Statement of Need for Group III-V Epitaxy

1. Description of the Facility:

Executive Summary:
III-V semiconductors are of profound importance for a huge range of applications that underpin modern society. They also lead to many groundbreaking advances in fundamental science. This broad impact is projected to continue in many areas that are closely aligned with EPSRC and wider national priorities. UK research and development in the III-V field is highly active in the university sector and industrially. Advanced materials epitaxy and processing have been, and will remain essential to exploit the many advantageous features of III-V semiconductors and to maintain the prominent position of the UK. This Statement of Need, developed through wide consultation with the community, concerns the availability of such world-class epitaxy and processing capability through the model of a III-V Mid-Range Facility (MRF).

A national facility is required to provide the III-V semiconductor community in the UK with a "research foundry" service supplying high quality crystal growth and device fabrication capabilities. The service will support world-class research carried out in universities and industry throughout the UK. The facility will serve the needs of a large number of researchers who do not have in-house capabilities but whose research is enabled by the ready availability of high quality, bespoke epitaxial wafers and devices through a service model. The facility will be strategically positioned alongside specialist research capability in research groups across the UK and will play a national role in coordinating such assets to support III-V research.

An *indication* of the size and cost of a facility is based upon a community consultation organised by the authors and on data from the operation of the current National Centre for III-V Technologies. For the proposed facility to provide the service across the four major III-V materials (III-As, P, N, Sb) plus the capability to develop emerging materials, the facility requires a minimum of 4 Molecular Beam Epitaxy (MBE) machines and 3 Metalorganic Vapour Phase Epitaxy (MOVPE) reactors. In addition, fabrication facilities in cleanroom environments are required to develop a broad range of devices including the provision of nanofabrication capability.

The facility will consist of a main contractor and associated partner universities to provide the service. Core staffing to provide the required level of service is of the order of 17 personnel; comprised of scientists/engineers, support technicians, administration and management. The facility will require a director, operations manager and a contribution from senior university staff to oversee the facility. The total operational costs of an established facility of this scale are of the order of £11-13M over 5 years producing around 5,000 epitaxial wafers and associated device fabrication. Capital costs to equip a brand-new facility to the necessary levels, including adequate clean room construction, are at least £50M. Use of existing facilities would require investment but the cost would be significantly lower than the £50M.

<u>Description of the services the facility should provide:</u>

1. **World-class III-V Epitaxy provision *(must have):***
The National Facility should be a centre of excellence for the supply of epitaxial wafers. The facility must include the latest MBE and MOVPE techniques to provide world-class epitaxy for the community. The facility should have the capability and infrastructure to supply the major III-V materials including III-arsenides, phosphides, nitrides, antimonides and their alloys, and emerging materials such as bismides.
The facility should be professionally managed with a focus on delivery of high quality wafers in a timely fashion and to user specifications. The access model should be transparent, efficient and designed to encourage a high level of utilisation of the facility to maximise the cost benefit. The expertise developed in the facility will be available as a sustainable national knowledge resource and will include provision to coordinate the development of new techniques, materials and devices both within the facility and working with the external community.

2. **Device Fabrication provision (*must have)***
The facility should include device fabrication capability across a broad range of devices including lasers, LEDs, detectors, transistors, quantum devices, amplifiers, modulators and solar cells. Nanoscale fabrication will allow the development of quantum dots, nanowires, photonic crystals, and high frequency electronics. The facility should work with the community to increase the capability for integration of III-V materials with silicon-based photonics/electronics.

3. **Pump-Priming (*must have*)**
As a centre of excellence, the facility must be able to research and develop new capabilities and to remain relevant to the needs of the community. There should be provision for developing underpinning capabilities through two approaches:

a) *Community-led Pump Priming:* A pump priming scheme will allow researchers to request a limited number of free wafers/devices for feasibility studies prior to grant development. Awards will be made by an independent panel reviewing submitted proposals. The current National Centre has successfully run such a scheme, which has led to two fully funded grants with several more in preparation.
b) *Facility-led capability development:* Acting as a centre of excellence, the facility will identify and develop a number of new capabilities emerging from national and international trends. Development proposals should emerge from active engagement with the community and coordinated activities with complementary research groups outside of the facility. Proposals should be reviewed and approved by the steering committee of the facility before development.

4. **Industrial engagement (*must have*)**
The III-V community includes an active and supportive industrial base whose needs are generally well met by the 'mid-range' scale of a MRF. Although the facility should be funded to primarily support EPSRC research grants and these will have priority, there should be a remit to work with industrial customers through an appropriate financial model. The facility can play a leading role in maximising the impact of national research by helping the academic base connect with industrial users, and by supporting industrial users to develop technologies to higher Technology Readiness Levels (TRL).

5. **Roadmapping (*must have*)**
The facility should continue to develop the roadmap for III-V semiconductors in consultation with the community. There are numerous benefits such as identifying research trajectories, providing a voice for the community, developing a strategic partnership with EPSRC for capability and delivery plan, providing guidance to a new generation of researchers and providing an entry point for industry to engage with academic research. The roadmap should include a more detailed survey of capabilities in the UK including epitaxy, fabrication, characterization, integration, design and packaging. Synergies with other MRFs and facilities should be developed.

6. **Training (*must have*)**
The facility should have resources available to allow new and established researchers from the academic and industrial base to benefit from its expertise. Examples include running in-house training courses in epitaxy or cleanroom techniques, utilising knowledge transfer partnerships to increase industrial engagement, affiliating with CDTs and actively participating in European training networks.

7. **Brokering (*desirable*)**
The facility should provide a technology 'brokering' service whereby researchers are introduced to a broader range of additional capabilities outside of the facility. Many researchers are often unaware of the potential to significantly enhance their research through access to additional techniques and expertise. The need for such a service was referred to in the community consultation in several different contexts such as packaging, integration and advanced characterization. The MRF is ideally placed for brokering due to the many years of experience in semiconductor technologies concentrated in the facility and the breadth of its interactions in the wider scientific community.

8. **Conferences and Workshops (*desirable*)**

The National Centre currently organizes the annual UK semiconductor conference with an average attendance of over 300 delegates. The facility should expand on this successful self-funded activity and develop additional satellite events in the community including roadmapping events.

9. **Expert Consultation (*desirable*)**

As a centre of excellence, the facility should provide expert consultation based on the concentration of expertise and its active engagement with the community through Roadmapping and other community focussed initiatives. Advice should be available across the community and to EPSRC, research councils, government and the international community.

2. Strategic Case:

EPSRC's strategic plan is focused on two goals: "**Research and Discover"** and **"Research and Innovate"**. III-V semiconductors, with their broad fundamental properties and track record in device innovation and applications align very closely with these goals. Indeed the current III-V Centre supports grants across 22 EPSRC themes principally in ICT and Physical Sciences, helping to achieve a **balanced research portfolio**. A future III-V MRF enabling the **new and exciting research** outlined below will support a similar range of themes particularly across optoelectronics, electronic devices, light-matter interactions, quantum optics, energy materials and **cross-disciplinary** applications such as healthcare. These areas are all '*maintain*' or '*grow*' in the current EPSRC portfolio and are closely aligned with **national priorities** such as energy efficiency, manufacturing innovation, big data, communications, advanced materials and exploiting quantum technologies. The **impact** of a III-V MRF is outlined in section 3.

Why is this facility needed now or in the future?
III-V research continues to be vibrant and fruitful with globally significant impacts and is strongly represented in EPSRC's research portfolio. Headline figures from the current facility provide a clear indication of **present demand** and continued buoyancy of the field with support for 51 grants in the last 4 years totalling £43m in 20 leading UK Universities. Access requests have increased 40% in the last two years with the result that *a significant part of this demand extends beyond the current contract period* (full details in section 4).

To identify ***future*** **research** enabled by a new MRF, a community consultation meeting was held on the 15th September in Birmingham. In eight themed working groups, 74 academic and industrial delegates identified future research directions in line with EPSRC priorities, capabilities needed and the suitability of an MRF model (the process is outlined in section 8).

There was clear endorsement for the role of a III-V MRF, with specific advantages outlined in the summaries below.

1. III-V Photonics:
This theme was classified into three overarching topics: integration with electronics, integration of different photonic components and photonic devices. All of these were seen as requiring essential access to advanced epitaxy, sophisticated fabrication and device concepts for applications in solar cells, detectors and LEDs to name a few. Developing new laser wavelengths to extend the applications space for III-V photonics in areas such as healthcare, sensing and communications, was also identified as being of high priority. Integration of photonic components requiring broad skill sets and significant infrastructure across epitaxy, fabrication and systems design was seen as important. Epitaxial regrowth was also agreed to be an important topic, particularly for industrial users.
The ***facilities of an MRF*** provide the access to the required range of capabilities and materials. Aspects such as integration with silicon, packaging, scale-up and modelling/design will need coordination of additional external resources, which can be facilitated by the MRF. An MRF is also seen as an important gateway to larger facilities and European programmes such as the JePPIX photonics foundry.

2. III-V Electronics:
This group highlighted the significant growth in opportunities for GaN electronics in RF and power applications. With the availability of GaN on 150mm silicon, this research is also shifting to a system level approach and higher TRLs. There remain significant challenges in epitaxy and device fabrication including reliability and high voltage operations. Other important areas include antimonide-based electronics, which remains a fruitful area of research with good progress made in recent years.
The ***facilities of an MRF*** provide valuable concentration of expertise and easy access for a broad range of researchers including those interested in design, modelling and systems level development.

3. Device Fabrication and Integration
The UK has excellent expertise in III-V fabrication at the single component level; there is a strong need to keep world-class facilities in place for this. Research at higher TRLs requires packaging and scalable component platforms with integrated technologies. UK capability in this area needs to be developed and the MRF should help to form a national strategy that also includes interfacing with larger volume capability in industry or foundries. Whereas many universities have fabrication facilities available to them, **the capabilities of an MRF** provide the necessary wafer scale, reproducibility and process innovation expertise to meet a broader range of research needs including a systems level approach.

4. Basic Science
The basic science of III-V semiconductors is a vibrant research area and the UK is world-leading in fields such as quantum dots, polariton condensates, metamaterials, quantum transport and THz devices. There are exciting opportunities in 2D materials, topological insulators and transport in new materials. The work is at the cutting edge of epitaxy research where new physical phenomena are only revealed in the highest quality materials. The **facilities of an MRF** will provide a broad range of materials and advanced device supply to support this area. Clearly the facility cannot undertake all basic III-Vs research in the UK, but will coordinate its activities with other groups, particularly those with epitaxy dedicated to specific materials systems.

5. III-Nitride materials and devices
This area has become hugely significant in the last 20 years with the global impact of nitride lasers, LEDs and electronic devices. Indeed, the award of the 2014 Nobel Prize in Physics for the development of blue LEDs is a recognition of the outstanding achievements in this field. Future opportunities include UV LEDs, sensors, green and THz lasers, electronics, solar cells and H_2 generation. There is also significant epitaxy development required in areas such as quantum dots and nanowires. The UK has a leading position on integration of GaN on large area silicon, with significant potential for further exploitation. **The facilities of an MRF** will provide access to advanced epitaxy, and the robust processing expertise needed for high quality nitride devices. There is an additional need for some packaging capability, reliability testing and modelling expertise that will greatly improve the understanding of this complex III-V material.

6. Narrow band-gap materials and devices
The area is particularly important for the development of new lasers, LEDs, detectors and enhanced imaging in the infra-red. There is strong industrial and defence-related demand for the research with applications in gas and pollutant sensing, countermeasures, spectroscopy and quantum technologies. Other basic areas of research include the excellent transport properties of materials such as antimonides leading to low power high frequency electronics, and their potential in spintronics and thermovoltaics research. **The facilities of an MRF** are attractive due to the multiple material combinations on offer, and the range of expertise available to enable the wider community to explore epitaxy options.

7. Emerging Materials
Emerging materials is an underpinning research activity in III-V semiconductors. The theme is characterised by a spectrum of maturity in the quality and understanding of the epitaxy and material properties. New research opportunities include bismides where key devices such as lasers have recently been demonstrated; mismatched alloys for extended wavelengths and integration on silicon; magnetic materials, boron nitride, 2D materials. **The facilities of an MRF** will provide selected emerging materials when there is synergy with established epitaxial methods and materials available in the facility. For less mature materials, the MRF should work with external research groups helping to foster progress by sharing its expertise and helping to broker materials exchange. This will ensure the UK remains at the forefront of new III-V materials research and that the facility remains relevant to the community needs.

8. Nanomaterials and Devices

Nanostructured III-V materials open up huge opportunities for novel physical phenomena and new device concepts. Future research directions are focused on the discovery of new physical properties such as quantum effects, III-V device integration (especially on silicon) and nano-scale device concepts. Innovative epitaxy and nano-fabrication techniques are key to accessing the most esoteric physical phenomena. The UK is strong in many fields, such as quantum dots and photonic crystals and there is increasing capability in areas such as nanowires. Like the emerging materials field, the **facilities of an MRF** offer a concentration of expertise and materials choice that is highly valuable to users and other epitaxy groups in the UK.

3. Impact:

The importance of III-V semiconductors

In the UK, semiconductors (including III-Vs) have a strong economic impact across many sectors. The UK electronics industry contributes ~£16bn annually to the UK economic output, providing direct employment for 300,000 people in 12,000 UK companies. UK Photonics is similarly impressive with an annual output of £13bn in 2013. Components based on III-V semiconductors have had a profound impact on our modern technological world: the internet would not exist without high speed telecoms lasers, mobile communications is based on high speed GaAs amplifiers, digital media has been driven by successive generations of optical storage, highly efficient GaN LED lighting is leading to a huge reductions in carbon emissions and III-V photonics has had a major impact on a range of healthcare and medical developments. The impact of III-V semiconductors is further exemplified by the award of the 2014 Nobel Prize for blue LEDs, following previous awards in both fundamental (fractional quantum Hall effect, 1998) and applied fields (semiconductor hetero-junctions, 2000).

At the fundamental research level, the diversity of material properties within the III-V family provides the scope for new generations of devices with unique properties. There is no doubt that new III-V devices and applications will emerge over the next decades based on the excellent research conducted by UK researchers including those supported by the facilities of a III-V MRF. The future impact of III-V semiconductors will come from underpinning technologies essential for developments in quantum technologies, big data, satellites, robotics and autonomous systems, healthcare, advanced materials, smart (low carbon) buildings and energy storage, to name but a few.

The impact of a III-V MRF

The impact of a III-V MRF will be felt primarily through its enabling role for the **academic research** outlined in section 2 and through its engagement with UK industry. The MRF will also strongly contribute to the development of **leadership and training** of future researchers. A facility supporting upwards of 30 research grants at a time has huge impact on the training of hundreds of PhD students, RAs and industrial partners. Other explicit impact measures will include in-house training facilities, sustainable support for national expertise, the nurturing of new research communities through the impact of a National Roadmap for III-V technologies, and facilitation of conferences and workshops. **Research excellence metrics** such as publications and citations are also enhanced through cost effective access to the best materials and capabilities (the current facility output has enabled the publication of over 800 research papers in the last ten years).

Beyond academic research, there is significant industrial strength in the UK with many companies competing globally in established and emerging markets. Experience shows an MRF is an attractive model for bringing industry and academic interests together. The current facility is working directly with over 50 leading companies, including some previously spun out from the facility. For instance in GaN, Plessey is now manufacturing LEDs on 6-inch silicon at Plymouth, Devon, based on technology developed in the Cambridge part of the MRF. IQE is also manufacturing GaN epitaxial layers on 6-inch silicon at its factory in Wales, and other companies in the UK are ready to manufacture devices in the UK when the MRF work is ready for technology transfer. Other companies directly accessing and exploiting a range of III-V R&D in the UK include, NXP, Oclaro, Rohm, Huawei, Teraview, Cascade Technologies, Toshiba, Sharp, Selex, E2V, Hitachi, Intense Photonics, MSquared Lasers, Seren Photonics, CST Global, SAFC, Gas Sensing Solutions, Compound Semiconductor Photonics, Seagate, Renishaw, Land Instruments, Dynex and many more. These and other companies have expressed support for III-V facilities in the UK. In addition many companies actively recruit graduates and strongly value the training of potential future employees by the facility and its academic customers.

Effective management of shared access to capital resources is a critical feature of the MRF model. The III-Vs MRF will play a leading role in the **dissemination of best-practice** in access management, such as ISO qualification, across the MRF portfolio and EPSRC's strategic equipment processes, helping to increase the impact and **cost benefit** of national research resources.

4. Users:

The main beneficiaries of the facility will be UK academic researchers working on III-V science and technology, most of whom do not have their own growth or advanced processing facilities, and who will benefit from reliable and ready supply of leading-edge materials and devices. These researchers are mainly in the disciplines of physics, engineering and materials science. The output of the facility will map strongly to EPSRCs strategic portfolio as described in Section 2, principally in ICT, Physical Sciences and Engineering, but also across disciplines.

An *indication* of expected demand for the facility is obtained from three sources outlined here:
1. **The current EPSRC III-V National Centre** provides clear evidence for demand. In the contract period from 2010 to 2014, the National Centre has supported 51 EPSRC grants with total value of £43m in 20 leading Universities. These include 38 responsive mode grants, 3 programme grants, 1 platform grant, 5 fellowships, 4 first investigator grant, a number of impact acceleration awards, and 14 pump priming feasibility studies. Grants on the Web (GoW) indicates the work is distributed across 22 themes in EPSRC's current portfolio. These figures represent awarded grants (after peer review). The Centre has received 78 formal access requests in the present contract period and a large number of informal enquiries, indicating the level of demand that exceeds peer review success. There are also a number of non-EPSRC grants supported (EU, ERC, DSTL,TSB) and access requests from over 50 companies.
The III-V National Centre contract runs to June 2015. There are 19 EPSRC grants that extend beyond this date, with 7 grants due to complete in 2017. There are additionally 18 grants in peer review which if successful will likely start after the contract is finished. A body of EU and industrial contracts also extend beyond the current contract. *This data shows quantifiable demand from the community for MRF-level epitaxy/device provision beyond the contract period of the current III-V facility.*

2. **Community Consultation**: To estimate *additional* future demand, a community consultation meeting was held on 15th September in Birmingham. In total there were 74 delegates at the meeting with 20 apologies received due to timing issues. 51 academics and over 20 industrial supporters attended. The academics present at the meeting together hold a combined grant portfolio of over £140m from EPSRC (information from GoW). There was clear endorsement of the need for an MRF from the meeting. Furthermore, the community gave a comprehensive indication of the breadth and depth of the exciting new research opportunities expected to be pursued in the next 5-10 years. These were summarised in Section 2. It was clear a significant proportion of this research would translate into demand for the output from a III-Vs MRF.

3. **Business development activities of the National Centre:** More quantifiable estimates of future demand were obtained from the business development activities of the current, Sheffield-led, III-V National Centre. A set of detailed interviews with leading academic users was conducted in 2014 with over 20 users outlining firm intentions to submit significant EPSRC grant applications within the next two years, and requiring access to the National Centre if renewed. Detailed information on scientific and service level needs was also obtained from the discussions, and these have been incorporated into this document.
In addition to this direct engagement with users, the NC business development team conducted a short anonymous survey of a general group of potential users across academia and industry. Over 70 of those who responded indicated an interest in working with the National Centre in the near future.

5. Justification:

The need for a III-V MRF in the UK was discussed explicitly in the consultation meeting. The community consensus was that there is a clear need for a facility that provides on-demand, high quality epitaxy and device fabrication to enable a broad range of research across the UK.
Key factors in support of a facilities model for this community are as follows:

- Epitaxy of high quality material to a given specification is a highly specialised skill and requires the effective utilisation of significant resources. There is a high level of demand from the community for a broad range of bespoke materials and devices; the concentration of expertise in an MRF provides the sustainable critical mass of expertise for the long-term benefit of the community. This includes the provision of leadership and training to sustain UK capability and impact in this important field.
- There is a high capital cost associated with III-V epitaxy and advanced fabrication facilities. The typical cost of a state-of-the art MBE or MOVPE reactor is £1-2m and requires at least one full time skilled operator plus consumable costs. Similarly, a suite of III-V processing equipment required to translate wafers into useful devices costs of the order of £4-5m (not including cleanroom costs). Justification of these costs requires the very high utilisation rates found in a MRF with significant sharing of infrastructure, calibration, test samples and process development costs across a broad user base.
- Effective, user-focused demand management and the development of best-practice in the management of shared infrastructure is a critical element of the MRF model and will have long-term benefits for EPSRC and the user community.
- Concentration of expertise, robust management, and strong engagement with the community through roadmapping, workshops, industrial involvement etc. are all factors that will allow a III-Vs MRF to develop a leading role and help the community engage actively with national priorities, government initiatives and large EU programmes

Limits and boundaries
The community is clear that the MRF cannot provide all the research needs going forward and an appropriate relationship with alternative sources and complementary capabilities in the research community must be developed. Specific examples that emerged through the community discussions are as follows:

- Device packaging is a capability the community requires, although the demand is not yet quantified. The facility can broker the outsourcing of packaging and will help to organise a community meeting to ascertain the extent of future demand.
- In several areas, including emerging materials and integration, there is a clear need to utilise other resources in the community and coordinate these resources. The facility will take a lead on this coordination exercise including the use of the III-V roadmap.
- A roadmap should be developed for fabrication facilities, taking account of the range and scale of facilities in the UK.
- The facility should not take on work that is best done elsewhere, particularly work that can be sourced from commercial foundries if there is cost benefit. This is a key responsibility for the facility management.

6. Sustainability:

How will the facility ensure its future sustainability?
The facility will:

- Ensure it is continuously meeting the needs of the community through active engagement with researchers and strong management of the service provision through key performance indicators.
- Ensure its capabilities remain relevant to the emerging needs of the community and EPSRC/National priorities. There must be an element of underpinning research included to ensure the facility can plan for a sustainable future.
- Include a budget for capital equipment and maintenance to ensure the facility can provide state-of–the art service and cost efficiency
- Ensure there is a robust business model that includes provision for non-EPSRC income streams and a model for re-investment in skills and infrastructure.
- Be led by a Director who will ensure there is a strong vision and ambition to extend the reach and impact of the facility's expertise. This should include a remit to play a role in the exploitation of research results such as facilitating the generation of intellectual property and taking a lead in technology transfer to industry.
- Ensure continuity of staffing and expertise, including the provision of clear training and career development paths.

What is the most appropriate access model for the facility?
The current III-V facility model, evolved over many years, is very suitable for supporting the III-V community. To be clear, this is not a free-at-the-point-of-use model. Instead, 80% core infrastructure and operating costs are provided by EPSRC upfront. EPSRC funded users access the facility by including costed access requests on grant applications. On successful award of a grant (after peer review), the additional 20% costs *for that user* is secured from the grant funding.
The model is attractive for several reasons and *we recommend its adoption for any future facility.* Researchers benefit from shared access to core funding, which is explicitly reflected in reduced grant costs. The facility benefits from strong relationships with successful researchers, which also allows it to be well informed on emerging trends and new research. The model provides stability of employment for highly experienced staff, without whom the MRF cannot operate at the required high levels.
From an EPSRC perspective, the model creates an incentive for the facility to actively engage with the community and ensures the full benefit of the facility's expertise is utilised in the grant application process. The overall research quality is improved and the cost benefit of a facility operating at full capacity is realised. This model is particularly suited to a III-V facility where much of the service is in developing techniques, materials and new devices and not just providing access to standard services such as characterisation.
It is critical that the facility's capabilities can evolve and a sufficient element of the budget (~10% based on current facility model) should be set-aside for the development of underpinning capabilities and pump-priming.

Non-EPSRC funded users: In the model, additional financial support and sustainability is achieved through a provision of capacity over and above that required for EPSRC-funded users. Current data suggests a figure of ~1000 wafers per year is required to meet the core needs of EPSRC funded users. With suitable operational arrangements such as extended operating hours, the facility will have capacity to provide additional wafers/devices to industry and non-EPSRC funded users. This will be charged at full economic cost, plus an element of overhead for re-investment in the facility. Such a business model leverages core infrastructure to increase impact and sustainability. For this model to work, it is critical that reliable and efficient equipment is in place to meet all demands.

Management Structure: Key to a sustainable business model is a strong and clear management structure, ensuring the facility fulfils the diversity of roles at the highest level and with full accountability. The Director of the facility should be responsible for overall management, supported by operational and strategic committees, including an external steering committee. An operations manager should oversee all service and financial management in the facility including coordination across multiple sites.

7. Context:

Existing facilities in the UK:
In addition to the current EPSRC National Centre for III-V Technologies, there are laboratories with III-V MBE facilities in Cambridge, Nottingham, Warwick, UCL, Leeds, Lancaster, Liverpool, Manchester and Imperial College. These are specialist laboratories with equipment dedicated to specific research interests of the institution involved, funded through standard EPSRC or other funding routes. A number of these have unique capabilities and supply wafers to other groups, both academic and industrial. There are operational MOVPE capabilities for GaN in Cambridge, Sheffield and Bath. Sheffield is the only UK university with facilities for MOVPE growth of As, P, Sb or Bi. Outside of the academic community epitaxial wafers of standard design are available in the UK from IQE in Cardiff.

There is a range of device fabrication capability in the UK with many universities having cleanrooms and general device processing facilities, often supporting student training. More significant capabilities required for an MRF, including dedicated equipment for III-Vs, large wafer and multi-wafer capacity, nano-scale processing, and industrial quality device performance are found in a limited number of universities. Glasgow and Sheffield provide this capability in the current III-V facility. There are also commercial suppliers such as CST Global, Kelvin Nanotechnology, INEX and Optocap (packaging).

There are many international facilities for III-V semiconductor research. At the individual university level, the situation is similar to that in the UK. There are some international centres that work on a contract basis such as IMEC (Belgium), Fraunhofer Institutes (Germany), RENATECH (France), NREL (plus other US laboratories), RIKEN (Japan), Tyndall (Ireland) etc. Commercial foundries similar to IQE also provide standard materials usually in volume.

Accessing these facilities
Researchers with the above 'on-site' capabilities in epitaxy or device fabrication utilise these facilities for their own research through standard grant funding. Researchers without these facilities may obtain materials through collaborative research providing the funding is available, and the collaborating institutes have capacity to offer the material in a reasonable timescale without adverse impact on their own research. The **proposal for a III-V MRF complements** this approach by providing ready access to wafers and devices that is time and cost effective and to which researchers without on-site capability can pursue their own research agendas. Those with on-site capability can also access additional expertise or supplement capabilities though the facility.

Researchers can access international facilities through various means but *in general* these overseas institutes are not responsive to UK needs in the manner required to achieve top-level competiveness. It is also unlikely that economies of scale would be achieved by the community seeking overseas support in an uncoordinated manner.

If the facility were not funded:
If EPSRC were not able to support this facility there would be significant impacts on UK research. Initially there are 19 research grants supported by the current facility that will require alternative options immediately. There are then a significant number of current and past users who have indicated their intention to use a III-V facility for future research, including to access European funding. These researchers will need to find new means to achieve this, including applying for significant responsive mode funds for the equipment and running costs currently provided by the facility (with significant risk of duplication of infrastructure). New collaborations would need to be developed in the community to ensure alternative supply is available. It is likely this will take a significant amount of time and will lead to an interruption of research momentum nationally that may take several years to recover. In many cases researchers will be forced to seek material and collaborations abroad (for instance in MOVPE where no alternative supply exists in the UK), and in some cases this may lead to

researchers leaving the UK. As well as the major deleterious impact on UK university research, there would also be severe negative impact on UK industry in terms of long term input of new development directions, on short term collaborations in prototyping new devices, and in the supply of highly trained personnel for careers in industry.

8. People

Who was involved in the preparation of this statement of need?
A community meeting was convened in Birmingham on the 15th September, 2014 by the current III-V National Centre (MRF), led by Professor Jon Heffernan (Director) and Professor Rob Martin (Chair of steering committee). The meeting was structured around the key questions required for the Statement of Need and a workshop format was used.
In order to cover the broad spread of III-V research, eight working groups were formed around major themes (noting that there is considerable overlap of these themes). To ensure high quality, balanced and representative discussions, the working groups were led by two moderators who are respected experts in the fields.

The themes and working group leaders were:

1. **III-V Photonics:**
   Professor Peter Smowton (Cardiff), Professor Richard Penty (Cambridge)
2. **III-V Electronics:**
   Professor Ian Thayne (Glasgow), Professor Peter Houston (Sheffield)
3. **Basic Science:**
   Professor Dave Ritchie (Cambridge), Professor Maurice Skolnick (Sheffield)
4. **III-Nitride materials and devices:**
   Professor Rob Martin (Strathclyde), Dr Trevor Martin (IQE, Cardiff)
5. **Narrow bandgap materials and devices:**
   Professor Tim Ashley (Warwick), Dr Phil Buckle (Cardiff)
6. **Device Fabrication and Integration Technologies:**
   Professor Douglas Paul (Glasgow), Dr Wyn Meredith (CST, Glasgow)
7. **Emerging Materials:**
   Professor Stephen Sweeney (Surrey), Professor Jon Heffernan (Sheffield)
8. **Nanomaterials and Nanodevices:**
   Professor Hiuyun Liu (UCL), Dr Ed Clarke (Sheffield)

The working groups mapped out research trajectories over the next 5-10 years, the UK position in these research areas, the capabilities required to meet research needs, and to what extent an MRF was a suitable model for delivering these capabilities.

Professor Rob Martin chaired the final summary session, and each working group leader reported back on findings to the audience. There was an opportunity for the audience to comment and add additional information. The meeting ended with an agreement from the floor that Rob Martin and Jon Heffernan would coordinate preparation of the SoN, with the input of the working group leaders and circulate to the community for comment before the submission deadline.
The output of the meeting has been summarised in this document. Professor Jon Heffernan provided additional sources of information comprising operational statistics from the current National Centre, and the result of business development activities the centre has conducted with potential users in the community.

A draft document was circulated to the community on the 6th October, 2014 with a request for further input and endorsement by 10th October.
In total, there were 91 positive endorsements of the statement received and additional comments and views expressed. The document was revised to include this input and the final version of the document was circulated to the community on the 14th October, 2014.