Outline of the scientific and/or economic and social challenge

Crystal growth & nanotechnology. The technology of the last century has been dominated by the development of electronics and utilizing electrons as information carriers. This relatively rapid development started from a first bulky point-contact transistor made out of one single crystal of germanium [1] which was subsequently used to build the first transistor-based Sony radio [2]. Now, at Intel one fabricated Central Processing Unit [3] consists of 1.4 billion transistors. All this was enabled by the development of crystal growth methods, such as the most widely used Czochralski method [4], which made the growth of the above-mentioned first germanium single crystal possible [2]. The Czochralski method enables manufacturing of huge 250 kg dislocation-free silicon crystals. This method is behind many everyday devices. The miniaturization of devices was also enabled by the development of growth techniques such as thin film growth methods and other nanotechnologies.

Novel photonic materials concepts. In recent years, different novel material concepts have been developed in the areas of photonics: photonic crystals, metamaterials, and plasmonic materials. These could enable photonics to develop as much as electronics. Photonic crystals are materials that exhibit a photonic bandgap effect. Metamaterials are engineered composites that exhibit superior electromagnetic (and other like mechanical properties) not observed in the constituent materials. They can exhibit novel and extreme properties and capabilities including opposite phase and energy velocity; artificial magnetism [5], negative refractive index [6], subwavelength resolution imaging [7], space-and-time cloaking ability [8], and others [9]. Their electromagnetic properties can be very strongly modified by manipulating matter on the micron and nanoscale level. Artificial materials with tailored electromagnetic response functions (metamaterials) constitute a rich field of research due to their capabilities of facilitating the design of highly demanding optical devices. They bring many new ideas/properties/functionalities into the field which were hitherto unavailable. One of the pioneers in the field is our Partner - prof. M. Wegener (KIT) [10, 11, 12, 13, 14, 15, 16, 17]. Nanoplasmonic materials are hybrid (usually metallodielectric) materials in which collective electron oscillations—known as plasmons—at the metal–dielectric interface of nanoelements interact with photons at a characteristic frequency and give rise to localised surface plasmon resonances (LSPR). These resonances in turn lead to increased absorption and scattering of light. These effects, together with the local-field enhancement (LFE) around the nanoplasmonic elements, can amplify subsequent optical processes such as photoluminescence, optical nonlinearities or Raman scattering (surface-enhanced Raman scattering - SERS). The LSPR properties strongly depend on a number of factors, among them the type of nanostructure used, the chemical compositions of the nanoplasmonic elements, the environments surrounding

[2] 40 years after Czochralski developed his crystal growth method, with which the first Ge crystal was grown and used for the first transistor, John Bardeen, Walter Houser Brattain and William Bradford Shockley, for the discovery of the transistor got the Nobel prize for physics in 1956.
the nanoelements, and the sizes, size distribution, and shapes of the nanoelements [18]. The potential use of plasmons in e.g. solar cells, [19] cancer treatment [20], surface plamon enhanced Raman spectroscopy [21] and plasmon-based lasers [22, 23] has already been demonstrated. Other applications are being investigated, such as: optical information storage [24, 25]; new types of photonic devices [26, 27]; alternative solar energy conversion systems [28, 29]; highly efficient light sources [30]; plasmonic biosensors [31, 32]; and plasmonic metamaterials [33, 34].

**Identified challenge.** Despite major developments in these fields, the development of metamaterials, plasmonic materials and other materials with extraordinary electromagnetic/optical properties is still a big challenge for current fabrication techniques. The majority of manufactured materials are two-dimensional with properties, functionalities and applications limited by the manufacturing methods. For example, in the case of nanoplasmonic materials most current fabrication techniques arrange metal nanoparticles on dielectric surfaces [35, 36]. The methods used are either time-consuming and costly (e.g. lithography), or restricted to the creation of two-dimensional structures on a limited production scale. *Simple and fast fabrication methods for three-dimensional bulk metamaterials and plasmonic nanocomposites that offer control over the size, shape and chemical composition of the plasmonic elements have been missing.* While volumetric materials could bring new optical phenomena, they have been mostly unavailable. The well-established crystal growth techniques, as well as novel developed methodologies, could lead to a plethora of novel materials and to applications in various fields. It could be as revolutionary as the Czochralski method has been in electronics.

Thus, the scientific and economic challenge of ENSEMBLE³ is to utilize crystal-growth techniques, as well as developing new methodologies for manufacturing novel advanced materials with special optical/electromagnetic properties, which will find applications in such fields as photonics, optoelectronics, telecommunication, solar energy conversion, medicine and/or aerospace.

ENSEMBLE³ will build on the strengths of Polish science and technology - where historically crystal growth is a very important field, famously developed by prof. Jan Czochralski whose crystal growth method remains the most widely-used technique for manufacturing single crystals of semiconductors. *Czochralski crystals are used in everyday life - every person having a computer, mobile phone or other optoelectronic/electronic device has a small piece of a Czochralski-grown crystal placed in the device.* Unsurprisingly, Czochralski is the most cited Polish scientist.

By developing novel crystal growth-based technologies and novel materials with new/enhanced electromagnetic properties (e.g. plasmon enhanced), new research paths will be created, at the same time enabling application of the developed materials in nanophotonics, optoelectronics, telecommunication,

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medicine, photovoltaics and photoelectrochemistry. Examples of what the research will focus on include: development of novel technologies and materials for nanoplasmonics, metamaterials, nanophotonics and applying them in medicine i.e. for early diagnosis of cancer utilizing active nanoplasmonic microresonators as sensors for exosomes from healthy and unhealthy cells; in photovoltaics - enhanced efficiency solar cells by utilizing materials with plasmon-enhanced up-conversion processes; in photoelectrochemistry - as two-phase or multi-phase materials with broadband absorption and highly efficient and stable electrodes for hydrogen generation; in telecommunication as novel efficient optical amplifiers in wavelength ranges currently untapped; and many others. The aims of the project perfectly suit the development of Mazovian Region in Poland, which already has crystal growth and optoelectronics-based companies.

ENSEMBLE³ addresses the fundamental needs of National and European society by developing a new range of materials and materials technologies for novel nanophotonic devices which will certainly have wealth-creation potential for National and European industries and the potential to improve the every-day lives of National and European consumers in terms of their advanced technological, optoelectronic, telecommunication and other applications. Sustainable cooperation with three leading European research institutions in the fields of functional materials and crystal growth technologies will be established. ENSEMBLE³ will trigger long-lasting contributions to both the regional high-tech economy and national and European sustainable socioeconomic development through closer cooperation with industry while engaging decision makers and other stakeholder groups in supporting and fostering innovative research at ITME and UW.

ENSEMBLE³ research and innovation area fits very well within the National Smart Specializations (pl. ‘KIS’) such as KIS 18: Optoelectronic systems and materials; KIS 13: Multifunctional materials and composites with advanced features, including nanoprocesses and nanoproducts; and KIS 1: Medical engineering technologies, including medical biotechnologies. It is a beyond-the-state-of-the-art research and innovation programme that will explore pioneering ideas originated in our research groups and in the worldwide research community. Additionally, the European Union has a strong focus on developing European industrial capabilities in Key Enabling Technologies (KETs). Four of six of the selected technologies (nanotechnology, advanced materials, photonics, and advanced manufacturing technologies) fit perfectly into ENSEMBLE³. Also Regional Smart Specialization (pl. ‘RIS’) for the Mazowieckie Voivodship describes KETs as having a horizontal, multi-faceted impact on the economy in which implementation of KETs should be prioritized, particularly in the context of specific areas of smart specialization in the region. The specialisation areas for European Structural and Investment Funds (ESIF) 2014-2020 for the Mazowieckie Voivodship which are connected to our Proposal are: Smart Engineering and Tooling; Research & Innovation Capabilities: Manufacturing & industry.

![Figure 2. The application areas ENSEMBLE³ will address.](image-url)
Crystal growth and novel photonic materials at the crossroads. The functional materials group of Łukasiewicz-Institute of Electronic Materials Technology (L-ITME) proposed utilization of crystal growth techniques such as directional solidification for manufacturing volumetric metamaterials and nanoplasmonic materials. It proposed utilizing self-organized materials obtained by eutectic solidification for manufacturing materials with unusual electromagnetic properties for potential use in the field of photonics (photonic crystals, metamaterials, plasmonic materials) [37, 38, 39]. This concept was well received by the scientific community. The research on the edge of these two fields — metamaterials/eutectic composites - led to exciting results [40, 41, 42, 43, 44]. The group also proposed to utilize direct doping of dielectric matrices with plasmonic nanoparticles for manufacturing bulk nanoplasmonic materials [45].

Originally, the metamaterials field started from the theory of electromagnetism, and only later were the first experimental demonstrations developed. Later, several top-down techniques were used to make such materials, however the methods used were either time-consuming and costly (e.g., lithography), or restricted to the creation of two-dimensional structures on a limited production scale. L-ITME was one of the first to propose manufacturing metamaterials with the bottom-up approach and also utilizing the self-organization mechanism. These original ideas in utilizing crystal growth for manufacturing metamaterials and plasmonic materials, and especially utilizing directional solidification of eutectics, started a research path which led to various novel results by other research groups including: new eutectic-based polaritonic materials in the THz range [46, 47]; eutectic epsilon-near-zero metamaterials as terahertz waveguides [48]; template-directed directionally solidified three-dimensionally mesostructured eutectic photonic crystals [49]; self-assembled, nanostructured, tunable metamaterials via spinodal decomposition [50]; micropillar templates for dielectric-filled metal arrays and flexible metamaterials [51]; or high-operating-temperature direct ink writing of mesoscale eutectic architectures [52]. All that work will be the seed of the research and innovation to be developed in ENSEMBLE3. Other bottom-up methods which were utilized to manufacture metamaterials and plasmonic materials include: colloidal chemistry demonstrating up to millimetre-scale samples of well-ordered tightly arranged nanoparticles [53, 54, 55], self-assembled nanoparticle clusters [56, 57], metal-particle assemblies arranged into liquid crystalline phases [58], laser-induced self-organization of metallic

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[56] J. A. Fan, ...., N. J. Halas, P. Nordlander, G. Shvets, F. Capasso, Science 2010, 328, 1135.
nanostructures in 3D [59], gold nanorods assembled via anodized alumina templates [60, 61], block copolymers [62], silicon-based dielectric metamaterials [63], nanoparticles aligned in porous matrices [64] or a bottom-up nanolithography [65].

Thus, the originality of L-ITME’s research is in (i) utilizing crystal growth methods to manufacture novel photonic materials (metamaterials, plasmonic materials and other materials with special optical/electromagnetic properties); (ii) utilizing the eutectic self-organization mechanism for this; and (iii) developing a novel method for manufacturing bulk nanoplasmatic materials (active and passive), called Nano Particle Direct Doping enabling production of bulk materials made of dielectric matrices with incorporated various nanoparticles, made by direct doping without a chemical process.

The Centre, therefore, works on the development of novel crystal-growth based materials technologies and novel advanced materials with special optical/electromagnetic properties which can find application in various fields such as photonics, optoelectronics, telecommunication, solar energy conversion, medicine and/or aerospace. The research is based on the results already obtained in DAP’s group’s pilot projects in this research area. Our original approach includes research on:

New generation plasmonic materials. Recently we have developed a fast, low-cost, bottom-up method for manufacturing nanoplasmatic composites - the NanoParticle Direct Doping method (NPDD) [46]. This method is based on the direct doping of dielectric matrices with plasmonic nanoparticles and enables the fabrication of volumetric three-dimensional materials through a non-chemical process, Figure 3. The concept is based on utilizing matrices with lower melting temperatures than those of the admixed nanoparticles. In this way, a variety of nanoparticles—of several different sizes, shapes and chemical compositions—can be introduced into the matrix simultaneously. Other doping agents such as rare-earth (RE) ions, or quantum dots (QDs) can also be incorporated. The manufacturing of such materials is enabled by the self-deagglomeration and self-dispersion of nanoparticles which occur in this method due to the micro-cavitation process in the narrow nozzle at the crucible bottom. Utilizing this method, we have already demonstrated nanoplasmatic materials with: (i) spherical metallic nanoparticles [46], (ii) non-metallic nanoparticles [46], (iii) anisotropic nanoparticles (nanowires) [66], (iv) materials

Figure 3. Nanoplasmonic rod made of glass doped with silver nanoparticles obtained by the NPDD [46], with a localized surface plasmon resonance at ~405nm, and optical dichroism demonstrated by a yellow colour of the rod on the white background (transmitted light) and blue colour on a black background (scattered light).

[66] M. Gajc, B. Surma, ..., G. Grzela, A. Urbas, J. Gomez-Rivas, D. A. Pawlak, Bulk plasmonic nanocomposites with anisotropic electromagnetic properties obtained by NanoParticle Direct Doping method, 2018 to be submitted.
co-doped with other chemical agents such as rare earths and quantum dots [67, 68]. This method and subsequent developments based on it, together with the novel materials produced, can be expected to find application in the following areas:

(i) **Applications in telecommunication**
(ii) **Lighting applications (RGB phosphors QD-based lasers [69], High power LEDs, displays**
(iii) **Biophotonic sensors**
(iv) **Nonlinear optics, THz light sources**

**Eutectic composites with unusual electromagnetic properties.** We have proposed that directionally-grown self-organized eutectic structures could show unusual electromagnetic properties i.e. as metamaterials [38, 41, 43, 45]. For example, an optically anisotropic self-organized volumetric eutectic metamaterial for mid-infrared plasmonics utilizing ZnO:Al is demonstrated with plasmonic resonance for S polarization and no resonance for P polarization [70]. An additional interesting phenomenon is the observation of the plasmonic Berreman mode in this material [71].

During growth, eutectic composites form structures with precipitate/particle sizes ranging from hundreds of microns to tens of nanometers. Eutectics are versatile and there are many advantages of utilizing eutectic growth for creating materials with special electromagnetic properties: (i) they are simultaneously monolith and multiphase; (ii) almost any materials can be used as the component phases, including oxides, semiconductors, metals, organic compounds, materials with special properties (ferroelectric, ferromagnetic, optically active); (iii) many special geometrical motifs can be obtained (lamellar, fibrous, globular); (iv) the structure refinement can often be controlled from the micron to the nano regime. Eutectic composites possess two different types of properties: additive and product properties. Additive properties are limited by the properties of the constituent phases, while product properties only exist in the eutectic, not in the individual phases. Typically they are investigated as high strength and high resistance materials at high temperatures [72] or for ultra-hardness [73], while their optical properties started to be explored only recently.

Below are the examples of materials we plan to exploit:

(i) **Materials for solar energy conversion**
(ii) **Photonic elements**
(iii) **Hydrogen production and water purification**

**Optical characterization at nanoscale, especially with the scattering-type Scanning Near-Field Optical Microscopy (s-SNOM) studies.** We have available novel apparatus for characterization of optical/electromagnetic properties at the micron and nanoscales. This includes a specially designed s-SNOM set-up. s-SNOM is an ultimate probe of light-matter interactions at the nanoscale. It is a powerful technique for mapping complex optical properties of materials and optical phenomena with nanometer scale spatial resolution [74]. **One of the pioneers of this method is our Partner - Prof. R. Hillenbrand** [75, 76, 77]. In the s-SNOM system, the AFM tip is illuminated with a focused laser beam. Acting as an optical antenna, the tip converts the incident light into a strongly

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confined near-field spot (nanofocus) at the tip apex, which locally illuminates the sample surface. Due to the strong optical near-field interaction between the tip and sample, the elastically scattered light contains information about the local optical properties of the sample surface. Thus, by recording the scattered light the local dielectric properties can be mapped. The spatial resolution depends on the radius of the tip apex and is typically in the range of 10 - 30 nm. Thus, even very long electromagnetic waves (i.e. from infrared region) yield the same very high spatial resolution. The backscattered radiation (signal amplitude - detected directly, phase - measured with interferometer) is recorded simultaneously with the topography, yielding nanoscale resolved near-field images. The s-SNOM is a revolutionary tool in numerous applications such as: nanoscale infrared spectroscopy; non-invasive imaging of stress/strain fields; mapping density and mobility of free-carriers; mapping local conductivity; imaging nanoscale phase transitions; identification of materials; probing secondary structure of single protein complexes [78]; probing molecular disorder [79]; ultrafast spectroscopy of electronic nano-motion [80]; studying single viruses; and many others [81, 82]. Some of the most exciting are the possibilities of analyzing/exciting the local field in photonic nanostructures [83]; metamaterial super lenses; optical surface waves; and mapping and controlling surface plasmons [84, 85].

Neaspec [86] scattering-type scanning near-field optical microscopes allow for background-free amplitude and phase resolved near-field imaging and spectroscopy in transmission and reflection mode. The new setup available at the DAP's laboratory possesses a scale configuration unique in the world, which enables measurements over a very broad wavelength range (from UV to far infrared, 400 nm - 17 μm). The system is equipped with a high-power, wideband, tunable UV-Vis-NIR light source: femtosecond Ti:Sapphire laser (Coherent Chameleon Ultra) integrated with an Optical Parametric Oscillator (Coherent Chameleon OPO) which covers the spectral range from 350 to 3500 nm; and a wideband, coherent infrared light source with optical range from 5 to 16 μm. Simultaneous optical phase and amplitude detection is possible with an integrated interferometer. The measurements’ spatial resolution is 10 x 10 nm. This configuration was custom-designed and manufactured for the Laboratory of Materials Technologies. The scientific impact will be in the ability to investigate in-depth various exciting phenomena observed in the materials synthesized in ENSEMBLE³ Centre, while we will be demonstrating new applications of s-SNOM.

ENSEMBLE³ is a new Centre in the area of crystal growth-based technologies, novel functional materials with innovative electromagnetic properties, and applications in nanophotonics, optoelectronics and medicine. Thus, the main focus is on development of novel materials and novel technologies. However, to be able to develop materials in the application directions, cooperation with the world’s leading experts in these fields is also needed.

The strength of ENSEMBLE³ is in the recruitment of Group Leaders from the best available scientists in an open international competition. The new leaders will bring their know-how and their knowledge in the mentioned group areas, and will bring novel ideas which, combined with the know-how and knowledge existing already in L-ITME and UW and the advanced partners, will lead to research excellence. Thus, the research at the interface of the groups will lead to exciting new results and with potential for applications. The work in particular groups is described here taking into account the freedom of choice of their research directions within the ENSEMBLE³ research agenda.

[86] www.neaspec.com
To achieve effective research and innovation impact in ENSEMBLE\textsuperscript{3}, in addition to the (i) Functional Materials Technology group we plan to have the following groups: (ii) Light-matter interaction theory, (iii) Optical nanocharacterization, and three groups oriented towards particular applications of the novel photonic materials which will be developed in the centre: (iv) Solar energy conversion, (v) Biophotonic applications, and (vi) Photonic elements, and three more groups oriented towards production: (vii) Oxide Single Crystals, (viii) III-V compound Semiconductors, and (ix) Disruptive Technologies.

(i) Functional Materials Technology – prof. Dorota A Pawlak’s (DAP’s) group. This group will be responsible for development of the novel material technologies, based on the technologies already developed in DAP’s team (directional eutectic solidification, eutectic layers, nanoparticles direct doping, directional solidification of organic and inorganic single crystals and composites) as well as any necessary developments. The group will develop materials according to the specific needs/properties/functionailities and applications which the other groups will work on/look for including the application groups as well as the theory and characterization groups. This group will also be a 'materials scouting' group developing new materials and proposing potential new research ideas and directions on a materials basis. The research and findings of this group will be used as the groundwork by other teams, including theory, characterization and application teams.

(ii) Theory of light-matter interaction. The current state-of-the-art in the field of optics & photonics requires comparing any kind of experimental results directly with solutions of the vector Maxwell equations for the geometry under consideration. Without theory, experimental results can not be often explained and published in high-impact journals. However, a local experiment-theory collaboration brings things to a different level. First, the scientific feedback loop between experiment and theory can be sped up significantly. Second, theory and numerical simulations can be used to design new experiments. This requires that computational photonics reaches a level at which it has quantitative predictive power. Importantly, at this second point, scientific creativity can be brought into our centre by the theory group, which must be much more than a service provider to the experimentalists. Examples of immediate relevance for our centre are nanoplasmonic structures and optical metamaterials. The theory group will focus on the application of existing state-of-the-art numerical methods, available via commercial program packages. The development of novel methods will only be addressed if specific results cannot be achieved.

(iii) Optical nanocharacterization. This group will be responsible for characterization of the optical/electromagnetic properties of the materials developed in the other groups at the micron and nanoscales. The group will provide such characterization as chemical properties/refractive index mapping compared with the electromagnetic field distribution. It will verify novel design concepts for materials, structures and devices in regard to their material properties and function as optical devices - in cooperation with the Light-matter interaction theory group. This group will use novel advanced techniques of materials characterization including systems working beyond the light diffraction limit. The group leader and the group members will be scientists specialized in characterization of electromagnetic phenomena and their mechanisms including both macroscopic properties as well as the ones at the nanoscale. Apparatus currently available only at the Centre itself will enable luminescence lifetime measurements by time-resolved fluorescence confocal microscopy, characterization of Raman scattering and luminescence at micron and nanoscales by Tip-Enhanced Raman Spectroscopy (TERS) and Fluorescence Spectroscopy (TEFS), performing experiments only limited by the imagination of the scientists involved, to characterize the properties of materials using scattering-type Scanning Near-Field Optical Microscopy (s-SNOM) coupled with nano-FTIR spectroscopy, characterization of macroscale luminescence properties, transmittance and reflectance at the nano-micron scale in UV and IR with microspectrophotometers and a broad range of wavelengths with the Fourier Transform Infrared Spectrometer (FTIR) and others.
(iv) Solar energy conversion. This group will be responsible for leading the materials development in the direction of solar energy conversion applications. Recent achievements in solar energy engineering [87] focus on composite and multi-layer materials exhibiting highly optically-nonlinear properties which increase light conversion efficiency. The research goal of the group will be development of novel methods for obtaining materials in areas of photovoltaics and photoelectrochemistry. Up to now, we have successfully demonstrated [77, 78] utilization of eutectic composites for generation of hydrogen in water splitting (even resulting in a current small contract with a company). Hydrogen is one of promising renewable energy sources. The main advantages of hydrogen fuel are: high energy conversion efficiency, carbon free emission; the ability to be produced from renewable energy sources; and its ability to serve as a storage medium. The new approaches in which hydrogen can replace traditional fuels are electricity/heat production and fuel for vehicles. Thus, these approaches will be our directions. We have also shown interesting results on increasing weak up-conversion process with plasmons in a eutectic composite. Up-conversion and plasmonics are on the roadmap of photovoltaic technology, which is why this is another essential direction for the group to work on.

(v) Biophotonic applications. The research will include the new ideas of the group leader employing the materials developed in the centre.

(vi) Photonic elements. This group will be responsible for expanding applications for materials developed in the project for photonic elements functionalities and applications, which will be beyond the-state-of-the-art in modern optics. We have already demonstrated various properties and functionalities of materials produced in DAP's team. These could be developed into applications, in addition to anticipated new ideas from the group leader and group members. Particularly interesting would be lighting applications where we have already demonstrated volumetric materials doped with quantum dots and plasmonic nanoparticles. Other interesting applications might use materials co-doped with RE ions and plasmonic particles with enhanced luminescence [46] at the telecomm. wavelengths as efficient optical amplifiers. Other applications were we have shown preliminary interesting properties or which we are considering working on include nonlinear optics [88], THz sources and integrated optical isolators (periodic eutectic composites demonstrating Faraday effect).

(vii) Oxide single crystals. In L-JITME's Department of Functional Materials we have experience of over 30 years in the technology of crystallization of oxide single crystals. We develop and investigate novel single crystals and technologies to make them, as well as undertake orders for specific needs of the ordering party or jointly conduct research on new materials. We have expertise in the following materials: (i) Active laser materials - especially laser materials for near-infrared, for microlasers and lasers with broad emission spectrums (1-3 µm). Examples of matrices include: YAG, YAP, YVO; while examples of dopants used include Nd, Pr, Er, Yb, Eu, Tm, Sm, Ho. For ultrafast femtosecond diode-pumped lasers, we developed the technology of CaGdAlO$_3$:Yb crystals. (ii) Nonlinear materials for second harmonic generation. (iii) Crystals as passive modulators, such as YAG:Co, YAG:V,YAG:Cr, MALO:Co. (iv) Substrate materials i.e. for GaN including NdGaO$_3$, (v) Piezoelectric materials. (vi) Relaxor ferroelectrics, such as SBN, CBN - smart functional materials which can simultaneously act as a sensor, a signal processing component and an actuator (vii) New scintillating materials, like LuAP, LuAG crystals doped with Pr or Ce ions are potential materials for PET and PEM tomographs,(viii) Materials for optical isolators such as Tb$_3$Sc$_2$Al$_5$O$_{12}$ (TSAG) - a promising new material for likely applications in telecommunications.

Chosen impacts include: (i) Microlasers - based on our materials, due to compact dimensions, interesting energy parameters and good beam quality, they could find a range of applications in telemtry, defence, medicine and telecommunication. (ii) Lead free relaxor ferroelectrics - The European Parliament's directive banning the production of new electrical and electronic devices containing hazardous substances such as lead forces the search for new efficient materials as substitutes for the ones used so far. (iii) Passive modulators - emission modulation is required in many applications, and often is obtained through the use of saturable

absorbers as passive modulators. (iv) Positron emission mamography, PEM, a new technique used for breast cancer detection. The previous generation of PEMs was based on LSO:Ce crystals. The newest PEM apparatus in Japan is based on LuAG:Pr crystals which have almost two times shorter scintillation decay times with comparable scintillation efficiency. Qualitatively better crystals were developed and obtained in our laboratory.

(viii) III-V Compound semiconductors. In L-ITME’s Department of Functional Materials we have experience of over 30 years in the technology of IIIIBV compounds including synthesis, monocristalization, mechanical processing and characterization. Our high purity and high-quality materials meet the world standards. In this field we carry out: (i) research and development of single crystals and alloys manufacturing methods; (ii) investigations of semiconducting materials properties (electrical, structural, optical) and purity; (iii) small scale production of materials such as GaAs, InAs, GaP, InP, GaSb, InSb and other special alloys of very high purity (made on the customer’s request); (iv) development of manufacturing methods and measurements for thermoelectric materials, topological insulators and materials for spintronics. We offer materials in the form of: single crystal ingots: diameter 2” X 4” & orientation <100>, <111>, <110> or <310>; substrate wafers, oriented, one- or double-side polished; single crystal seeds and other pieces upon request. Additionally, to the IIIIBV materials we also have equipment and know how to manufacture SiC single crystals.

Chosen impacts include: (i) Frequency conversion in the Mid-IR and THz region. Recently there is an urgent need for high brightness, portable laser sources operating at room temperature which are tunable throughout the atmospheric windows at 2.5 µm and 8-13 µm. This comes from various applications such as IR countermeasures, laser radar, high speed reliable IR communications, remote sensing of chemical and biological agents, in medicine, environmental sensing, and others. In this respect, GaAs has broad IR transparency and high nonlinear optical susceptibility while GaP seems to be the best optical material. It has negligible two-phonon absorption in the near IR, high nonlinear coefficient, higher thermal conductivity and broad transparency and high thermal stability. (ii) THz generation. Due to their high efficiency for THz generation GaP and GaAs (wide band gap materials) are used. The small-gap materials (such as InAs and GaSb) have the potential to be used as surface-field THz emitters in compact THz sources, optically excited by an Er3+-doped femtosecond fiber laser. Thermally treated GaSb has an efficiency comparable to GaAs. One of the strongest THz surface emitters is InAs - a promising source of optically excited THz radiation and an attractive candidate for compact and lightweight time-domain THz spectroscopy and imaging systems powered by femtosecond fiber lasers with emission wavelengths at λ~1.55 µm.

(ix) Disruptive technology. The Disruptive Technology group will be responsible for the identification of new research paths in the Centre concerning the development of novel materials in the Centre as well as novel optical phenomena and applications of the materials produced. The group will consist of scientists minimally at the post-doctoral level responsible for the identification of new research paths. Employed in the Centre as well as at each of the advanced partners, the scientists of this group will enable easy cross-linking of the research and innovation potential as well as industrial needs between the Centre and the advanced partners in the project, leading directly to new solutions and joint research projects. They will also directly collaborate with the Technology Transfer Officer to meet the needs and problems faced by industry and entrepreneurs.