National Epitaxy Facility Statement of Need

a) Vision/Quality: *Present the science that will be enabled by the proposed Statement of Need. Applicants should provide evidence of the quality of research to be enabled and the research areas which will be supported alongside why this facility/large infrastructure capability is now needed and will be needed over the proposed 5 years of running. If this would enable cross-disciplinary research, please state which other council's remit(s) this would fall. (6,000 characters incl. spaces)*

The vision for a National Epitaxy Facility is to provide UK researchers with a world-class epitaxy service that supports their need for the highest quality bespoke materials, thereby enabling pioneering, impactful semiconductor research and creating continuing academic and industrial advances over the next 5-10 years.

Semiconductors are of profound importance for a huge range of technologies that underpin modern society including the internet, smart phones, LED lighting and electric vehicles. They have also enabled many ground-breaking advances in fundamental science such as the Quantum Hall effect, which from 2020 is used to define the SI unit of resistance. It is the continuous discovery of new electronic and optical phenomena in semiconductors that has delivered remarkable benefits for over 70 years and which underpins the overall vision for this Facility. Combined with wafer-scale fabrication of devices, the electronic, photonic, spintronic, quantum, topological and magnetic properties of semiconductors will continue to provide a rich and broad science base and corresponding impact over the next decades. The role of epitaxy is critical to success. Translation of the favorable properties of semiconductors to functional devices is only achieved with very high purity materials (impurity levels of parts per billion), exceptional control of feature sizes (atomic-scale accuracy), and the excellent control of wafer-scale uniformity that only modern epitaxial tools can deliver.

Semiconductor research in the UK is of the highest quality. For example, the 91 attendees at our community consultation meetings have held grants worth over £900M; these were awarded following EPSRC peer review with research quality the primary assessment criterion. There is corresponding major industrial activity in the UK, with significant recent investments such as at Plessey and Newport Wafer Fab.

The key research areas and scientific opportunities that a Facility should support were identified in community consultations held over two days. Research directions were identified under five broad subject areas with topics outlined below:

Photonics: Photonics remains a major focus of semiconductor research in the UK and is characterized by materials, devices and systems from the UV to THz. New laser wavelengths remain a key target especially in mid-IR, THz, green and UV. High speed/low energy lasers such as VCSELs and quantum dot (QD) lasers are also required for next generation telecommunications. Photonic integrated circuits (PIC) including III-Vs on silicon, require new epitaxy methods such as selective area growth and is a key system-driven need for computing, communications, and sensing. Advanced detectors and structures such as nanowires for single photon and mid-infrared detection require novel epitaxy. Low energy micro-LEDs for lighting/displays and high efficiency solar cells are key to tackling climate change. Clear opportunities are to be found in fundamental research on new optical phenomena such as topological photonics and metamaterials.

Quantum Science & Technology: The UK has world-class R&D in quantum science and technology, underpinned by major industry-government investment of over £1bn. Quantum dot (QD)-based quantum photonics is a key strength, including single and entangled photon devices. There is a significant shift of emphasis to materials and devices for 1.3μm and 1.55μm operation in quantum communications. Scale-up of technologies such as site-control of QDs or nanowires is critical to progress in on-chip, system-level quantum photonics. Integration with silicon will be a key element of this research. Integration with other materials and systems is also important, including superconducting detectors, on-chip atomic systems, magnetometers, gravimeters etc. Research interests in new quantum phenomena include topological quantum photonics, polariton-based Bose Einstein condensation and room temperature single photon sources in GaN, BN or 2D materials.

Electronics: New directions in materials-based electronics 'beyond CMOS' is focused on heterogeneous integration of III-Vs with silicon, high power/high temperature electronics based on GaN, and emerging materials such Ga_2O_3. This research is critical to supporting the electrification revolution. 6/7G mobile communications as well as advanced imaging technology will require progress in RF/THz based electronics including high mobility devices based on InSb and novel device concepts.

New materials and emerging devices: The community sees integration of novel and 'hybrid' materials as an important new direction. Innovative epitaxy approaches are required, including epitaxial regrowth across multiple reactors, novel materials-printing methods and chemo-mechanical lift-off processes. Integration with silicon is of prime interest. Combining novel 2D materials with III-Vs/silicon is also an immediate opportunity. Furthermore, integration of II-VI materials with GaN and silicon will afford opportunities in electronics, energy and sensing applications.

Fundamental science of semiconductors remains a core discipline in UK research with a wealth of opportunities for new physical phenomena through materials design and epitaxy. Interests include: new quantum properties through control of coherence, the use of quantum photonics in fundamental science such as gravitational wave detection and in elucidating the nature of the quantum universe. New phenomena from advanced materials including valleytronics in 2D materials, time crystals and topological electronic/photonic phenomena were identified. At a device level, the availability of high power/ultrafast lasers will enable new directions in atto-second science and advanced detectors will have a major impact on astronomy and imaging. Advanced mid-IR and THz lasers for sensing will have an increasing impact on space/planetary exploration and innovative healthcare technologies such as liquid biopsy for cancer detection.

(5999 characters incl. spaces)

b) Users and Community Engagement: *There must also be information and evidence on the level of community engagement and support that has led to the Statement of Need. In the case of a National Research Facility this is especially important and the Statement of Community Need must be presented as a community backed document. A description of the UK communities that will benefit from the usage of this facility needs to be present, including the expected number and type of users (both academic and other stakeholders). Specific information should be provided on key research groups and their underpinning funding portfolio. Projected growth of the user base over the next 5 years should be indicated. (6,000 characters incl. spaces)*

The main beneficiaries of the Facility will be UKRI funded academic researchers working on semiconductor science and technology who rely on a supply of world class epitaxial materials. These researchers are mainly in the disciplines of physics, engineering, materials science, and cross-disciplinary life sciences. Industry is strongly represented in the community, and in the past few years major investments such as the £300m CS-Connected Cluster in South Wales have provided this growing research community with outstanding opportunities to translate basic research to globally significant manufacturing.

The community conducts a rich portfolio of research including materials development, novel devices and systems development, and applications-focused research involving significant industrial partnership. Researchers in this field are strongly represented in major national programmes of basic and applied/translational research including EPSRC programme grants (7 supported by the current Facility), manufacturing Hubs (2 supported), National Quantum Technology Hubs (2 supported) and Industry-led ISCF projects (2 currently supported). There is semiconductor research in almost all research-intensive Universities in the UK, with no obvious geographical bias.

Examples of leading research groups contributing to this statement of need include:

- The UCL group who are world leading in Quantum Dot (QD) lasers on silicon. Combined with the world-class Silicon Photonics group at Southampton and the CS Manufacturing Hub at Cardiff, the UK is in a leading position in this field (Combined awards £43m PI, £35m co-I)
- The large teams at Sheffield, Cambridge and Bristol have world leading Quantum Photonics research including major industrially-led projects under ISCF and Quantum Hubs (Combined awards £11m PI, £115m co-I)
- The Nitrides group at Cambridge has a 30-year history of world class research on GaN epitaxy including 5 spin-out companies and licensing agreements with Plessey. There are leading teams in Bristol, Cardiff, Glasgow, Sheffield and Strathclyde advancing GaN electronics and photonics (Combined awards £17m PI, £35m co-I)
- Teams in Cambridge, Southampton, Oxford, UCL and Surrey have made major contributions to telecommunications research over 40 years. Leading groups now working on quantum communications include Cambridge, Sheffield, Bristol plus the Quantum Communications Hub in York. (Combined awards £64m PI, £99m co-I) There is also a globally significant manufacturing base in the UK including, Lumentum, II-VI, IQE, Toshiba and Huawei.
- Major advances in mid-IR/THz quantum cascade lasers and detectors have been pioneered by the groups in Leeds, Sheffield, UCL, Heriot Watt, Lancaster and Cambridge. (Combined awards £37m PI, £89m co-I)

An indication of expected community demand for the Facility was obtained from three sources:

1. **Evidence from the current Facility:** Clear evidence for ongoing and evolving demand since the last SoN process in 2014 is obtained from analysis of the current Facility. In this period, the Facility supported 79 UKRI grants (32% increase over previous contract) with total value of £122m in 25 leading Universities. Grants on the Web indicates the research is distributed across 22 themes in EPSRC's current portfolio This includes 30 responsive mode grants, 7 programme grants, 7 fellowships, 2 Manufacturing Hubs, 2 Quantum Hubs, and 5 IUK/ISCF grants. The Facility also supported 24 pump priming feasibility studies in 16 institutions (7 successful follow on grants). These figures refer to peer-reviewed grants and are hence quantifiable measures of research quality. The Facility also issued 99 formal quotations, indicating the level of demand exceeding peer review success. The Facility has also had direct requests from 20 companies in this period. The current Facility contract runs to December 2021 and 18 supported grants extend beyond this date. An additional 9 grant applications in peer review will require epitaxy if successful. *This data shows a large, quantifiable, ongoing demand from the community for epitaxy provision beyond the contract period of the current Facility.*

2. **Community Consultation**: To estimate additional *future demand*, the community was directly consulted:

(a) **The major consultation exercise** was conducted via two online meetings held on the 9th and 14th October 2020. There were 91 delegates at the meetings (77 academic, 14 industry) with 22 apologies received due to timing issues, but confirming their support for the SoN through correspondence. The academic attendees together have a track record of over £600m in grant income from EPSRC in the last 10 years (information from GoW). In a number of cases, academics present confirmed they were representing the views of a broader group at their institution. In break-out sessions, the community gave a comprehensive view of the breadth and depth of the exciting new research opportunities expected to be pursued in the next 5-10 years and the requirements for a National Facility to support this research were outlined.

(b) A **questionnaire** on needs was sent to the community in advance of the consultation meetings. 77 returns were received and used to guide the structure of the meetings.

3. **Business development data:** Future demand was also evaluated from the business development activities in the current Facility. Throughout 2019/20, staff conducted a series of roadshows, visiting 11 universities and speaking with 45 academic staff and researchers. Detailed information on scientific interests was gathered, with the majority of these researchers indicating an intention to use the Facility within the next two years.

With an increase in user demand since the previous contract, and an expanded scope requested by the community in the community consultations, including new materials, we expect user demand to grow by at least 30% in the next 5 years from its existing strong base.

(5949 characters incl. spaces)

c) National Importance and Context: *A clear explanation of the existing UK and international landscape, in terms of the available facilities and equipment, and how this will address a genuine UK need. The Statement of Need should address existing capabilities of equipment and access to it and how this capability/facility is a vital part of the landscape or how a new investment would enhance the landscape if none exist in this area. How would this Statement of Need deliver against EPSRC published balancing the portfolio and strategic priorities should also be addressed.*

Reference should be made to any relevant roadmaps, for example the EPSRC equipment roadmaps. (4,500 characters incl. spaces)

The societal impact of semiconductors and its national importance is profound and transformational. To give just a few examples; the unprecedented impact of the internet is founded on ultrafast lasers based on InP; LED lighting based on GaN has led to a 10% (2000TWh) reduction in global electricity consumption; and high mobility transistors based on GaAs are key to mobile communications. Epitaxy is an essential part of the innovation chain in this impact.

The UK electronics industry contributes ~£16bn annually to the UK economic output, employing 300,000 people in 12,000 UK companies. UK Photonics has similar output of £13bn and employs 69,000 people in 1500 companies.[1] The global market for compound semiconductor components, is expected to reach $43bn by 2025, including 3D sensing and LIDAR using VCSELs and APDs (£3bn), high speed photonics for communications ($3bn), GaN/SiC power devices for the electrification revolution ($10bn).

Since the last SoN for an epitaxy Facility in 2014, there have been major changes in the context and landscape for semiconductor R&D in the UK. Government strategy is focused on Britain's future outside of the EU. The industrial strategy and recently published R&D roadmap[2] determines a future of technological innovation through a resurgence in manufacturing and a focus on sovereign capability. In areas where semiconductors and epitaxy play a key part, large investments have been made, including over £1bn in the Quantum Technologies Programme, a £50m Compound Semiconductor Catapult, £300m in the Royce Institute, over £130m in EPSRC manufacturing hubs, and UKRI's £2.6bn ISCF programme. There are huge global opportunities for semiconductors, all closely aligned with EPSRC strategic priorities of a Productive, Healthy, Resilient, Connected Nation, e.g.

- Quantum devices for computing, communications and sensing
- Low power electronics for the government net-zero strategy[3]
- Advanced healthcare technologies in a post-Covid world
- Demand for zeta-Byte bandwidth telecommunications

A strong industrial base is present in the UK with leading companies such as IQE, Lumentum, Plessey, Huawei, and II-VI all manufacturing semiconductor-based products for global markets. The launch of the £300M CS-Connected semiconductor cluster in South Wales has been a major development with IQE and Newport Wafer Fab building a foundry for over 100 production MOVPE reactors consolidated via a recent £45M Strength in Places award. Semiconductor researchers across the UK can now access resources to progress from basic UKRI-funded discovery to mass manufacture and major economic/societal impact for the UK.

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[1] https://photonicsuk.org/revolutionising-our-world/uk-photonics-output

[2] https://www.gov.uk/government/publications/uk-research-and-development-roadmap/uk-research-and-development-roadmap

[3] https://www.royce.ac.uk/content/uploads/2020/10/M4ET-Low-Loss-Electronics-Roadmap.pdf

Semiconductor R&D is strongly represented in EPSRC's portfolio, particularly in ICT, Physical Sciences, Quantum Science & Technology, and the Manufacturing the Future programme. Semiconductors are also represented in Innovate UK programmes and there is a track record of excellent academic-industry partnership including in ISCF, CDTs, Strength in Places, Manufacturing and Quantum Hubs.

Epitaxy is a key to advanced semiconductor innovation, as is outlined throughout this document. Outside of the National Epitaxy Facility (Sheffield, Cambridge, UCL) there is a longstanding base of epitaxy groups in the UK, including at Leeds (MBE), Cardiff (MBE, MOVPE), Glasgow (MBE,MOVPE), Cambridge (MBE), Nottingham (MBE), Warwick (MBE,CVD), Bristol (MOVPE), Manchester (MBE), Swansea (MOVPE) and Lancaster (MBE). The relationship between these groups and the national Facility was established clearly in the community consultation meetings. These epitaxy groups conduct research in their chosen areas of specialization and researchers in the UK may access materials from them through academic collaboration. A broader set of researchers in the community request a National Facility complementary to these groups to provide the epitaxial materials they need for their specific research aims through a bespoke service model. This is the core role and the national importance of the proposed Facility. The role is fully described under **The Potential Facility** section. It is a unique approach in the international context, and is instrumental in the competiveness of UK research in this field.

(4500 characters incl. spaces)

d) Impact: *What potential impact will the proposed Statement of Need have on the research community and how will it work with industrial interests, across the range of types of impact (scientific/academic, people, economic, skills and training, socio-economic etc.), and is there a clearly thought through pathway for expanding the user base and accelerating the identified impacts. How can such a facility support training of skilled people, or enable potentially transformative research with impact on the society and/or the economy.*

(3,000 characters incl. spaces)

The primary impact of the Facility *on the community* will be to enable world-class semiconductor research by providing bespoke epitaxial materials from a centre of excellence with leading expertise, strong management, and concentration of capital resources. The Facility has a significant amplifying effect on the conception and funding of high-quality peer-reviewed grants in this field. Without the Facility, much innovative and adventurous research, including the requisite training and skills development, could not be conducted due to prohibitive costs and lack of investment. Since the last SoN in 2014, the current Facility has supported 79 grants (£122m), and stimulated a further 112 applications for epitaxy provision. Compiled data from this period shows success rates for grant applications using the national Facility exceeding 50% - higher than EPSRC average. This indicates that the Facility not only enables new research proposals from the community, but the quality of proposals requesting use of the Facility is exceptionally high.

There is also a rapidly expanding industrial presence in the UK for semiconductors, including major manufacturers such as Lumentum, IQE, II-VI, and Plessey and a thriving community of spin-out companies. In addition, the creation of the CS-Connected cluster in South Wales completes a vital element of the impact agenda in this field. Now UK researchers have all the resources in place within the UK to manage their research from the low TRLs supported by EPSRC, through higher TRL R&D supported by IUK, and ultimately into the commercial sphere. The National Facility plays a key role in supporting researchers across this R&D spectrum by providing epitaxy in all parts of the TRL chain. As an example, in the quantum field, the recently funded ISCF project 'QFoundry' will establish a foundry service for semiconductor quantum devices developed under a succession of Facility-supported EPSRC/IUK grants.[4]

A key impact of the proposed Facility is its role in training researchers and staff to meet the burgeoning need for experts in semiconductor epitaxy in the major industrial initiatives described above (see details in **The Potential Facility** section). The current facility has a strong track record in this respect.

Within this flourishing R&D environment, the Facility is well positioned to expand its user base. The current Facility has already demonstrated the expansion of its user base with the development of Group IV epitaxy since 2017 (5 grants totaling £15m, 5 further proposals in peer review). The initiatives proposed for the new Facility include more advanced materials development by working with external groups, and drawing on resources such as characterization in the Royce Institute and advanced fabrication facilities such as those proposed for a Silicon Photonics National Facility. This will lead to a broader user base in the near future.

(2998 characters incl. spaces)

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[4] https://csconnected.com/uk-sets-sights-on-global-markets-for-quantum-technologies/

e) Justification: *Justify why this model is the most appropriate, as opposed to other approaches (such as local provision / strategic equipment, etc.). Reasons to be considered may include the need for specialised expertise in the technique, a new technique that is still at the early stages, unique capabilities (rather than just extra capacity), efficiencies of scale, fostering new communities or any other well founded and clearly explained justifications for a National Research Facility.*

(4,500 characters incl. spaces)

The need for a National Epitaxy Facility in the UK was clearly expressed in the community consultations. Validation of the community's view is supported by data from the current Facility which shows success rates for peer reviewed grant applications that include the Facility is 52%; higher than EPSRC averages. The availability of a Facility thus not only stimulates new research proposals, but the quality of those proposal is significantly enhanced through its use, leading to a clear benefit to UK research and clear value to the community.

Specific justification for a *Facility* model for epitaxy provision is as follows:

Alignment with the definition of an NRF

- There is a high investment cost required for epitaxy and associated materials characterization. The typical cost of a state-of-the art MBE or MOVPE reactor is £1-3M with correspondingly high infrastructure and recurrent running costs. Multiple such reactors are required to serve the community needs. Justification of these resources requires the concentration and high utilization rates found in a National Research Facility, where costs are spread across a broad user base.
- Epitaxy is highly specialized and requires experts with skills, knowledge and experience gained over many years. The community recognizes that concentration of expertise in a Facility creates a critical mass, long term added value and a sustainable resource serving the whole community.
- Effective, user-focused demand management and the development of best-practice in the management of capital assets is a key feature of the proposed National Epitaxy Facility bringing long-term benefits for UKRI and the user community.

Justification for a Facility within the UK research landscape:

An epitaxy Facility sits within a broader research landscape for semiconductors and epitaxy. The community identified the benefits of a Facility model, the relationship with other resources in the UK, and the key role a Facility plays in providing coordination and leadership for the benefit of the whole research community.

- The central identified role of the proposed Facility is to provide high quality epitaxy materials to satisfy the demand from users who do not have their own epitaxy equipment. The Facility should provide a well-defined range of materials where there is significant demand (principally III-V and Si/Ge based Group IV semiconductors) and where a flexible and accessible epitaxy *service* to users can be provided.
- In addition, the community requires a Facility that *supports* the development of new materials. In particular, the community endorsed an expansion of the successful pump priming (PP) scheme run by the current Facility to allow it to fund and manage PP in external epitaxy groups. This function is seen as important in supporting the path to maturity of new materials research - evaluating when such materials may be appropriately offered as a service through a facilities model, and evolving the structure and make-up of the Facility over time. Within the current contract period (2017-), the existing Facility has experience of expanding its materials provision through successfully developing a user base for Group IV materials (£15m in grants supported to date).

- The community requests a Facility that plays a leadership role in the UK. This includes assisting users to access expertise and additional capability across the entire research landscape; including links to other epitaxy groups, other NRFs, national institutes such as the Catapult network, Fraunhofer UK, the Royce Institute, major industrial initiatives such as CS-Connected and international research facilities.
- There is an identified critical need for the Facility to work closely with coordinated assets for device fabrication across the UK and to represent and support users in accessing these facilities seamlessly.
- A Facility provides invaluable training in epitaxy and associated techniques including for users, PhD students, PDRAs, visiting researchers and industry.
- The National Facility is a focal point for the community and provides added value over the core function of epitaxy provision. The Facility should therefore play a leading role in community-driven roadmapping, managing the annual UK semiconductor conference (over 300 delegates) and other symposia, promoting and supporting industrial engagement, promoting outreach, and having a role in advocacy for the community and UKRI.

(4441 characters incl. spaces)

f) The potential facility: *A description of the facility proposed and its primary function, including an indication of what the facility/infrastructure should provide to be of maximum benefit to the research community (what technologies and capabilities should be available, what services should it provide, what type and number of staff would it need). How will it link to other capabilities (for example other NRFs, large scale laboratories, institutes etc).*

(6,000 characters incl. spaces)

A National Epitaxy Facility will support world class semiconductor research in the UK through the provision of a bespoke "research foundry" service supplying the highest quality epitaxy of key research materials. It will serve the needs of a large number of researchers who do not have in-house epitaxy but whose research is enabled by the ready availability of high quality, bespoke epitaxial wafers and devices. The Facility will primarily support EPSRC-funded researchers and will be strategically positioned alongside specialist research capability in other epitaxy groups across the UK, playing a national role in coordinating such assets for the community. The Facility should consist of a main contractor providing overall management and leadership of the Facility with associated partner organizations. A detailed description of the Facility is outlined next:

1. **World-class epitaxy provision***:* The National Facility will be a centre of excellence in epitaxy and this is its core role. The Facility must include the latest MBE and MOVPE equipment plus a suite of characterization equipment to provide world-class epitaxy for the community. The Facility should have the capability and infrastructure to provide all the major III-V materials (III-As,P,Sb,N,Bi) plus Group IV materials including Si, Ge, and associated alloys, in a range of wafer sizes (up to 300mm). It should provide for integration of different materials, especially III-Vs with Group IV materials driving opportunities for hybrid materials research and heterogeneous device integration. The Facility should be professionally managed, preferably ISO qualified, with KPIs focused on delivery of high quality wafers to user specifications in a timely fashion. The access model must be designed to encourage quality and a high level of utilization to maximize the cost benefit. The expertise developed in the Facility should be available as a sustainable national knowledge resource and include provision to coordinate the development of new techniques, materials and devices
2. **Pump-Priming:** As a centre of excellence, the Facility must be able to research and develop new capabilities and to play an active role in the trajectory of epitaxy research in the UK. Since the previous statement of need in 2014, the existing Facility has successfully managed a pump priming (PP) scheme for this purpose (24 studies, 7 successful follow-on grants). The scheme should continue to be managed by the Facility, and to use the service of an external review committee to ensure quality and governance. The PP scheme should consist of three elements:
   a) *Community-led Pump Priming:* Requests from researchers for an appropriate number of wafers for feasibility studies prior to grant development.
   b) *Facility-led capability development:* The Facility should identify and develop new opportunities emerging from national and international trends
   c) *Pump priming of external groups:* A clear request from the 2020 consultations was for the Facility to expand its role in the development of new materials research (Ga_2O_3, II-VI, SiC, TMDCs, topological insulators identified as currently of interest). To enable this, the Facility should add to the existing mechanism for PP and have a budget to allow the funding of studies in epitaxy groups outside of the core Facility members. The Facility will support this PP work with active promotion to the community, management of the process, financial administration, monitoring of outcomes
3. **Industrial engagement:** The proposed Facility should have a remit and dedicated capacity to work with industrial customers with an appropriate financial model. The Facility

will play a leading role in maximizing the impact of national research by helping the academic base to connect to industrial users, including support for industrially led Innovate UK projects and other industrially sponsored research such as EPSRC manufacturing hubs. It should also assist researchers in development of intellectual property and support industry in evaluating early stage materials research

4. **Brokering:** The Facility should provide a technology 'brokering' service helping users access a broader range of capabilities outside the Facility. There was a strong desire in the community that an epitaxy Facility should be coordinated with external fabrication facilities such as those at Cardiff ICS, Glasgow JWNC, Southampton ORC, Swansea CISM and Strathclyde TIC, as well as new initiatives such as the proposed National Silicon Photonics Fabrication Centre. The Facility should also play a key role in connecting users to other capabilities in the UK, especially relevant NRFs (e.g. National Ion Implantation Centre, SuperSTEM, National Centre for X-ray Tomography) and the Royce Institute

5. **Training and Outreach*:*** The Facility has a clear national role in developing the next generation of epitaxy experts, including training of PhD students in the facility and working with CDTs and industry. The Facility should also support fellowship programmes for researchers wishing to specialize in epitaxy and should accommodate visiting national and international researchers to strengthen its impact

6. **Roadmapping:** The Facility should have resources for roadmapping future scientific and technological opportunities. The Facility should work with other organizations including the Royce Institute, the Catapult Network, EPSRC manufacturing and quantum hubs, the KTNs, The Royal Society, the Institute for management, and other professional bodies.

7. **Conferences/Workshops:** The National Facility should continue to organize the annual UK semiconductor conference (and satellite events) on behalf of the community. The community also requested 'pan-epitaxy' workshops, promoting shared best practice in different epitaxy techniques and related materials processing methods

8. **Expert Consultation:** The Facility has a role in providing strategic and impartial advice to UKRI and government as well as advocacy for semiconductor R&D

(6000 characters incl. spaces)

*g) **Indicative resources:** There will be a future steps to establish the scope and scale for any funded activity. At this point we require indicative costs only over 5 years of operation. These should be split into capital requirements and yearly recurrent costs. In cases where there are existing UK capabilities or equipment that the proposed activity could utilise, the Statement of Need should describe both:*

•The costs of supporting this if the existing capabilities or equipment did not exist.
•The costs of this if it were to use existing capabilities and equipment.

(3,000 characters incl. spaces)

There is an existing National Epitaxy Facility comprised of a consortium of the University of Sheffield, UCL and the University of Cambridge. The Facility provides epitaxial materials across the full range of III-V semiconductors (III-As,P,Sb,N,Bi) and in key Group IV materials. UK research based on these materials remains world class, of critical mass and projected to have continued impact over the next 5-10 years at least. A proposed new Facility should therefore continue to provide a similar level of support to meet the demonstrable community demand. To address the need for support of new materials development identified through the community consultations, a new Facility should have additional resources available for management of a broader pump-priming capability.

The current Facility is based on a 5-year budget of £11,685,000 (ex VAT) supporting the following resources:

(a) Capital provision of £1,706,000

(b) Recurrent costs of £1,996,000 per annum based on the present Facility make-up (100%FEC)

The current Facility include 6 MBE and 6 MOVPE reactors supporting the growth of 1170 wafers per annum for the community. There are 15 technical and administrative staff employed in the Facility, comprised of scientists/engineers, support technicians, administration, operations management and quality control (total 13.5 FTE). There are 8 academic staff with time directly allocated to the Facility including the Director who is a senior Professor in the University of Sheffield.

A new Facility requires this level of recurrent costs, with ~15% uplift for inflation plus an additional budget of £300k to support external pump priming of new directions and materials development (£13,750,000 total recurrent costs). Additional capital in the current Facility has been funded through various schemes over the years (including strategic capital equipment, Quantum Technologies equipment capital, and core equipment calls from EPSRC). Future indicative capital needs are of the order £1m to support upgrading of MBE control electronics (UCL), maintenance and characterization upgrades (Cambridge) and the development of integrated Atomic Layer Deposition (ALD) as an extension of core epitaxy for hybrid materials and epitaxial regrowth/integration (Sheffield).

The costs of replicating from scratch the *capital alone* of the existing Facility would be of the order of £70-80M. A suite of new epitaxy reactors (MBE and MOVPE) and associated service infrastructure costs (including extensive H&S infrastructure) would cost of the order £25M. Characterization equipment to support this range of epitaxy would cost of the order £15M. The nature of high purity semiconductor epitaxy research means reactors must be located in dedicated high quality laboratories, usually cleanrooms. The cost of providing such dedicated space is estimated at £30-40M.

(2854 characters incl. spaces)

h) ***Authors and Community Engagement:*** *A list of who was directly involved in writing the Statement of Need (name, institution / company*

and research interests). (4,500 characters incl. spaces)

This document is the result of a multi-staged process of consultation with the community.

1. Site visits to users in 11 Universities in 2019/20
2. A questionnaire to the community seeking input in July 2020
3. Two online town hall meetings on 9th/14th October 2020

The total number of community members engaged in the exercise was 136 (104 academics and 32 industrial).

Management support for the town hall meetings was provided by staff from the current facility, the KTN and Dr John Lincoln (Photonics Manufacturing Hub). The format was as follows: after introductory talks, there were parallel breakout sessions with discussions and virtual whiteboards used to capture input from all delegates (821 separate post-it notes were collected). Under five topic areas (photonics, electronics, quantum, new materials, fundamental science) delegates discussed research needs/opportunities, potential impact of the research, the role of epitaxy, and specific requirements for a National Epitaxy Facility. The outputs of meetings as well as data from the current National Facility were subsequently used to assemble this statement of need.

The document was written by Prof. Jon Heffernan and Prof. Maurice Skolnick. The document was then reviewed by Prof. Rob Martin (Strathclyde, chair of the Facility steering group), Profs Huiyun Liu and Alwyn Seeds (UCL), Prof. Rachel Oliver (Cambridge), and Dr Ian Farrer (Sheffield) for scientific quality and consistency. The document was then commented on by chairs of the breakout sessions for accuracy and representation. The document was also read by Prof. Peter Smowton (Cardiff) as an independent final review before sending to the community. The document was sent in mid-November to all members of the community engaged in the consultation exercises. All responses were then incorporated and a final document circulated before uploading to EPSRC. A full list of all those engaged and supporting the document is as follows:

Academia

Edik Rafailov (**Aston**)

Maziar Nezhad (**Bangor**)

Robert Armstrong, Emily Meads (**Bath**)

Krishna Balram, David Fermin, Edmund Harbord, Martin Kuball, Judy Rorison (**Bristol**)

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Craig Allford, James Atkinson, Anthony Bennett, Manoj Kesaria, Qiang Li, Juan Viterbo, Sam Shutts, Peter Smowton, Stephen Sutton (**Cardiff**)

Iddo Amit (**Durham**)

Tommaso Antonelli (**St Andrews**)

Gerald Buller (**Heriot Watt**)

Isaac Luxmoore (**Exeter**)

Abdullah Al-Khalidi, David Childs, Ravinder Dahiya, Richard Hogg, Anthony Kelly, Chong Li, John Marsh, David Moran, Douglas Paul, Marc Sorel, Edward Wasige (**Glasgow**)

Mary Matthews (**Imperial**)

Nigel Mason (**Kent**)

Peter Carrington, Manus Hayne, Edward Laird, Andrew Marshall (**Lancaster**)

Animesh Jha, Edmund Linfield, Christopher Marrows (**Leeds**)

Paul Chalker, Ian Sandall, Tim Veal (**Liverpool**)

Huiyun Liu, Siming Chen, Michael Pepper, Alwyn Seeds, Mingchu Tang, Michael Wale (**UCL**)

Colin Humphreys **(Queen Mary)**

Patrick Parkinson (**Manchester**)

Aleksey Kozikov, Jonathan Mar (**Newcastle**)

Jessica Maclean, Sergei Novikov, Amalia Patane (**Nottingham**)

William Navaraj (**Nottingham Trent**)

Robert Taylor, Andrew Briggs, Thorsten Hesjedal, Dominic O'brien (**Oxford**)

Edmund Clarke, Merlyne DeSouza, Ian Farrer, Mark Fox, Kris Groom, Im Sik Han, Dimitry Krizhanovskii, David Mowbray (**Sheffield**)

Martin Charlton, Senthil Ganapathy, Frederic Gardes, Dan Hewak, Yaonan Hou, Callum Littlejohns, Graham Reed, Luca Sapienza (**Southampton**)

Martin Dawson, Naresh Gunasekar, Rob Martin, Fabien Massabuau, Alessandro Rossi, Michael Strain (**Strathclyde**)

Stephen Sweeney (**Surrey**)

Stuart Irvine, Dan Lamb (**Swansea**)

Mark Ashwin, Richard Beanland, Gavin Bell, Maksym Myronov, Ana Sanchez, Vishal Shah (**Warwick**)

Christina Wang (**York**)

<u>Industry</u>

Andrew Ramsay (**Hitachi**)

Iain Thayne (**35CONSULT**)

Gilles Rousseau(**Allectra**)

Alasdair Fikouras (**AvicenaTech UK**)

Boumedienne Boudjelida (**Bruker**)

Ainslie Chinembiri (**Chitendai Ltd**)

Chris Meadows(**CS Connected**)

Michael Robertson, Pamela Jurczak, Quan Lyu, Sandy Ting (**Huawei**)

Iwan Davies, Denise Powell (**IQE**)

Ali Anjomshoaa, Wyn Meredith (**CSC**)

Matthias Kaur (**Lightricity**)

Chris Button, Neil Whitbread (**Lumentum**)

Yameng Cao (**NPL**)
Anthony Springthorpe (**NRC**)
John Lincoln (**PhotonicsUK**)
John Whiteman(**Plessey**)
Jon Fuge, Nick Weston (**Renishaw**)
Ad Ettema (**Omicron**)
Mat Wasley (**KTN**)
Valerie Berryman-Bousquet (**Sharp**)
Max Sich, Scott Dufferwiel (**Aegiq**)
Andrew Johnson (**Wafertech**)
Greg Johnson, Venothan Naidoo (**Zeiss**)

(4474 characters incl. spaces)