:53 PM
3	Mix of semiconductor materials and device level knowledge	3/22/2018 11:36 AM

4	Lack of experienced candidates from uk - we typically recruit in India	3/21/2018 1:37 PM
5	Hands on ready-to-go exact expertise	2/22/2018 4:30 PM
6	No specific knowledge in the area of optics for semiconductor light emitters, or in knowledge of semiconductor electronic devices (LED, LD, VCSEL) to recruit to a position involving device R&D Candidates sometime lacking commercial awareness and ability to find innovative solutions to physics based problems	2/21/2018 5:18 PM
7	A lot of candidates struggle to display basic engineering knowledge and most are software based which is not what we want.	2/19/2018 9:33 AM
8	Understanding of semiconductor use	2/16/2018 1:46 PM
9	Analog Design Sram design	2/16/2018 11:32 AM

Q7 On a scale of 1–5, how ‘workforce ready’ would you say each category of new starter is, and how important is this to your organisation?

Answered: 16 Skipped: 0



	1) NOT EQUIPPED AT ALL	2) MOSTLY UNEQUIPPED	3) NEITHER UNEQUIPPED NOR READY	4) SOMEWHAT READY	5) COMPLETELY READY	TOTAL	WEIGHTED AVERAGE
Higher (postgraduate) Degrees	0.00% 0	12.50% 2	18.75% 3	68.75% 11	0.00% 0	16	3.56
First (undergraduate) Degrees	0.00% 0	25.00% 4	37.50% 6	37.50% 6	0.00% 0	16	3.13
College-level qualifications	6.67% 1	20.00% 3	20.00% 3	53.33% 8	0.00% 0	15	3.20

#	COMMENTS FOR "HIGHER (POSTGRADUATE) DEGREES"	DATE
1	Its a case of matching expectation and reality.	4/8/2018 7:10 AM
2	Very High	3/22/2018 5:53 PM
3	high	3/22/2018 11:36 AM
4	High	3/21/2018 11:31 AM
5	High	2/21/2018 5:18 PM
6	Expected	2/19/2018 9:33 AM
7	We can always use a strong technical expert.	2/17/2018 12:06 PM
8	Important	2/16/2018 10:39 AM

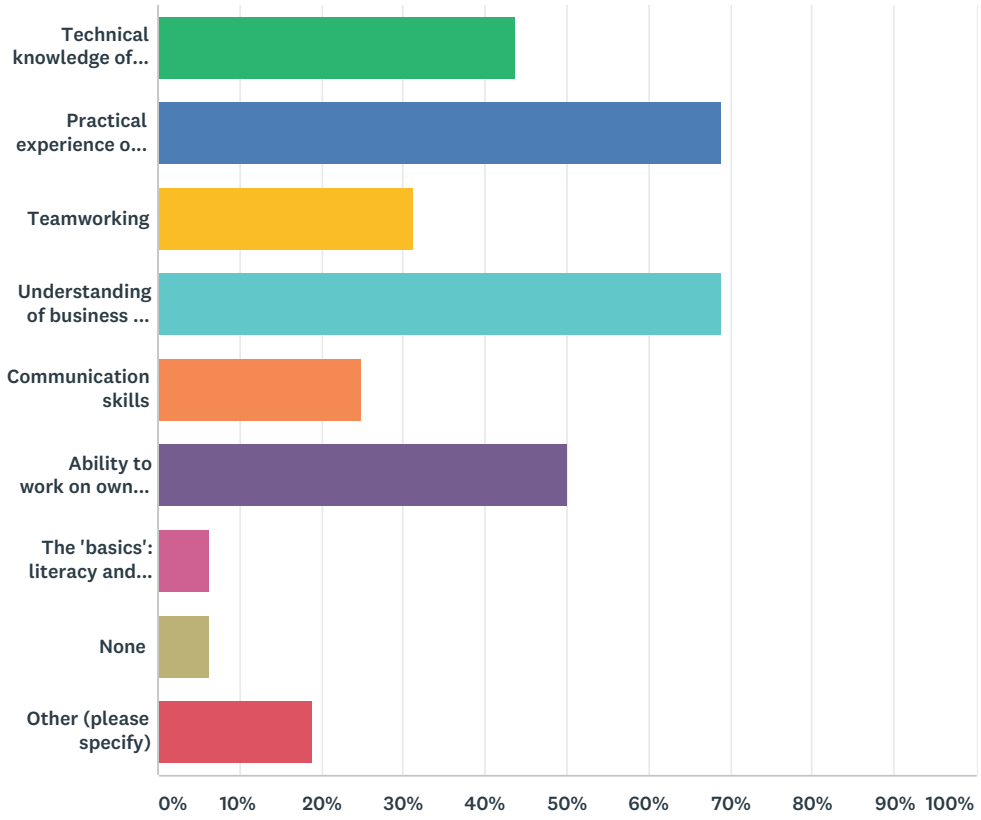
#	COMMENTS FOR "FIRST (UNDERGRADUATE) DEGREES"	DATE
1	Its a case of matching expectation and reality.	4/8/2018 7:10 AM
2	Very High	3/22/2018 5:53 PM
3	high	3/22/2018 11:36 AM
4	High	3/21/2018 11:31 AM
5	Not important	2/21/2018 5:18 PM

6	Really important	2/19/2018 9:33 AM
7	We can always use a strong technical expert.	2/17/2018 12:06 PM
8	Important	2/16/2018 10:39 AM

#	COMMENTS FOR "COLLEGE-LEVEL QUALIFICATIONS"	DATE
1	Its a case of matching expectation and reality.	4/8/2018 7:10 AM
2	Very High	3/22/2018 5:53 PM
3	Medium	3/21/2018 11:31 AM
4	We don't recruit at this level	2/21/2018 5:18 PM
5	Important	2/19/2018 9:33 AM
6	We can always use a strong technical expert.	2/17/2018 12:06 PM
7	Important	2/16/2018 10:39 AM

Q8 In what way(s), if any, do new starters not meet your reasonable expectations in any of the following skills areas (select all that apply)?

Answered: 16 Skipped: 0

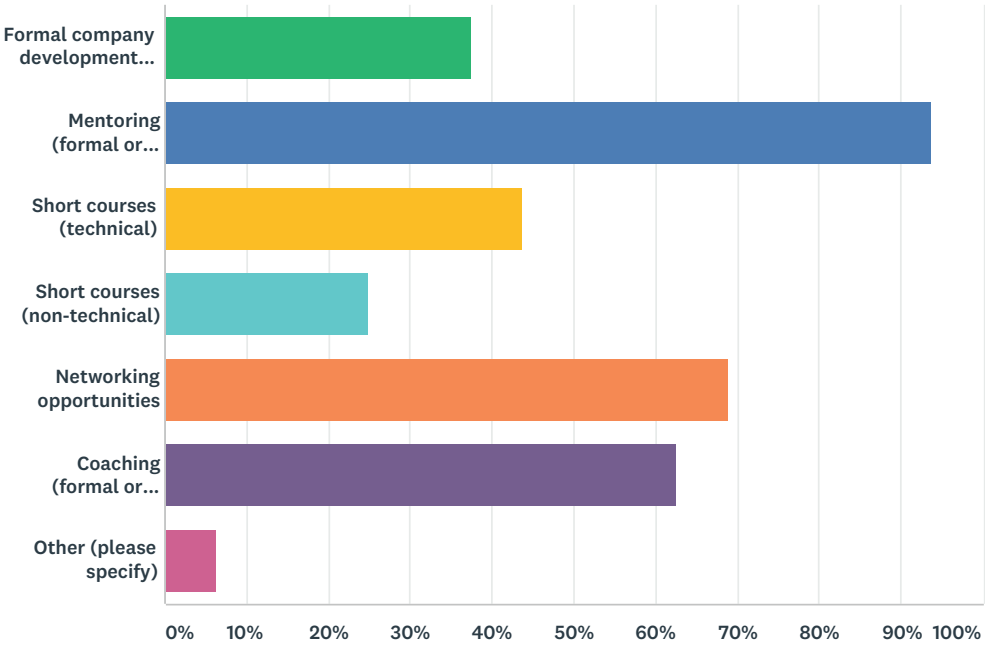


ANSWER CHOICES	RESPONSES	
Technical knowledge of compound semiconductors	43.75%	7
Practical experience of compound semiconductors	68.75%	11
Teamworking	31.25%	5
Understanding of business and commercial acumen	68.75%	11
Communication skills	25.00%	4
Ability to work on own initiative	50.00%	8
The 'basics': literacy and numeracy	6.25%	1
None	6.25%	1
Other (please specify)	18.75%	3
Total Respondents: 16		

#	OTHER (PLEASE SPECIFY)	DATE
1	We have gaps in all areas at all levels and the issues need to be address as a whole to create - a development flow. The Communication of the opportunites in this field also need to be highlighted.	3/22/2018 5:53 PM
2	Semiconudtcor experience in a commercial context	3/22/2018 11:36 AM
3	My business in semi conductors not compound - although have an interest and I'm based in South Wales (Directotr of international semi conductor company)	3/21/2018 1:37 PM

Q9 For new starters, in what ways does your company/organisation support their professional development and training?

Answered: 16 Skipped: 0

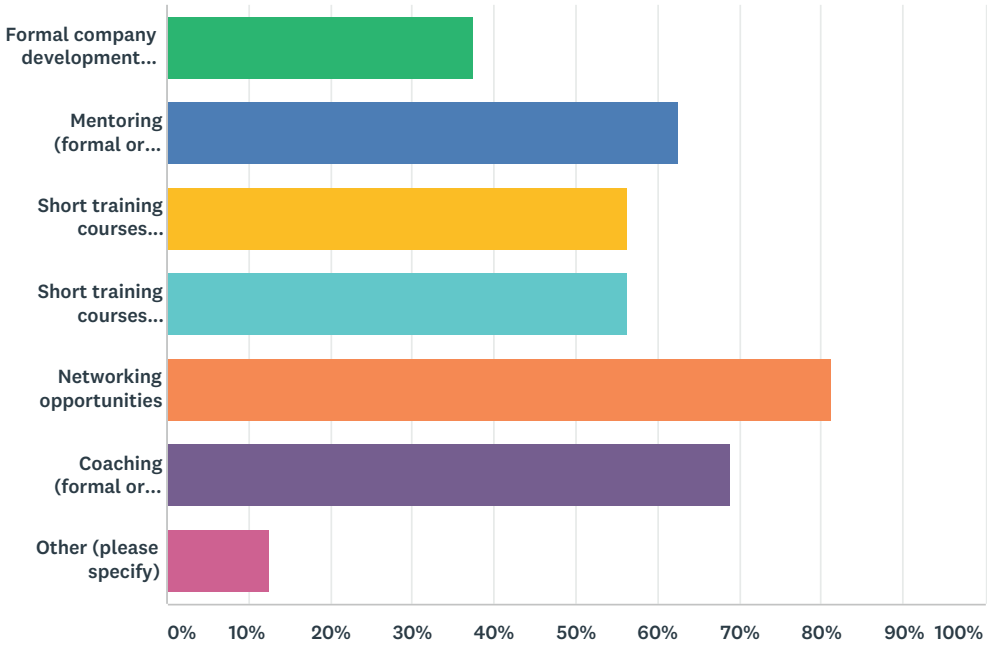


ANSWER CHOICES	RESPONSES	
Formal company development programme	37.50%	6
Mentoring (formal or informal)	93.75%	15
Short courses (technical)	43.75%	7
Short courses (non-technical)	25.00%	4
Networking opportunities	68.75%	11
Coaching (formal or informal)	62.50%	10
Other (please specify)	6.25%	1
Total Respondents: 16		

#	OTHER (PLEASE SPECIFY)	DATE
1	Bespoke solution design to cover skills gaps, full development strategy for all individuals joining the company. Structured to the role, responsiblities and existing knowledge\experience.	3/22/2018 5:53 PM

Q10 For existing staff, in what ways does your company/organisation support their professional development?

Answered: 16 Skipped: 0

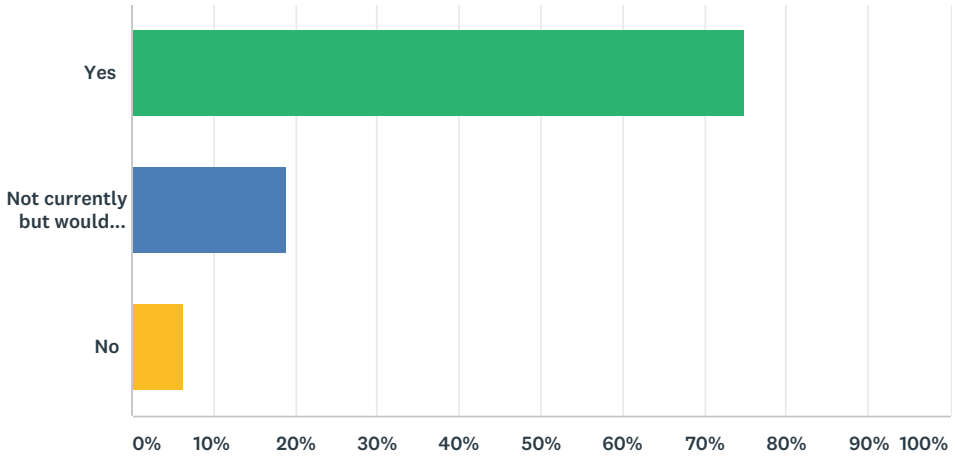


ANSWER CHOICES	RESPONSES	
Formal company development programme	37.50%	6
Mentoring (formal or informal)	62.50%	10
Short training courses (technical)	56.25%	9
Short training courses (non-technical)	56.25%	9
Networking opportunities	81.25%	13
Coaching (formal or informal)	68.75%	11
Other (please specify)	12.50%	2
Total Respondents: 16		

#	OTHER (PLEASE SPECIFY)	DATE
1	As above	3/22/2018 5:53 PM
2	Software specific training	2/21/2018 5:18 PM

Q11 Do you offer student work placements?

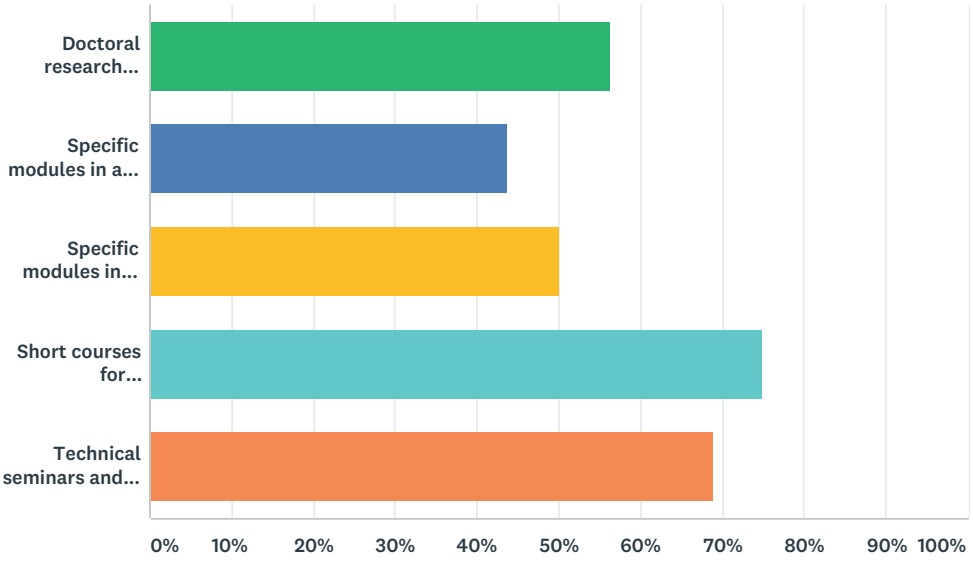
Answered: 16 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	75.00%	12
Not currently but would consider	18.75%	3
No	6.25%	1
TOTAL		16

Q12 Looking ahead (over the next 5 years), what future needs in compound semiconductors might your organisation require to support its growth?

Answered: 16 Skipped: 0



ANSWER CHOICES	RESPONSES	
Doctoral research programmes	56.25%	9
Specific modules in a postgraduate degree course	43.75%	7
Specific modules in undergraduate degree course	50.00%	8
Short courses for professional development (CPD)	75.00%	12
Technical seminars and conferences	68.75%	11
Total Respondents: 16		

UK Electronics Skills Foundation
North End House
North End
Ashton Keynes
Wiltshire
SN6 6QR

www.ukesf.org

info@ukesf.org | @theUKESF | facebook.com/UKESF

Stew Edmondson MA MBA BSc CEng FIET (CEO) can be contacted on 07894 899544