PREIN

Flagship for Photonics Research and Innovation (PREIN)

Annual Report 2022

CONTENTS

SUMMARY 2022

The end of 2022 marks the mid-term of the Flagship for Photonics Research and Innovation (PREIN). Our performance is reflected by the steady increase over the past four years of several key performance indicators, including a large number of high-level publications and references to our work, a growing number of joint research publications and projects, significant external funding, and many MSc/PhD degrees produced.

It has been another exciting year for us, as we continue to make significant efforts to advance light-based technologies. While we have launched many activities to support the field of photonics and photonics-enabled areas, our mission remains the same: foster research and innovation, promote the societal benefits of photonics technologies, and encourage studies in science in general.

In the last year, we have seen some remarkable achievements in our research program, including breakthroughs in the development of new materials, devices, and applications. Our research efforts have focused on a wide range of areas, from the fundamental physics of light-matter interactions to the design and optimization of photonics-based components for various applications.

One of our key priorities has been to strengthen our partnerships with industry and academia, both locally and internationally. We believe that collaboration is essential for driving innovation and translating research into tangible benefits for society. Our partnerships have enabled us to accelerate the development of photonics technologies, and to create new opportunities for collaboration and knowledge exchange.

One important objective of the Flagship is to strengthen the photonics ecosystem. We are constantly working toward this goal with a very large fraction of our research results in open-access and with the development of our infrastructure, facilities and services offering to external users. We are also committed to fostering talent and developing the next generation of photonics researchers and entrepreneurs. In the past year, we have continued to support education and training programs that provide students and young professionals with the skills and knowledge they need to succeed in the photonics industry, which keeps on growing in Finland above the global average.

As we look forward to the coming year, we are excited about the opportunities and challenges that lie ahead. We remain committed to advancing the field of photonics, and to leveraging the power of light for the benefit of society. Thank you to all our researchers and staff for your continued support and collaboration as we work towards this goal.

Goëry Genty & Jyrki Saarinen

FLAGSHIP PROGRAMME

IN BRIEF

PREIN – The Flagship for Photonics Research and Innovation

PREIN – The Flagship for Photonics Research and Innovation was selected among the first six flagship initiatives to the Academy of Finland flagship program in 2019. In 2020, four additional flagships were nominated to complete the flagship program. The Academy of Finland flagship program supports high-quality research, creates future know-how for significant societal and economic impact.

PREIN is a research and innovation platform focusing on light-based solutions covering the entire innovation value chain from fundamental and applied research to prototype and technology development, industrial collaboration, and start-ups. PREIN is committed to develop high-class education and research environments, state-of-the-art open-access infrastructure, as well as promote innovation culture and diversity. PREIN is a national initiative between four partners:

- Tampere University (TAU) - Coordinator
- University of Eastern Finland (UEF)
- Aalto University (Aalto)
- VTT Technical Research Centre of Finland (VTT)

PREIN has set scientific, societal, and educational impact objectives and monitors the achievement of them annually, as well as reports bi-annually results to the Academy of Finland. The PREIN Flagship, among the other five selected during the first flagship period had their mid-term evaluation in 2021 and were granted a new funding period.

Tampere University

UNIVERSITY OF EASTERN FINLAND

Aalto University

VTT

PREIN STRUCTURE 2022

In 2022, the structure of the PREIN was changed so that the Flagship administrative and research management were separated from each other to allow the research work package leaders to focus on the scientific aspects. The steering structures remained the same with some changes in responsible persons. The cooperation and shared themes between the different work packages have been enhanced, as well as the involvement of all partner organizations in the work package activities.

There has been a significant structural development of the work packages based on the self-evaluation, and extremal evaluations conducted in 2021 and to anticipate for the new flagship program funding period. This includes the introduction of a new works package as well as slightly re-aligning the research focus of the existing work packages.

Regular meetings of the important bodies, Steering Committee, Management Group and support teams have continued in person and on-line during the year 2022.

STEERING COMMITTEE

TAU
Jyrki Vuorinen
Jyrki Mäkelä

UEF
Tapio Määttä
Kari Lehtinen

Aalto
Matti Kaivola
Jyri Hämäläinen

VTT
Tauno Vähä-Heikkilä
Kari Rönkä

BOARD OF STAKEHOLDERS

SCIENTIFIC ADVISORY BOARD

PREIN

MANAGEMENT GROUP

Goëry Genty Director (TAU)
Jyrki Saarinen Vice Director (UEF)
Zhipei Sun (Aalto)
Jussi Hiltunen (VTT)
Tea Vellamo Admin, Coordinator (TAU)
Diao Li Admin (Aalto)
Juha Purmonen Impact Manager (UEF)
Raili Termälä Impact Specialist (UEF)
Kristiina Pispala Communications (TAU)
Minna Luhtanen Finances (TAU)

WORK PACKAGES
WP1 Light Field Control
WP2 Materials and Structures
WP3 Active Photonic Components
WP4 Applied Research
WP5 Quantum Technologies
WP6 Technology Transfer

OUTREACH TEAM
Juniversity (TAU)
Aalto Junior (Aalto)
Luma Eastern Finland (UEF)

INNOVATION TEAM
Research and innovation services representatives

COMMUNICATION TEAM
Communications representatives

ORGANIZATION 2022

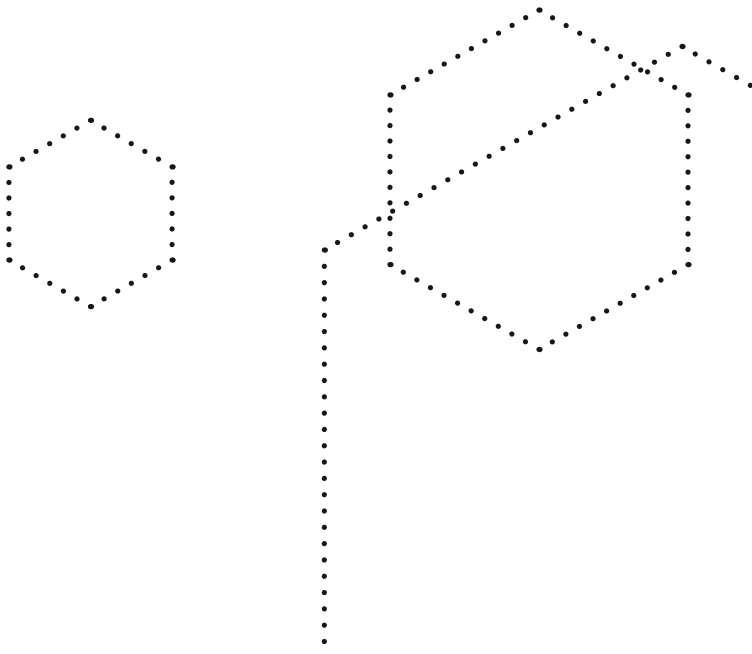
The management and leadership structure and key positions in the PREIN Flagship have mostly been retained in 2022 with the same organizational structure. Professor Goëry Genty from Tampere University leads the Flagship as Director of PREIN and is responsible for the overall flagship management and scientific program. Professor Jyrki Saarinen from the University of Eastern Finland continues as the Vice-Director being responsible for the activities related to impacts and economic growth.

The activities of PREIN are monitored by the Steering Committee consisting of institutional representees in decisive positions in the partner organizations. The Steering Committee oversees the activities of the Flagship monitoring its progress and key performance indicators. The Steering Committee also acts as the link to the institutional level of the partner organizations ensuring resource and infrastructure development and institutional commitment of the organizations. Changes in positions in the partner organizations are reflected in the composition of the Steering Committee. New members were nominated to the Steering Committee, with former members Jussi Hiltunen (VTT), Mikko Merimaa (VTT), and Jukka Jurvelin (UEF) stepping aside and the new members Tauno Vähä-Heikkilä (VTT), Kari Rönkä (VTT), and Kari Lehtinen (UEF) taking their positions in early 2022. The renewed PREIN Steering Committee had its first meeting in April where the new Work Package and management structure was confirmed.

The main change implemented in the management structure has been separating the management and the scientific aspects, freeing the work package leaders from the managerial work and allowing them to focus more on the scientific activities. The Management Group now includes the directors, the administrative coordinators, the principal investigators from each partner, and the impact persons. The Management Group has the authority to make decisions regarding everyday activities of PREIN such as recruitment and initiating new sub-topics in research.

The administrative coordinators facilitate everyday management, acting as the link to the supporting outreach, innovation and communication teams. The administrative capacity of PREIN has been increased by recruiting new people in 2022; Kristiina Pispala to manage the PREIN communications activities and Raili Termälä to support the outreach and impact activities. The Communications Team communicates internally about the Flagship in the partner organizations and promotes external communications. The Outreach Team focuses on the activities directed at children and young people and produces events and material on photonics directed to these target groups. The Innovation Team monitors the potential of research results and promotes their transfer to the innovation pipeline in collaboration with the work package devoted to impacts (WP6).

The research foci of the five work packages introduced in 2019 have been modified according to the most recent development in their respective research themes. In addition, a new works package on quantum technologies, a topics gaining prominence, was introduced in 2022. Currently, four WPs focus on fundamental research and one on applied research. In addition, the sixth WP is dedicated for technology transfer. The structure of organizing the research has been slightly modified for the new program period by naming representatives from all partners into key positions in the work packages considering the gender balance and the equal division of responsibilities among the partner organizations. One person takes the main responsibility as the work package chair is responsible for the WP management and scientific progress and acting as the contact point between the work package and the Management Group. This WP chair position will be rotated on an annual basis.



The research themes of the work packages in the new program period are:

WP1 Light Field Control
WP chair Andriy Shevchenko/ Aalto

- Interferometry
- Optical metamaterials and metasurfaces
- Polarization and coherence control
- Artificial intelligence photonics
- Nanoscale localization

WP4 Applied Research
WP chair Juha Toivonen/ TAU

- Environmental and medical sensing
- LIDAR technologies and remote sensing
- Solar energy

WP2 Materials and Structures
WP chair Polina Kuzhir/UEF

- Advanced materials
- Novel structures
- Photonics integration platforms
- Hybrid materials and structures

WP5 Quantum Technologies
WP chair Zhipei Sun / Aalto

- Generation and detection of quantum light
- Advanced modulation of complex quantum states
- Emerging platforms for quantum technologies

WP3 Advanced Photonic Components
WP chair Mircea Guina/TAU

- Mid-infrared laser sources
- Visible laser sources
- High-energy pulsed sources for eye-safe wavelengths
- Single photon sources
- Cryogenic optoelectronic components
- Photonic integrated circuits

WP6 Development and Transfer
WP chair Sanna Uusitalo/ VTT

- Facilitate innovation transfer to companies
- Provide testbeds and prototypes for industry
- Promote photonics-based solutions to industry

ADVISORY BOARDS

Scientific Advisory Board

PREIN is supported by a Scientific Advisory Board comprising of high-level international scientists who are also heads of significant photonics research centers. In 2022, the Scientific Advisory Board was partially renewed for the new flagship funding period. New European members were selected to the Scientific Advisory Board to facilitate arranging visits to the flagship partner universities. One important aspect in the naming of the representatives has also been ensuring a gender balance and therefore one more female representative will be named in 2023 to complete the Scientific Advisory Board composition.

Scientific Advisory Board

Prof. Maria-Pillar Bernal
FEMTO-ST Institute Franche-Comté Electronics Mechanics, France

Prof. Fedor Jelezko
Ulm University, Germany

Prof. Lluis Torner
Institute of Photonic Sciences ICFO, Spain

Prof. Sergei Turitsyn
Aston University, United Kingdom

Board of Stakeholders

The Board of Stakeholders, which includes representatives from national funding agencies, ministries, small companies and large corporations, links the Flagship to both public and private sectors. Tight collaboration with stakeholders allows PREIN to affect policymaking and receive feedback on industrial needs. The Board of Stakeholders was renewed in 2022 with new representatives named for the new program period. Of the stakeholder representatives, Risto Linturi is a futurist and tehnology visionary, Timo Ahopelto from Lifeline ventures represents venture capitalists, Antti Sunnari from Dispelix represents start-up companies, whereas the other company representatives are from small to medium sized enterprises, large Finnish and large international companies. The Stakeholders collaborate with the Flagship in thematic events and discussions in addition to dedicated annual Board of Stakeholder meetings. The Board of Stakeholders were invited to join the Optics and Photonics days in 2022 where they participated in the stakeholder panel on talent attraction to photonics studies and industry. In addition, the stakeholders were invited to join the opening ceremony of the Photonics Center in Joensuu in November 2022.

Board of Stakeholders

Timo Ahopelto
Lifeline Ventures

Jyrki Huttunen
Oplatek/Bevenic

Reijo Kangas,
Business Finland

Samuli Laukkanen
Vaisala

Risto Linturi
Futurist

Maija Lönnqvist
Ministry of Economic Affairs and Employment

Matti Mannonen
Technology Industries of Finland

Eero Salmelin
Huawei Finland

Antti Sunnari
Dispelix

RESEARCH & RESEARCHERS

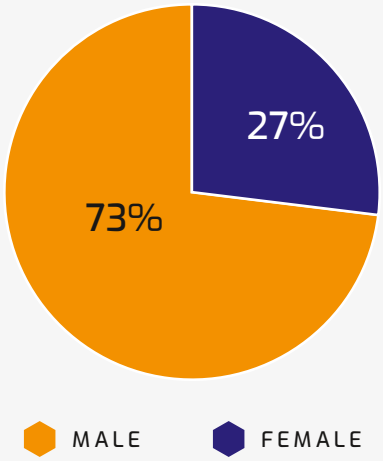
The PREIN research roadmap launched in 2020, has been implemented and further developed to increase the partners' collaboration. Based on the new research themes, the work packages have been modified from the beginning of 2022 and a new work package on Quantum Technologies was included.

In the end of 2022, a new call for shared research themes was launched between the PREIN partners to further stimulate the collaboration. The projects starting in 2023 will involve all PREIN partners in key research areas and new doctoral and post-doctoral researchers will be employed for a two-year period.

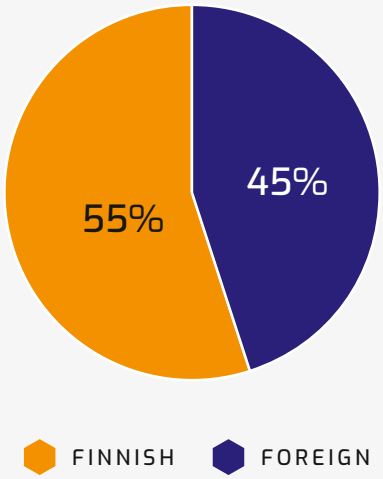
The number of researchers involved in PREIN activities has increased with a total of up to 500 researchers involved in PREIN related projects either full-time or part-time.

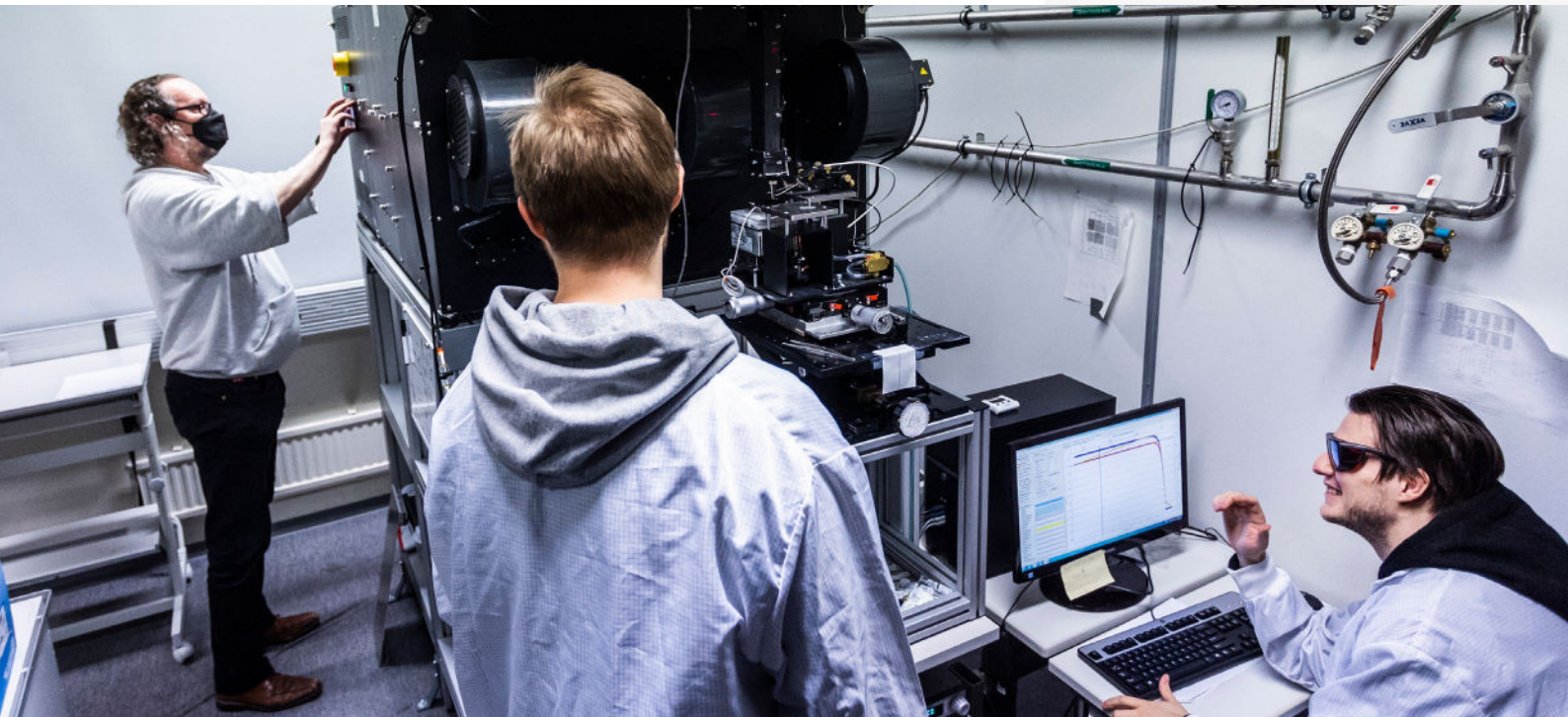
Gender balance and diversity constitute two important key performance indicators in the flagship program and PREIN is continuously working to increase the percentage of female researchers and international researchers. The percentage of international staff is almost up to the target level, however, the covid pandemic slightly slowed down the positive development.

Gender division of Employees



Nationality of Personnel





RESEARCH HIGHLIGHTS

WP1: Light Field Control

Overview

The objective of WP1 is to provide novel approaches for controlling and utilizing key properties of optical fields including spatial localization and confinement, temporal and spectral characteristics, as well as polarization and coherence properties.

Selected 2022 Highlights

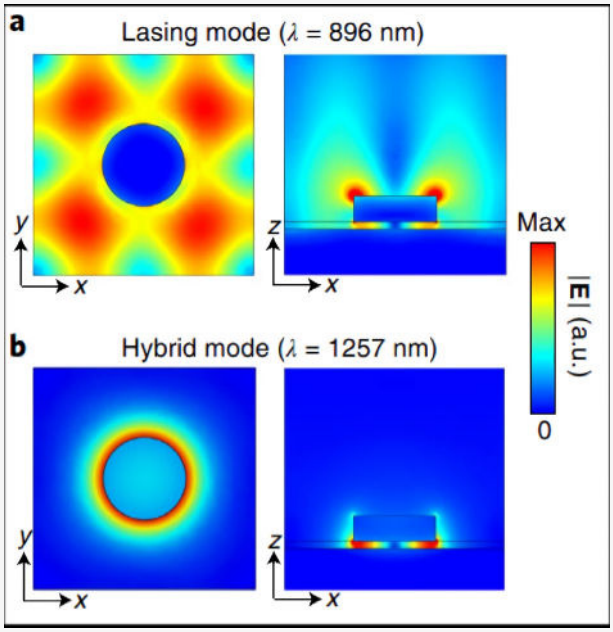
- Magnetic switching in a plasmonic laser (Aalto): lasing in a magnetic nanoparticle lattice combined with dye molecules has been demonstrated. The lasing properties were studied for different magnetization characteristics and we observed that degenerate lattice modes are split when introducing the magnetic field.

- Optical beams with arbitrary group velocities in free space (Aalto): theoretical and experimental methods to generate and study optical beams with adjustable group velocity in free space have been developed. The intensity peak of the beams was shown to propagate with superluminal, sub-luminal, zero, and negative velocities and exhibit positive, negative, or zero longitudinal acceleration. These beams could be be particularly useful in ultrafast optics, nonlinear optics, and optical tweezers experiments.

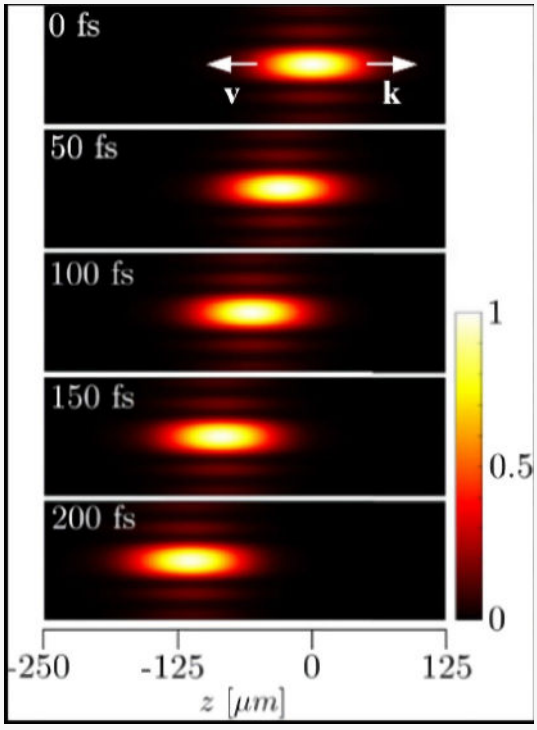
- Multiresonant high quality factor metasurfaces (TAU/UEF): multiple high-quality factor resonances (with Q ~ 1000) have been shown to simultaneously exist in plasmonic meta-surfaces. The multi-resonant approach can be extended to dielectric resonant waveguide gratings that could support quality factors on the order of 10 000.

- Turbulence resistant partially coherent vortex beams (TAU/UEF): partially coherent vortex beams combined with correlation induced focussing were shown to be robust against turbulence. Com-pared to a coherent beam, partially coherent self-focusing vortex beams feature over five order of magnitude higher peak intensity at the receiver plane.

- Polarization rotation using meta-surfaces (VTT/TAU/Aalto): meta-surfaces for 1550 nm wavelength deposited on top on mirrors were successfully designed and fabricated for polarization rotation. Investigations using 2D materials for polarization rotation were also carried out.



Modes of a magnetically switchable plasmonic laser.



Optical short pulse with a negative group velocity moving towards the light source.

Upcoming Developments

- Polarization splitting and rotation on 3 µm SOI platform: experimental demonstration of novel polarization splitting and rotation concepts with a broad wavelength range and insensitivity to fabrication tolerances. The final goal is to demonstrate an optical isolator with >100 nm bandwidth and <2 dB insertion loss.

- Nonlocal optical metasurfaces: design and demonstration of meta-surfaces, in which incident light excites in-plane propagating modes allowing for enhancing the Q factor of coupled light and local intensity of the field on the surface.

- Epsilon-near-zero structures and devices: fabrication of multilayer films to realize enhanced epsilon-near-zero structures and a coherence-tunable laser with an epsilon-near-zero mirror.

- Nonlinear imaging and manipulation of nonlinear effects in 2D materials: a back focal plane non-linear microscopy technique is being developed to probe experimentally the second- and third-order emission from monolayered 2D materials using optical vortices.

- Generation of spatio-spectral vector beam: generation of an electromagnetic field where all degrees of freedom, i.e., polarization, space, and frequency, are in a non-separable state. Such a classically correlated light field only shows a high degree of polarization if it is measured at a given transverse positions together with a specific wavelength, which shares some similarity with a mutli-partite entangled quantum state.

Selected 2022 Publications

1. Freire-Fernándezet al., "Magnetic on-off switching of a plasmonic laser," Nature Photonics **16**, 27 (2022).

2. Heilmann et al., "Quasi-BIC Mode Lasing in a Quadrumer Plasmonic Lattice," ACS Photonics **9**, 224 (2022).

3. Das, Halder, Partanen, Koivurova, and Turunen, "Propagation of Bessel-correlated specular and antispecular beams," Optics Express **30**, 5709-5721 (2022)

4. Laatikainen et al., "Spectral scale transformations of nonstationary optical fields," Physical Review A **106**, 023515 (2022)

5. Luo et al., "Turbulence-resistant self-focusing vortex beams," New Journal of Physics **24**, 093036 (2022).

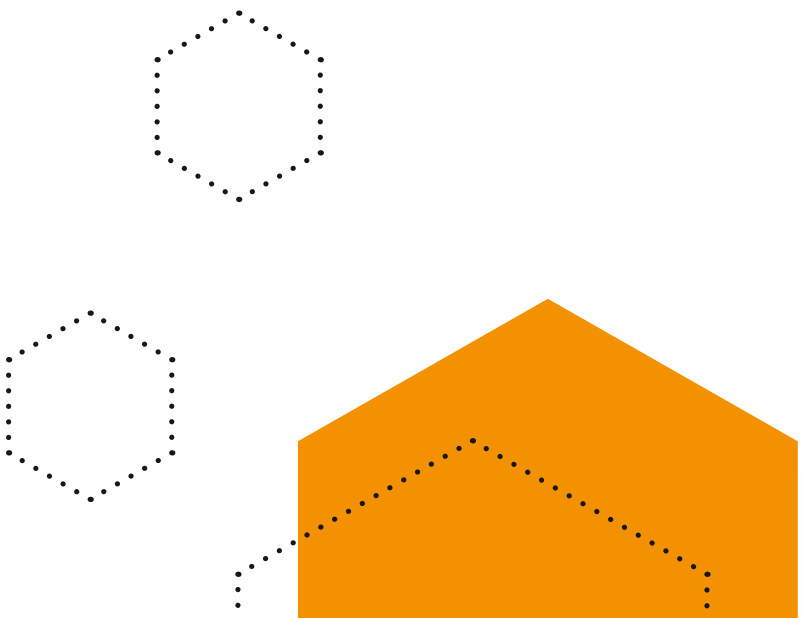
6. Salerno et al., "Loss-Driven Topological Transitions in Lasing," Physical Review Letters **129**, 173901 (2022).

7. Hildén et al., "Multifrequency Bessel beams with adjustable group velocity and longitudinal acceleration in free space," New Journal of Physics **24**, 033042 (2022)

8. Lyasota et al., "Mode interference effect in optical emission of quantum dots in photonic crystal cavities", Physical Review X **12**, 021042 (2022).

9. Luo et al., "Singular-value decompositions and electromagnetic coherence of optical beams," Optics Letters **47**, 5337-5340 (2022)

10. Stolt et al., "Broadband frequency conversion of ultrashort pulses using high-Q metasurface resonators," New Journal of Physics **24**, 025004 (2022).



WP2: Materials and Structures

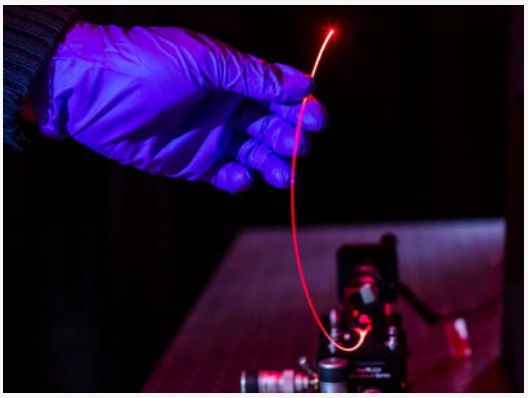
Overview

The development of new materials and structures is crucial for the emergence or improvement of new technologies, and this is particularly true for photonics. In WP2, we have studied the properties of new materials, novel structures and their integrated architectures to link the fundamental research performed in WP1 to the light sources and devices developed in WP3–WP4.

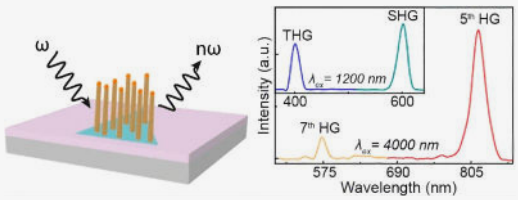
Selected 2022 Highlights

- Perovskite Absorbers for Efficient Indoor Photovoltaics (VTT/TAU): a new lead-free perovskite absorber based on pnictogens CsMAFA-Sb with near-ideal wide bandgap for indoor light harvesting has been developed. The corresponding indoor photovoltaics displayed a record indoor efficiency of 6.4%. Another class of materials Cu_2AgBiI_6 has also been found to be suitable for flexible solar cells.
- Bio-based optical fibers for sensing and short-distance communication (TAU/Aalto/VTT): biopolymer-based optical fibers have been fabricated with application perspectives for environmental sensing, interactive textiles and short-distance optical communication.
- Precision nanoparticle membranes and optoelectronics (TAU/Aalto): atomically precise nanoparticle-based monolayer membranes, precision doping and shell-isolated hybrid nanocomposites have been developed with unique mechanical and optical properties for integrated plasmonics and sensors.
- Optical studies of hybrid 2D and 1D materials (Aalto): mixed-dimensional van der Waals heterostructures have been studied by growing InP nanowires directly on two-dimensional MoS_2. The heterostructures were shown to exhibit a strong nonlinear response, including 2nd and 3rd harmonic generation, and odd-order high harmonic generation up to 7th order.
- Optical operando analysis of interfacial carrier dynamics within semiconductor photocathodes for efficient solar-driven fuel production (TAU/Aalto): ultra-fast transient absorption spectroscopy and carrier dynamics modeling were applied to optimize the TiO_2 protective layer on the surface of Si solar cells for advanced photo-catalytic applications, e.g., solar-driven hydrogen production or solar cells immersed in water.
- First Bioactive phosphate glass-based fiber with green persistent luminescence (TAU): a bioactive fiber with green persistent luminescence was successfully for the first time drawn from a composite preform made of a bioactive glass with commercial persistent luminescent microparticles (SrAl2O4:Eu2+,Dy3+).
- Graphene quantum dots for stochastic optical fluctuation super-resolution imaging (UEF): we have shown that ensemble of graphene quantum can exhibit complicated temperature-dependent intermittent emission. This dependency can be exploited to shorten blinking times and its systematic control could make submicron-size agglomerations of graphene quantum dots attractive for stochastic optical fluctuation imaging applications.

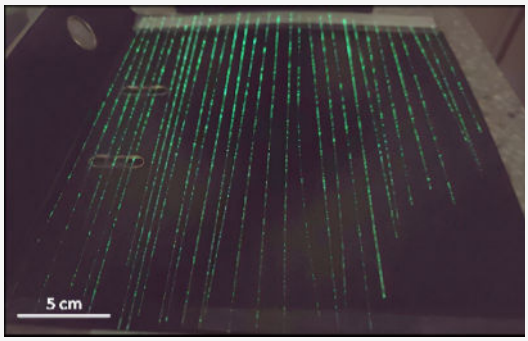
Cellulose-based optical fibers for sustainable optics and photonics applications.



Bio-based optical fibers: An emerging link between forest products and photonics.



Harmonic generation from InP nanowires deposited on two-dimensional MoS2.



Bioactive phosphate glass-based fiber with green persistent luminescence.

- AI assisted spectral scatterometry for photonics industry applications (VTT/UEF): we have devel-oped a machine-learning assisted spectral reflectance/transmittance scatterometry instru-ment capable of determining sample geometry variations from measured diffraction efficiency spectra. This provides novel opportunities for the inline quality control of manufacturing diffractive optical elements.

Upcoming Developments

- Metasurface-based nonlinear photonic compo-nents (TAU/UEF/Aalto): Engineering the coupling between nanoparticles will be realized via hybrid waveguide–metasurface devices. We will also experimentally investigate how nonlinear meta-surfaces can be phasematched using a resonant cavity setup and a multipass configuration.

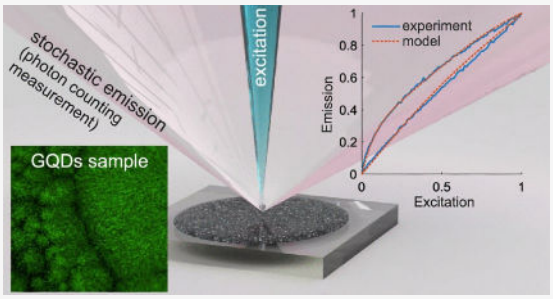
- 2D materials for pixels in novel miniature spec-trometers (Aalto): Building on our recent results, we will develop an array of single-pixel compu-tational spectrometer using new materials with enhanced performance.

- Two-color all-optical modulation using plas-mon-enhanced epsilon-near-zero materials (VTT/TAU): Obtaining materials with large and ultrafast nonlinear properties is a crucial step towards practical applications that require low power levels and small footprints. Epsilon-near-zero materials with plasmonic field enhancement is a promising approach and we plan to develop a structure with double epsilon-near-zero proper-ties for two-colour all-optical modulation which can then be used to realize all-optical time-to-fre-quency converters.

- Photonics sensor for microplastic in water (TAU/UEF): New active functionalized mid-infrared planar waveguides that are capable of detecting microplastics in water are under design and fabrication.

- Transparent metamaterials (UEF/Aalto): Rapid progress in photonics brings many examples of optical phenomena associated with the transpar-ency window due to resonant multipoles interac-tions in single particles and metamaterials. We intent to design and show experimentally a novel transparency effect in Babinet metamaterials made of metals and free-standing silicon based anapole metasurface to approach unprecedented broadband transparency in microwave, THz, and visible frequency ranges.

- Single-photon carbon emitters (UEF/TAU/Aalto): Two types of nanocarbon-based single photon emitters will be fabricated and characterized, based on color centers in diamond single crystal nanoneedles, and single-walled carbon nanotubes covalently functionalized via oxygen doping.



Fluorescence from graphene quantum dots (GQDs) for stochastic optical fluctuation super-resolution imaging.

Selected 2022 Publications

Kelavuori et al., "Thermal Control of Plasmonic Surface Lattice Resonances," Nano Letters 22, 3879-3883 (2022)

11. Yoon et al., "Miniaturized spectrometers with a tunable van der Waals junction," Science **378**, 296-299 (2022)

12. Garcia Arango et al., "Near-infrared rechargeable glass-based composite with green persistent luminescence from new Yb3+, Tm3+ co-doped oxyfluorophosphate glasses," Journal of alloys and compounds **927**, 167048 (2022).

13. Stolt and Huttunen, "Broadband frequency conversion of ultrashort pulses using high-Q metasurface resonators", New Journal of Physics **24**, 025004 (2022)

14. Som et al., "Strong and elastic membranes via hydrogen bonding directed self-assembly of atomi-cally precise nanoclusters," Small **18**, 2201707 (2022)

15. Soldano et al., "TCTA:Ir(ppy)3 green emissive blends in organic light-emitting transistors (OLETs)" ACS Omega **7**, 43719-43728 (2022)

16. Shafi, Das, Khayrudinov, Ding, Uddin, Ahmed, Sun, and Lipsanen, "Direct Epitaxial Growth of InP Nanowires on MoS_2 with Strong Nonlinear Optical Response", CheMate**34**, 9055–9061 (2022).

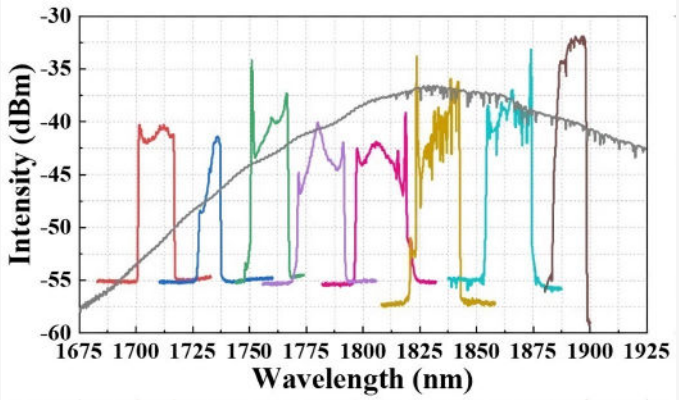
17. Ivaškevičiūtė-Povilauskienė et al., "Advantages of optical modulation in terahertz imaging for study of graphene layers", Journal of Applied Physics **131**, 033101 (2022).

18. Belko et al., "Hysteresis and Stochastic Fluorescence by Aggregated Ensembles of Graphene Quantum Dots", Journal of Physical Chemical C Nanomaterial Interfaces **126**, 10469-10477 (2022).

WP3: Active Photonics Components

Overview

This WP is at the interface between the material/structure science aspects in WP2 and the applications targets in WPs 4–5. Specific activities target proof-of-concept demonstration of novel photonic components for emerging applications in sensing and quantum technology. In particular, for sensing applications our joint work targets the development photonic integrated circuits-based light sources enabling to advance the work in WP4. Cryogenic optoelectronic devices and non-classical light sources are also being developed to support the advances in WP5 on quantum technologies.



Widely tunable ultrashort fiber laser that can be used for three-photon microscopy in the third biological window.

Selected 2022 Highlights

- Polarization and phase correlation properties of plasmonic nanolasers (UEF/TAU): the physical mechanism governing the spatial coherence and beaming properties of plasmonic nanolasers has been idenfied. By maintaing the periodicity constant and varying only a single lattice parameter, namely the diameter of plasmonic particles, transition from 1- to 2-dimensional lasing was observed which could open prospects for the development of nanoscale femtosecond lasers.

- Photonic lattices producing topologically nontrivial laser light (UEF/ Aalto): Photonic latices of a given symmetry can support several topologically nontrivial lasing modes. By tailoring the lattice periodicity and the diameter, lasing from the all four topologically different modes supported by the four-fold symmetric lattice was achieved.

- Green organic light-emitting transistor (Aalto): We demonstrated significant enhancement of the optical response of green organic blends for optimized doping concentration. This could lead to more efficient organic light-emitting transistors that combine the function of an electrical switch with the capability of generating light under appropriate bias conditions.

- First prototype of a vertical cavity surface emitting laser operating at 4 K (TAU/VTT): a vertical cavity surface emitting laser operating at 4.2K was developed for energy efficient optical links between cryogenic systems and room-temperature data storage systems. This is a major step towards demonstrating low energy per bit operation.

- State-of-the-art photonic integrated circuit -based hybrid SiN/GaSb tunable laser at 2.6 um (TAU/Vaisala – industrial collaboration): Photonic integrated circuits fabricated using Si3N4 waveguide platform exhibit low losses in a wide wavelength region extending from visible to beyond 2 um. This feature was exploited to demonstrate a high-performance integrated laser exhibiting broad wavelength tuneability near 2.6 um wavelength region.

- Broadband mid-infrared supercontinuum light (TAU): using a nonsilica, graded-index, multimode fiber, a two-octave supercontinuum was generated in the fiber with a near single-mode spatial intensity. Such source could create a path toward bright, ultrabroadband light sources for applications in the mid-infrared that require high spatial beam quality and high power.

- AI-based supercontinuum dynamics modeling (TAU): we have successfully train a feed-forward neural network to learn the differential propagation dynamics of the GNLSE, allowing emulation of direct numerical integration of fiber propagation, and particularly the highly complex case of supercontinuum generation. These results are of significance for the real-time optimization and control of nonlinear dynamics.

- Dual-comb fiber laser for high-precision spectroscopy (TAU): a novel design of a bidirectional dual-comb fiber laser based on an all-normal, all-polarization maintaining fiber scheme has been developed, providing new opportunities for high-resolution molecular spectroscopic applications

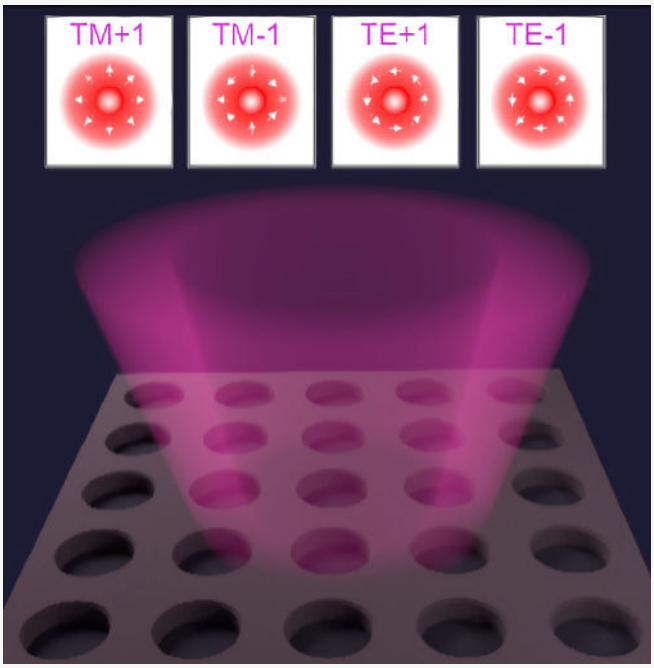
- High-power structured light (TAU): direct amplification of cylindrical-vector beams with axially symmetric polarization and doughnut-shaped shaped intensity profile was achieved in a picosecond master oscillator power amplifier system based on a double-clad ytterbium-doped spun tapered fiber with a ring-shaped active core. This opens new avenue towards the generation of high-power structured light for applications in sensing and imaging.

Upcoming Developments

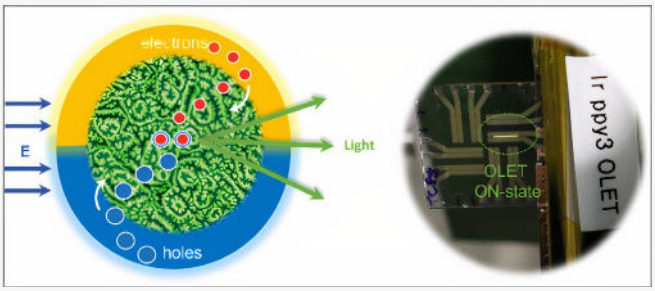
- Graphene-based THz emitters (UEF): we plan to use a 2D array of 1D narrow gap (few meV) graphene-based semiconductors (graphene nanoribbons or quasimetallic carbon nanotubes) coupled to an all-carbon THz antenna to demonstrate THz emission modulated via optical pumping.
- Plasmonic superlattice-based THz emitter (UEF): a field effect transistor with a channel formed by graphene yielding plasmonic instabilities at a sufficiently high DC current and combined with a periodic grating structure will be used as a source of THz radiation source
- Green Organic Light-Emitting Transistors (Aalto): the encapsulation processes for organic light emitting transistor will be developed.
- SiN/GaSb photonic integrated circuit laser (TAU): we will advance the assembly processes of the SiN/GaSb tunable photonic integrated circuit laser to enable sensing experiments
- Low-temperature operating vertical cavity surface emitting laser (TAU): we will demonstrate low-energy per bit (target < pJ/bit) cryogenic VCSEL operation.

Selected 2022 Publications

1. Mohamed et al., "Controlling topology and polarization state of lasing photonic bound states in continuum," Laser & Photonics Reviews **16**, 2100574 (2022)
2. Eslami et al., "Two octave supercontinuum generation in a non-silica graded-index multimode fiber," Nature Communications **13**, 2126 (2022)
3. Salmela et al., "Feed-forward neural network as nonlinear dynamics integrator for supercontinuum generation," Opticds Letters **47**, 802-805 (2022)
4. Droulias, Mohamed, Rekola, Hakala, Soukoulis, and Koschny, "Experimental demonstration of dark-state metasurface laser with controllable radiative coupling," Advanced Optical Materials **10**, 2102679 (2022)
5. Heilmann et al., "Quasi-BIC Mode Lasing in a Quadrumer Plasmonic Lattice," ACS Photonics **9**, 224 (2022)
6. Soldano et al., "TCTA:Ir(ppy)3 Green Emissive Blends in Organic Light-Emitting Transistors (OLETs)," ACS Omega **7**, 43719-43728 (2022)



Photonic lattices can be exploited to produce topologically nontrivial laser light.



The morphology of emissive blends can be efficiently engineered to enhance the optical and electronic properties of a light-emitting device.

WP4: Applied Research

Overview

WP4 develops photonics applications and interacts strongly with all the other WPs. It operates in the photonic ecosystem by taking input from fundamental research (WP1–WP3) and providing scientific, societal and economic impact through technological innovation and development.

Selected 2022 Highlights

- Plasmonics enhanced digital array biochip (VTT/UEF): Upconversion (UC) luminescence has great potential for highly sensitive and selective biosensing. We have now developed plasmonic structures which improve the efficiency of the upconversion luminescence, with enhancement as high as a few hundred times.

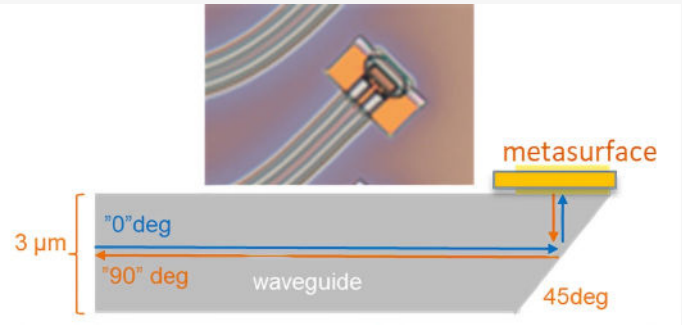
- Hyperspectral imaging and sensing of skin oxygenation (VTT): a non-contact skin oxygenation assessment device was developed using hyperspectral imaging. The quality of the prototype is on par with conventional pulse oximeters but we anticipate it can be further improved via specific spatial data averaging located over blood vessels.

- Plasmonics and metamaterials for enhanced detection (VTT): a compact, low-loss and broadband polarization rotators/splitters for microscopic silicon waveguides has been successfully developed by nanopatterned polarization rotating metasurfaces and by adding thin metamaterial films on top of up-reflecting total internal reflection mirrors. The next step is to optimize the integration of the metasurface to reduce the insertion losses.

- Mid-infrared hyperspectral sensor for stand-off sensing applications (VTT): a novel mid-infrared hyperspectral sensor employing a Fabry-Pérot interferometer based on micro-electro-mechnical system and a custom mid-infrared supercontinuum laser was demonstrated, allowing for the identification of black polypropylene and polyethylene.

- Optical Phased Arrays (VTT/UEF): a new design for the grating out-coupler of an optical phased array was developed using Fourier modelling. The new design could allow for large beam shaping and steering with potential application in LIDAR technologies.

- Pb-free flexible perovskite solar cells (VTT/TAU): led-free perovskite solar cells were developed based on antimony and bismuth. From these candidates, bismuth-based material appeared to be more promising in terms of power conversion efficiency (0.67%).



Top: Microscopic image of nanopatterned polarization rotating meta-surfaces deposited on top of up-reflecting mirrors. Bottom: sketched side view of the waveguide with integrated polarization rotating meta-surfaces.

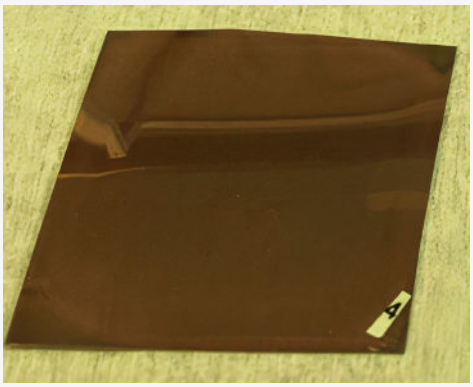
- Fluorene-based hole-transport material for highly stable perovskite solar cells in air (TAU): we have demonstrated inexpensive fluorene-based hole-transport materials capable of anchoring to the surface of a perovskite absorber and protecting it from moisture and oxygen. The chemical interaction between the material and the perovskite surface promotes an outstanding air stability of the corresponding devices, with only a 20% drop of the initial efficiency after 431 days of shelf storage.

- Structure-emission relationship in manganese-based perovskite nanocrystals (TAU/Aalto): we shave successfully synthesized cesium manganese chloride nanocrystals in a polymorphic structure that exhibits emission at 670 nm wavelength with a photoluminescence quantum yield of 40%. A proof-of-concept demonstration of photocurrent generated from the emitting nanocrystals indicates their suitability for luminescent solar concentrator applications.

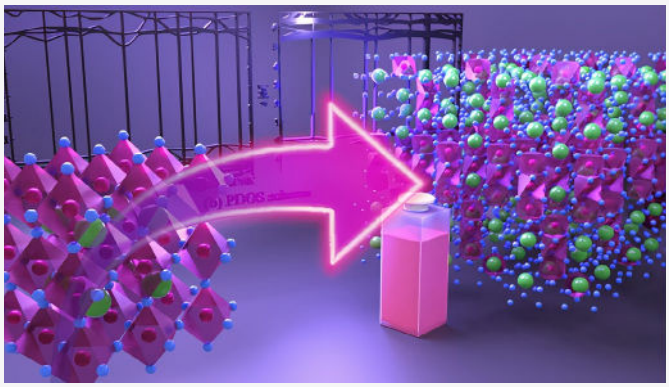
- Pinhole-resistant nanocrystalline rutile TiO_2 photoelectrode coatings for solar fuel reactor applications (TAU): Pinhole mediated corrosion of protective coatings limits the lifetime of semiconductor photoelectrodes in photoelectrochemical reactors. By tuning the atomic layer deposition TiO_2 process parameters and sequential heat-treatment we fabricated nanocrystalline rutile TiO_2 coating that showed superior resistance to pinhole formation on Si under alkaline conditions. These results allow increasing the lifetime of TiO_2 protected semiconductor photoelectrodes in solar fuel reactor applications.

Upcoming Developments

- Solar fuel production using TiO_2 -based photonic crystals (TAU/UEF): Inverse opal TiO_2 structures will be functionalized with plasmonic nanopar-



Bismuth-based led-free flexible perovskite solar cells.



Synthesis and structuring via hot injection route of manganese-based perovskite nanocrystals with emission at 670 nm.

ticles for external field enhanced photocatalytic performance.

- Plasmonics enhanced digital array biochip (VTT/UEF): a digital array of upconversion lumines-cence biochip for single molecule detection will be developed.
- Soil carbon monitoring with combined laser induced breakdown spectroscopy and reflectance spectroscopy (TAU/VTT): Moisture information from reflectance spectroscopy is expected to enable laser induced breakdown spectroscopy calibration in various environments.
- Detection and monitoring of microplastics (TAU/UEF/VTT): Detection methods for the wide microplastics problem will be developed based on hyperspectral imaging and Raman spectroscopy. Online detection methods for microplastics in different aqueous environments will also be studied.
- Cavity-enhance photoacoustic spectroscopy for detection of microplastic (Aalto/UEF): cantilever-enhanced detection will be implemented for sensitive identification of microplastics in various environments.

Selected 2022 Publications

1. Sharma et al., "Electromagnetic radiation detection using cantilever-based photoacoustic effect: A method for realizing power detectors with broad spectral sensitivity and large dynamic range," Sensors and Actuators A: Physical **337**, 113191 (2022)
2. Saleh et al., "Mid-infrared hyperspectral sensor based on MEMS Fabry-Perot interferometer for stand-off sensing applications," Scientific Reports **12**, 19392 (2022)
3. Mikkonen et al., "Sensitive multi-species photoacoustic gas detection based on mid-infrared supercontinuum source and miniature multipass cell," Physical Chemistry Chemical Physics **24**, 19481-19487 (2022)
4. Wang et al., "Hydrogen bonding drives the self-assembling of carbazole-based hole-transport material for enhanced efficiency and stability of perovskite solar cells," Nano Energy **101**, 107604 (2022)
5. Grandhi et al., "Enhancing the microstructure of perovskite-inspired Cu-Ag-Bi-I absorber for effi-cient indoor photovoltaics," Small **18**, 2203768 (2022)
6. Liu et al., "Moisture-assisted Near-UV emission enhancement of lead-free $Cs_4CuIn_2Cl_{12}$ double perovskite nanocrystals, 2 Nano Letters **22**, 311 (2022)
7. Pham et al., "Functionalization of TiO_2 inverse opal structure with atomic layer deposition grown Cu for photocatalytic and antibacterial applications," Optical Materials **131**, 112695 (2022)
8. Saari et al., "Tunable Ti3+-mediated charge carrier dynamics of atomic layer deposition-grown amorphous TiO_2," Journal of Physical Chemistry C **126**, 4542-4554 (2022)
9. Palmolahti et al., "Pinhole-resistant nanocrystalline rutile TiO_2 photoelectrode coatings," Acta Materialia **239**, 118257 (2022)

WP5: Quantum Technologies

Overview

WP5 was recently established to aim at benefiting from the developed components to advance the research of foundations and applications of quantum photonics as well as delivering emerging photonic technologies to the broad field of quantum research and applications.

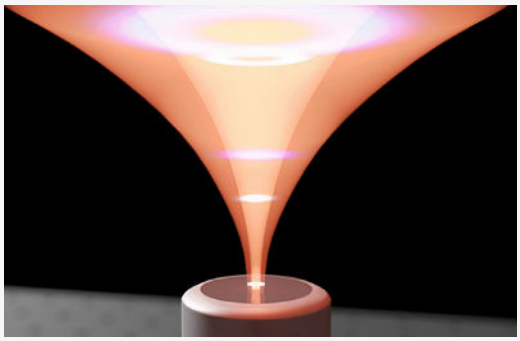
Selected 2022 Highlights

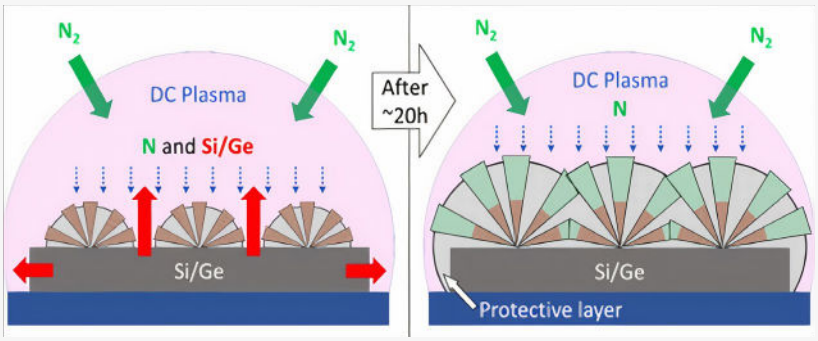
- Control of NV, SiV, and GeV centers formation in single crystal diamond needles (UEF): The formation of nitrogen-vacancy, silicon-vacancy, and germanium-vacancy centers was reported in single-crystal diamond needles during direct current discharge plasma enhanced chemical vapor deposition. The proposed approaches in combination with the revealed mechanisms for introduction of favorable impurities make single-crystal diamond needles promising candidates for scanning quantum sensing, quantum communication, and hyperpolarization experiments.

- All-optical nano-thermometry with color centers in diamonds (UEF/Aalto): Monitoring of tiny intracell temperature variations is of high importance to understand the mechanisms of exothermic/endothermic processes inside living cells. By using biocompatible diamond single-crystal microneedles enriched with nitrogen-vacancy/silicon-vacancy color centers, we have demonstrated all-optical in vitro temperature monitoring in the physiologically significant range (25–55 °C).

- Fast and blue luminescence in carbene-metal-amides (UEF): Gold-centered carbene-metal amides have recently emerged as promising OLED materials, showing highly efficient luminescence via thermally activated delayed fluorescence. Together with international partners, we have described a strategy for realization of bright, fast, and deep blue luminescence carbene-metal amides materials via systematic control of charge transfer and locally excited quantum states by nitrogen substitution.

- Observation of the quantum Gouy phase (TAU): we have measured the phase anomaly of evolving quantum waves passing through a focus and showed that multi-photon states behave differently from classical laser fields. This could lead to possible applications in quantum-enhanced sensing and sheds new light on its underlying mechanism.





Conceptual render displaying the difference between a laser and a two-photon quantum state being focused on a single mode fibre. Right: Control of nitrogen-vacancy (NV), silicon-vacancy (SiV), and germanium-vacancy (GeV) centers formation in single-crystal diamond needles.

Upcoming Developments

- Geometric phase and wave–particle duality (UEF/TAU): We will explore the connection between the geometric phase and wave-particle duality of photons in double-slit interference.
- Complementarity of quantum light correlations (UEF): the foundations of optical coherence theory will be studied within a quantum-informatic framework by considering complementarity between field correlations and photon correlations of quantized light.
- Diamond needles for quantum technology applications (UEF/Aalto/TAU): the potential of individual SiV centers in the single crystal diamond needle single-photon sources will be investigated.
- Characterizing meta-antenna arrays on heterostructure (TAU/Aalto): Magneto-optical characterization of strained encapsulated transition metal dichalcogenide monolayer heterostructure coupled to a hyperbolic meta-antenna array will be performed and development of a method based on strain engineering for stable quantum emission by using such meta-antennas arrays will be demonstrated.
- Development of all-dielectric RWG structures for SPDC (TAU/UEF): all-dielectric resonant waveguide grating structures resonant at two or more wavelengths will be designed and fabricated for spontaneous parametric down conversion and the generation of entangled photon pairs.
- Multimode PICs for high-dimensional quantum information (TAU/VTT): Free-space structured light states will be mapped into spatial modes of thick SOI waveguides for on chip processing.
- Semiconductor quantum systems (TAU): quantum electrodynamics will be studied in ultra-small volume semiconductor-metal nanocavities that are hosting a single or multiple quantum dots to generate single photons and photon-pair entanglement.

Selected 2022 Publications

1. Malykhin et al., "Control of NV, SiV and GeV centers formation in single crystal diamond needles," Diamond Related Materials **125**, 109007 (2022)
2. Golubewa et al., "All-optical thermometry with NV and SiV color centers in biocompatible diamond microneedles," Advanced Optical Materials **10**, 2200631 (2022).
3. Reponen et al., "Donor N-substitution as design principle for fast and blue luminescence in carbene-metal-amides," Advanced Optical Materials **10**, 2200312 (2022)
4. Cherchi et al., "A path towards attojoule cryogenic communication," in ECOC 2022, 48th European Conference on Optical Communication (2022)
5. Hiekkamäki et al., "Observation of the quantum Gouy phase," Nature Photonics **16**, 828 (2022)

RESEARCH OUTPUTS AND INTERNATIONAL RESEARCH COLLABORATION

Detailed bibliometric analysis conducted with Scopus/SciVal shows that PREIN research continues to be highly influential and the results in 2022 are extremely impressive.

The number of publications has remained high totaling at 335 internationally peer reviewed publications in 2022. Similarly, the proportion of publications in high-impact journals (IF>7) has increased by 25% from the previous year, reaching 88 publications in 2022. Up to 42% of PREIN-related publications are published in the top 10% journals and 13% of publications in the top 10% most cited publications worldwide in 2022. The field-weighted citation impact for PREIN-affiliated publications is consistently higher than the national average and articles from PREIN researchers are published in high-impact journals much more regularly than the national average.

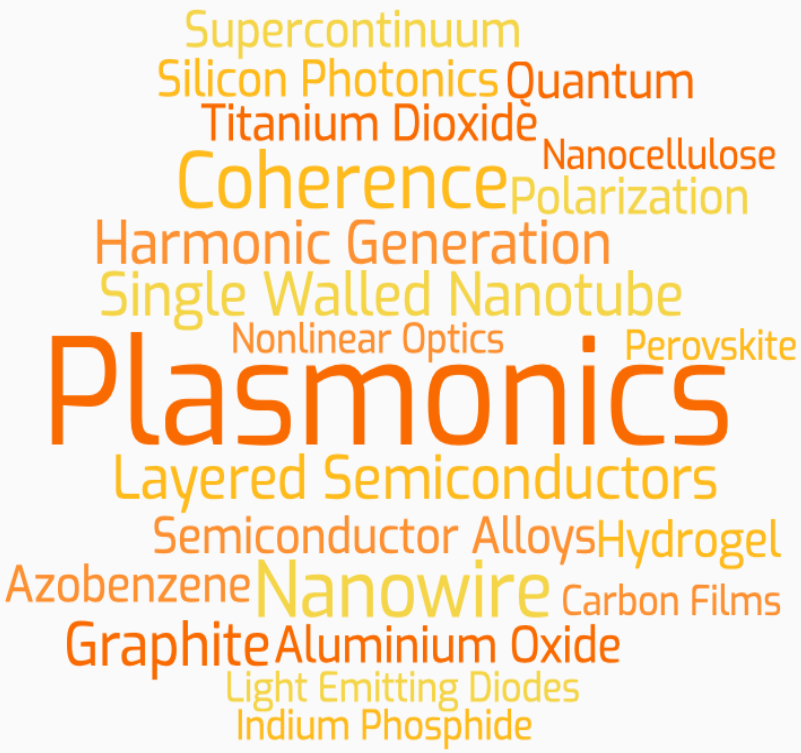
The level of international collaboration in research in PREIN is very high and PREIN has strengthened its strategic international research collaboration networks in 2022 with 64% of its publications including international collaborators. The number of international institutions with which PREIN collaborates has, however, somewhat decreased. Due to the political situation, collaboration with Russian universities and research institutes has decreased and this will be further reflected in research collaboration in the coming years.

One of the aims of the flagship programme has also been to increase research collaboration among the flagship partners. Internal collaboration initiatives have started to become visible through PREIN members' joint publications which increased from 2021 (38 joint publications) and totaled 44 in 2022.

Another important aspect is the accessibility of PREIN scientific output which has also improved with an annual increase of 7% so that in 2022 already 73% of articles were published in open access journals.

Key phrase analysis showed that a number of very active research areas reflecting well the WP structure of PREIN, but also represent new emerging research areas.

PREIN 2022 publications by journals
(only journals with more than 3 publications are shown).

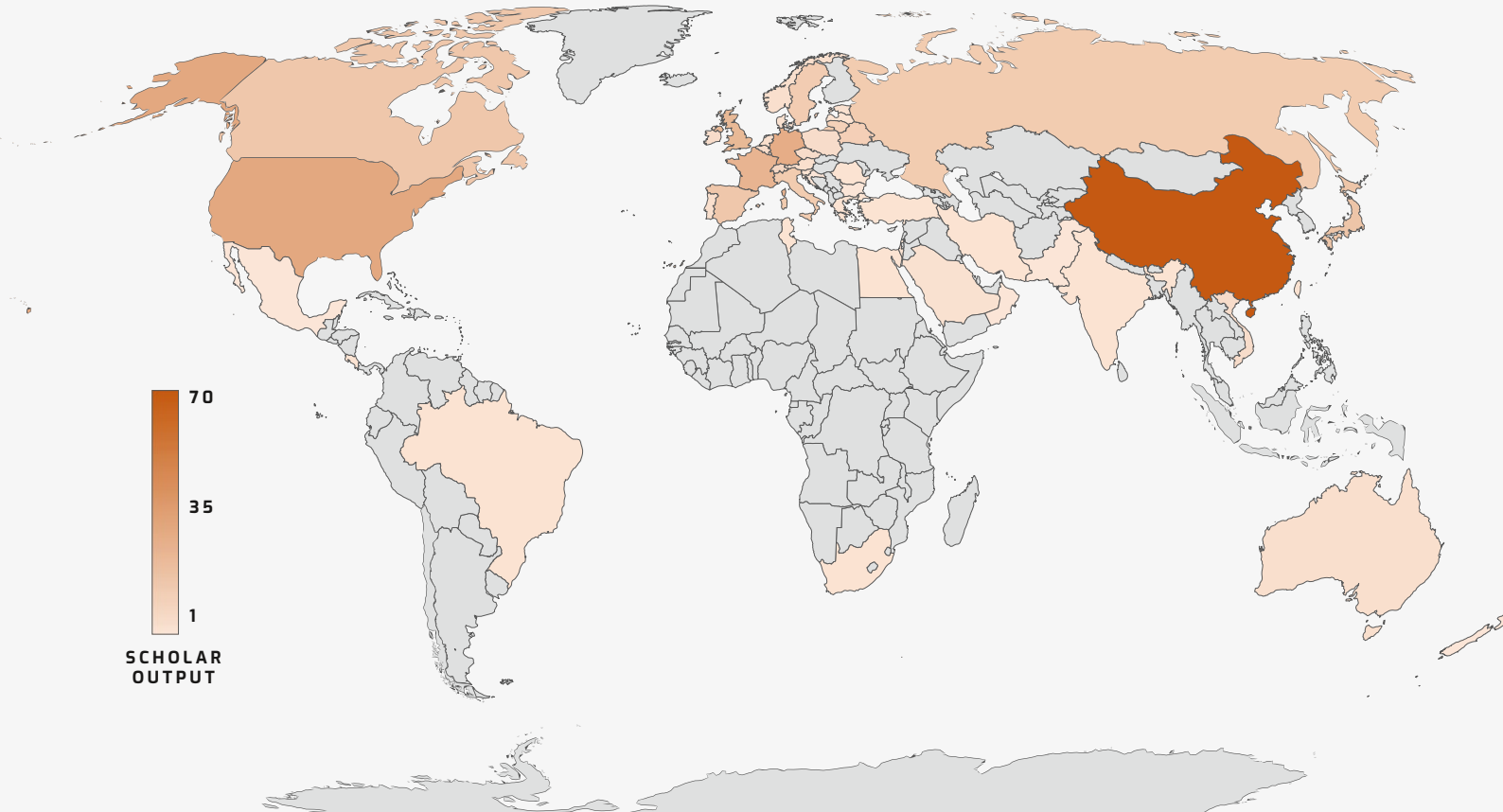


OF PUBLICATIONS ARE OPEN ACCESS **73%**

PUBLICATIONS IN HIGH-IMPACT (IF>7) JOURNALS **88**

IN TOP 10% JOURNALS **42%**

PREIN international collaboration network.



PREIN Events 2022 Timeline

- NEWSLETTER
- MEETINGS
- EDUCATION EVENTS
- FAIRS
- OUTREACH EVENTS FOR PUBLIC
- THEMATIC OUTREACH EVENTS
- PREIN WORKSHOPS

24–27 Jan
Photonics West Fair, San Francisco

8 March
Outreach representative meeting (on-line)

17 March
Women in Photonics – Meet-up to celebrate International Women's Day (on-line)

11 May
Kansallinen mikroelektroniikan ja fotoniikan seminaari, Helsinki

16 May
Photonics Starts from Design webinar

16–18 May
Valon viikko / Week of Light (on-line)

23 May
Photonics4XR webinar

30 May
Steering Committee meeting (on-line)

JAN · FEB · MAR · APR · MAY · JUN

PREIN newsletter 1/2022

3 Feb
Microelectronics and Photonics webinar

11 Feb
Women in Physics webinar (on-line)

15 Feb
Spectral Imaging and its Applications course, UEF (on-line/Joensuu)

18 Feb
Communications representative meeting (on-line)

PREIN newsletter 2/2022

1 April
Steering Committee Meeting, TAU (Tampere/ on-line)

13 April
Management Group Meeting (on-line)

20 April
Spectral Imaging and its Applications course, UEF (on-line/Joensuu)

PREIN newsletter 3/2022

6 June
Integrated polymer photonics systems training VTT (Oulu)

12–17 June
International Conference on Optical Angular Momentum, ICOAM, TAU (Tampere)

20 June
Management Group meeting

Month of Photonics

7–10 Nov
Opening week of Photonics Center, UEF (Joensuu/ on-line)
Photonics Applications –webinar series, UEF (Joensuu/on-line)

8 Nov
Management Group meeting
UEF (Joensuu)

9–10 Nov
Photonics Finland and PREIN: Forest & Photonics, UEF (Joensuu)

9–10 Nov
PREIN Workshop: Quantum Photonics UEF (Joensuu)

9 Nov
Steering Committee meeting (on-line)

30 Nov
Women in Photonics meeting, UEF (Joensuu)

6 Sept
PREIN annual event, TAU (Tampere)

6–8 Sept
Optics and Photonics Days, TAU (Tampere)

30 Sept
Tampereen päivä/ Tutkijoiden yö: Photonics workshops TAU (Tampere)

13 July
Valo hoitaa! – Läpimurto-teknologia fotoniikka mul-listaa terveydenhuollon Panel discussion Suomi Areena (Pori)

JUL · AUG · SEP · OCT · NOV · DEC

PREIN newsletter 4/2022

31 July – 5 Aug
Workshop on Nanocarbon Photonics and Optoelectronics, UEF (Polvijärvi)

9–16 Aug
Summer School, Glasses for Optical Fibres, UEF (Joensuu)

29 Aug
Communications representative meeting (on-line)

29 Aug
Management Group meeting, TAU (Tampere)

PREIN newsletter 5/2022

11 Oct
Latest advancements in free-form micro-optics Webinar

11–13 Oct
Shaking up Tech, Photonics workshop Aalto (Espoo)

PREIN newsletter 6/2022

12 Dec
PREIN workshop with GeneCellNano. VTT (Espoo)

Photonics West exhibition 2022 in San Francisco.

PREIN EVENTS 2022

Fair in January

Photonics West Fair and Conferences 2022 were held in San Francisco during January 22–27.

Since Photonics West involves leaders from academia and industry, the exhibition and conference have been defined as a key event where PREIN participates annually. The event provides opportunities to learn about the latest research, see the newest innovations, and meet with the global community during the week.

PREIN participated in the Photonics West exhibition together with Photonics Finland and ten photonics companies from Finland. The Finnish photonics participants included Emberion, Inkron, Oplatek, VTT, PiBond, Elfys, Comptek Solutions, Picophotonics and Reflekron.

Thematic events

National Microelectronics and Photonics Seminar in May

National Microelectronics and Photonics seminar was organized by Business Finland on May 11th in Helsinki. There were invited speakers from companies, universities, and research centers to discuss how value chains of microelectronics can be developed nationally and how to secure self-sufficiency of critical components. Prof. Jyrki Saarinen, Vice Director, and Juha Purmonen, Impact Manager, represented PREIN Flagship in the event.

The seminar was continuance of the discussion in National microelectronics and photonics webinar held in February by Business Finland Sustainable Manufacturing Finland Program and Technology Finland on the role of Finnish players in European value chain.

China-Europe Silicon Photonics Symposium in August in Espoo

VTT co-organized the 4th China-Europe Silicon Photonics Symposium on August 28-30, 2022. The event brought together industrial and academic technology leaders in silicon photonics technology and its application. It was bilocated in China and Europe and also accessible on-line. The Finnish part of the symposium took place in Espoo and included keynote speeches from PREIN researcher Dr. Matteo Cherchi (VTT) and VTT Lab visits.

Optics and Photonics Days (OPD) in September

The Optics and Photonics Days organized in Tampere reached its all-time record number of participants with about 350 academics and industry experts registered in the event. The participation from both sectors was quite evenly distributed (150 participants from academy, including 70 students, 190 persons from industry).

PREIN Flagship networking event and panel discussion gathered 140 persons, Student meet-up event 80 persons, Women in Photonics session 70 persons, 225 persons in Networking Dinner. There were 31 companies as exhibitors.

The OPD event highlighted 12 industrial oral presentations, 16 academic oral presentations, 4 panel discussions and 75 poster presentations.

PREIN Event in Optics and Photonics Days

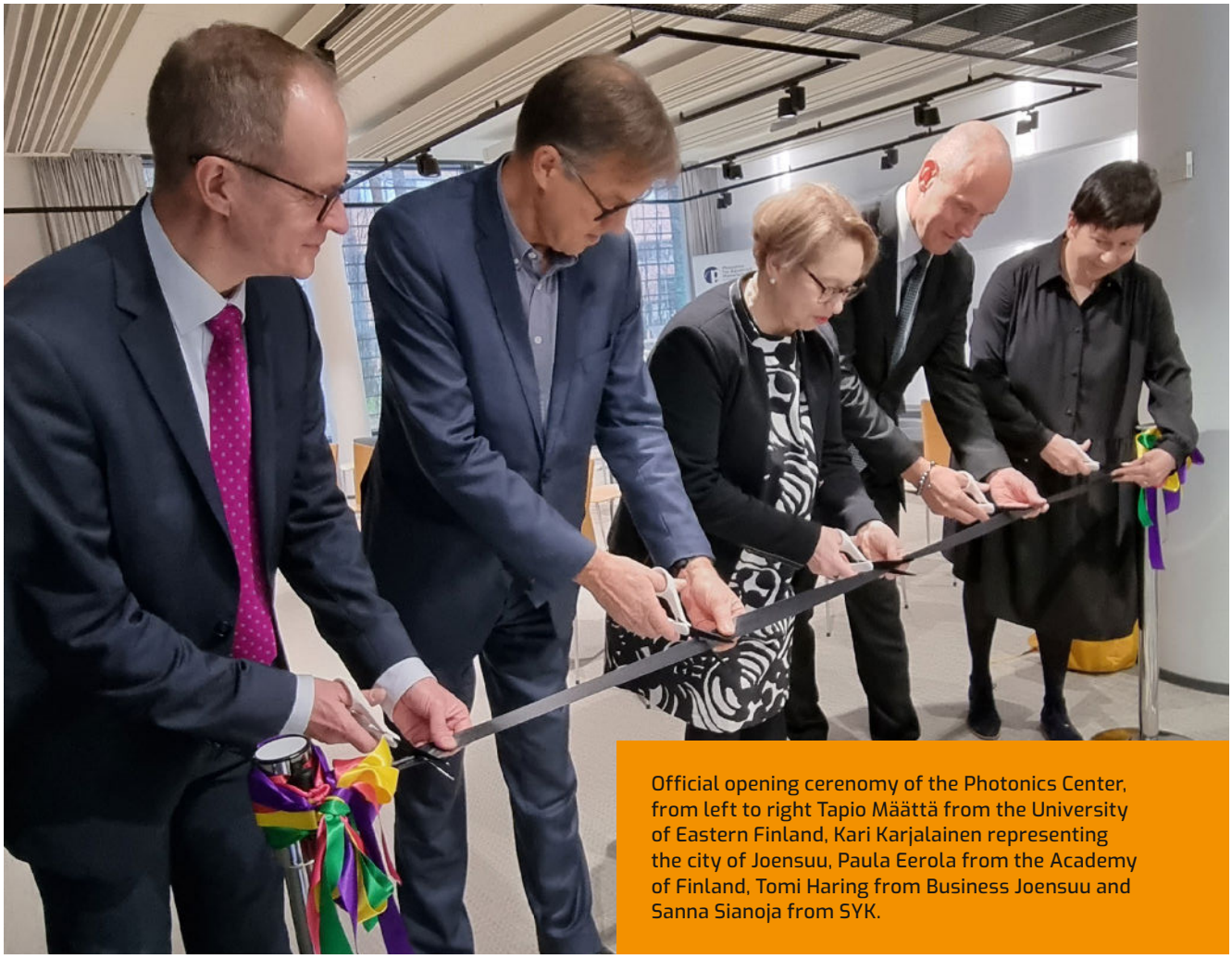
PREIN organized its annual event as part of the Optics and Photonics Days. In the event, recent research and other highlights were be presented and a thematic poster session aiming at strengthening collaborations between the different partners was organized. The presentations included an overview of the past year's activities, a research session, and a stakeholder panel discussion on photonics talent attraction and educational needs. The Stakeholder panel discussion brought together key stakeholders to discuss talent attraction policies and activities to increase the number of students and professionals in the field of photonics. Panelists included representatives from photonics companies, ministries and funding organizations.

Student Networking Event in OPD

There was a photonics student event targeted at master's and doctoral students from around the Finland. The event was an opportunity to network, but also to attend a discussion on the options of working in academia or industry.

Optics and Photonics Days 2022

NUMBER OF PARTICIPANTS **350**



Official opening cerenomy of the Photonics Center, from left to right Tapio Määttä from the University of Eastern Finland, Kari Karjalainen representing the city of Joensuu, Paula Eerola from the Academy of Finland, Tomi Haring from Business Joensuu and Sanna Sianoja from SYK.

Joensuu Photonics Center Opening Week in November

The Photonics center opening week in the beginning of November attracted over 300 visitors including company representatives, researchers, students as well as high-level invited stakeholders. The opening week was filled with photonics related events, presentations, and case examples from industry and research as well as workshops and networking events and visits to the new premises and the new Photonics showroom. The week started with the Grand Opening of the Photonics Center for guests and media on Monday November 7. The program consisted of high-level speakers and presentations followed by presentations from companies whose premises are located in the Photonics Center. Invited participants numbered about 50 people representing the Academy of Finland, University of Eastern Finland, Tampere University, VTT, Aalto University and other PREIN Flagship stakeholders. The impact of PREIN in research, industrial and company collaboration was highly noted as well as the role of Photonics Center as one of the keys to increase the importance of photonics in society.

The Open doors event at Photonics Center ended the week inviting anyone interested in photonics and the premises to visit. Over 50 guests wanted to see the new Photonics Center and showroom. Additionally, well over 20 photonics students participated in student event.

Forest and Photonics

Forest and Photonics is a unique professional event that brings together the forest and technology experts to network, collaborate and share their ex-

periences, challenges and solutions. Two full days were dedicated to the annual event that brought together forest and technology experts to network, collaborate and share their experiences, challenges and solutions. The event was organized in collaboration with Business Joensuu, Photonics Finland and the three flagships: PREIN, FinnCERES and UNITE. There were approximately 80 participants, including students interested in the topic.

Metrology for XR & Freeform Optics

The full-day seminar focused on presenting the know-how and possibilities in metrology for XR and freeform optics in Finland. In addition, manufacturing and especially the needs for XR and freeform optics metrology were presented. Top-notch speakers from VTT Mikes, Aalto University, University of Eastern Finland, Karelia University of Applied Sciences, Senop & Millog, Dispelix, Nanocomp, Trioptics, Panasonic, Ikron, OptoFidelity and Varjo Technologies were invited to the event. Registered participants in Joensuu and on-line numbered altogether 90 persons.

Workshop on Quantum Technologies

The two-day PREIN Workshop on Quantum Technologies focused on the development of components and schemes to generate, detect, and manipulate quantum states of light. These developments will lay the foundations for future quantum photonic networks and systems in quantum cryptography, computation, sensing, and simulation. There were around 30 participants in the workshop.

PREIN and GeneCellNano Networking Event in December

The networking event jointly organized by two flagships, PREIN and GeneCellNano, on December 12th, brought together 33 participants in VTT premises in Espoo.

The GeneCellNano flagship is the Gene, Cell and Nano Therapy Competence Cluster for the Treatment of Chronic Diseases. The members of GeneCellNano are University of Helsinki, University of Eastern Finland, University of Oulu, Aalto University and the Finnish Red Cross.

During the seminar, participants from both flagships discussed new collaboration possibilities between photonics and medical care and treatment of chronical diseases. The themes covered gene therapy, cell therapy, bio-photonics implants and nanomaterials for therapeutic applications, light-activated drug delivery, and fiber optics utilized in endoscopy and other photonics related treatments for chronic diseases.

Photonics for webinars

Women in Physics Webinar in February

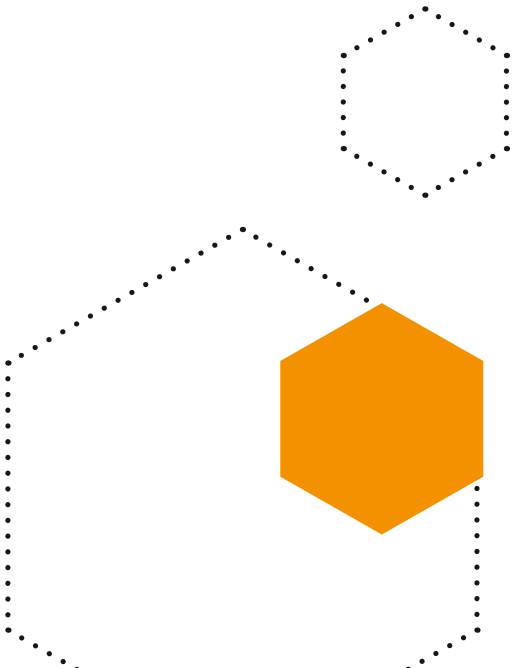
To celebrate the International Day of Women and Girls in Science 2022, the Optica Student Chapter of Tampere University organized a webinar 'Women in Physics' on February 11th at 11-12. The speakers were Professor Christine Silberhorn from Paderborn University, Germany and Director of Education and Science Peter Main from the Institute of Physics, United Kingdom.

Photonics Starts from Design -webinar in May

To celebrate the International Day of Light on May 16 PREIN and Photonics Finland organized a webinar on the research and development phase of photonics projects. The webinar focused on the views of researchers and experts in optical design industry.

Photonics4XR webinar in May

The webinar on Photonics4XR organized in May, showcased how photonics is involved in different Extended Reality (XR) technologies. In addition the working principles, challenges, future directions of XR and how photonics can support that future were discussed. The event gathered together both researchers and companies covering the whole XR value chain.



EDUCATION

The educational activities of the PREIN partners continued in 2022 with photonics degree education, different forms of educational collaboration between the partners and continuous education courses. There was a significant increase in photonics master's degree graduates in 2022 from the PREIN partner universities with the number reaching 70 new masters. The number of doctoral degrees remained steady with 16 photonics PhD graduates in 2022.

Master's Degree Educational Collaboration

The three PREIN universities, Tampere University, Aalto University and University of Eastern Finland have developed their educational collaboration particularly on the master's degree level. The educational collaboration between the PREIN partner universities continued with shared teaching in 2022. The University of Eastern Finland course on Optical Design was offered in collaboration with the partners. Students from all the partner universities also participated in the Applications of Photonics open webinar lectures where Finnish photonics companies present the ways in which they utilize photonics in their field of business.

Doctoral Education

Regular summer schools have been organized as a part of the doctoral education activities in PREIN, with an annual summer school in the University of Eastern Finland and a bi-annual summer school in Tampere University.

Summer School in Optical Fibre Glasses 2022

The summer school targeted mainly at doctoral students was organized in Joensuu in August 2022 attracted 23 participants. The teaching of the summer school was jointly organized by teachers from the University of Eastern Finland and Tampere University. The Summer School program expanded for one weeks with lectures and visits to photonics companies.

ICOAM 2022 Conference Group

Photonics Conferences

Conference on Optical Angular Momentum

The sixth Conference on Optical Angular Momentum (ICOAM) organized in June 2022 in Tampere attracted 123 participants. The conference covered topics related to twisted wavefronts, nonlinear optics, optical communication and matter-wave phenomena, as well as applications ranging from light-matter interactions to quantum information, to imaging and microscopy. In connection to ICOAM there was also a public lecture from Sir Michael Berry on the Physics of Light in 80 pictures attracting a large audience also outside the conference participants.

Conference on Nanocarbon Photonics and Optoelectronics

The ninth Nanocarbon Photonics and Optoelectronics (NPO2022) conference organized by the University of Eastern Finland in Polvijärvi in July attracted about 100 participants. The themes included the latest advances in carbon nanotubes, graphene and other reduced-dimensionality materials for photonic and optoelectronic applications.

Continuous Education and Courses

Specific short-term courses directed at companies and employees in photonics industry. These courses have been planned according to the needs and requirements to further increase photonics skills in related companies.

Spectral Imaging and its Applications

The training course was organized twice, on-line in February and face-to-face in Joensuu in April. The course was provided in collaboration with the Computational Spectral Imaging Lab of University of Eastern Finland within the PhotonHub, Photonics Innovation Academy initiative and in collaboration with Photonics Finland. The training was targeted at everyone wanting to gain and expand their practical knowledge on spectral imaging devices with no previous experience required.

Integrated Polymer Photonics Systems

VTT organized a three-day training on integrated polymer photonics systems in June in Oulu. The course provided an overview on the realization of functional systems using non-conventional fabrication technologies based on polymer-based materials and their printing and hybrid integration. Integrated polymer photonics systems are key building blocks in many disruptive product innovations like multidisciplinary environment and diagnostic sensors, displays, energy sources and wearable devices. The course was targeted at industrial concept developers, designers, manufacture engineers and test engineers in photonics and related industries.

Thick-SOI Photonics for Sensing and Imaging

VTT organized the continuous education training twice in 2022, in June and August in VTT premises in Espoo. The training focused on the Thick-SOI platform and its use for sensing and imaging applications in the near and mid-infrared region providing an overview of the platform and its feasibility for applications with a primary focus is on 3 µm thick silicon-on-insulator (SOI) waveguide technology. The training was targeted at industry representatives and did not require extensive background knowledge.

IMPACT

The results in scientific, societal and educational impact in 2022 have been on a high level with significant developments gained during the year.

Science and Innovation

Funding for scientific research topics and groups received in 2022 shows that the scientific level and its impact is extremely high in the flagship. Photonics researchers and research groups linked to PREIN were highly successful in the 2022 Business Finland, Academy of Finland and European Research Council.

Academy of Finland

The 2022 Academy of Finland funding granted for PREIN partners, consisted of funding for Academy Postdoctoral fellows, Research Council for Natural Sciences and Engineering project fundings, and projects funded in the ICT and the Green and Digital transformation project funding call.

Council for Natural Sciences and Engineering funding

Academy Project Funding is among the Research Council's most important funding instruments for promoting the quality, impact and renewal of research. The Research Council aims to fund research in a wide range of fields within natural sciences and engineering and to take into account the special characteristics of each field. The Academy of Finland's Research Council for Natural Sciences and Engineering granted funding for 67 Academy Projects of which five involved PREIN related photonics research groups.

Igor Koshevoy from the University of Eastern Finland received Academy for 2022–2026. According to the project description, light-emitting materials play a pivotal role in many applications, ranging from already conventional end-products such as LED displays and general lighting sources to advanced photonic technologies, which include information storage, encryption, optical signaling, bio-imaging, medical diagnostics, and therapy. The combination of new molecular constituents with multiple functions provides new ways for diversifying optical characteristics of materials, and for generating unconventional species with smart and tunable properties. In this project, we intend to develop new families of metal-based photoactive compounds, which are composed of specifically designed building blocks to produce dynamic and stimuli-responsive optical behavior in the solid state. New information and materials are expected to impact the fields of chemical and materials sciences, photophysics, with further extension into the areas of optoelectronics and biomedicine.

Tero Setälä from the University of Eastern Finland The project aims at developing novel spin-sensitive geometric-phase optical elements for the control of partially polarized and partially coherent random light beams. The specific goals of the project are a) introduction of the geometric phase for random light beams, b) design and experimental demonstration of the geometric-phase optical elements for the spin-controlled processing of partial polarization and partial spatial coherence of light beams and, c) to establish a spin-orbit formalism for controlling the recently found inner structure of spin in true three-dimensional light fields and to measure the structure in an evanescent wave. The project encompasses foundational theoretical, computational, and experimental research. The main site of research is the University of Eastern Finland (Joensuu).

Paola Vivo from Tampere University for the project Mind the (band)gap: nano-to-micro optimization of lead-free perovskite solar cells (PERLA). PERLA aims at a breakthrough in the rational design of lead (Pb)-free halide perovskites with a wide band-gap for high-performance solar cells. Our holistic investigation from nano-to-micro scale via computational and experimental approaches will reveal the chemistry and physics of defects of perovskites and identify the optimal device stack geometry. Finally, our unprecedented characterization at the film and device level under operational conditions will enable the advanced optimization of device stability. Our research on Pb-free perovskites of the last two years and our close interaction with top-notch perovskite research groups provide a solid scaffold for building PERLA's vision. Our results will promote the commercialization of sustainable photovoltaics.

Humeyra Caglayan and her research group. The Metaplasmonics research group members from left: Alessandro Pianelli, Anika Anu, Dipa Ghindani, Humeyra Caglayan, Jesse Pietilä, Arttu Nieminen, Rakesh Dhama, Carlos Rodriguez Fernandez and Ipek Anil Atalay.

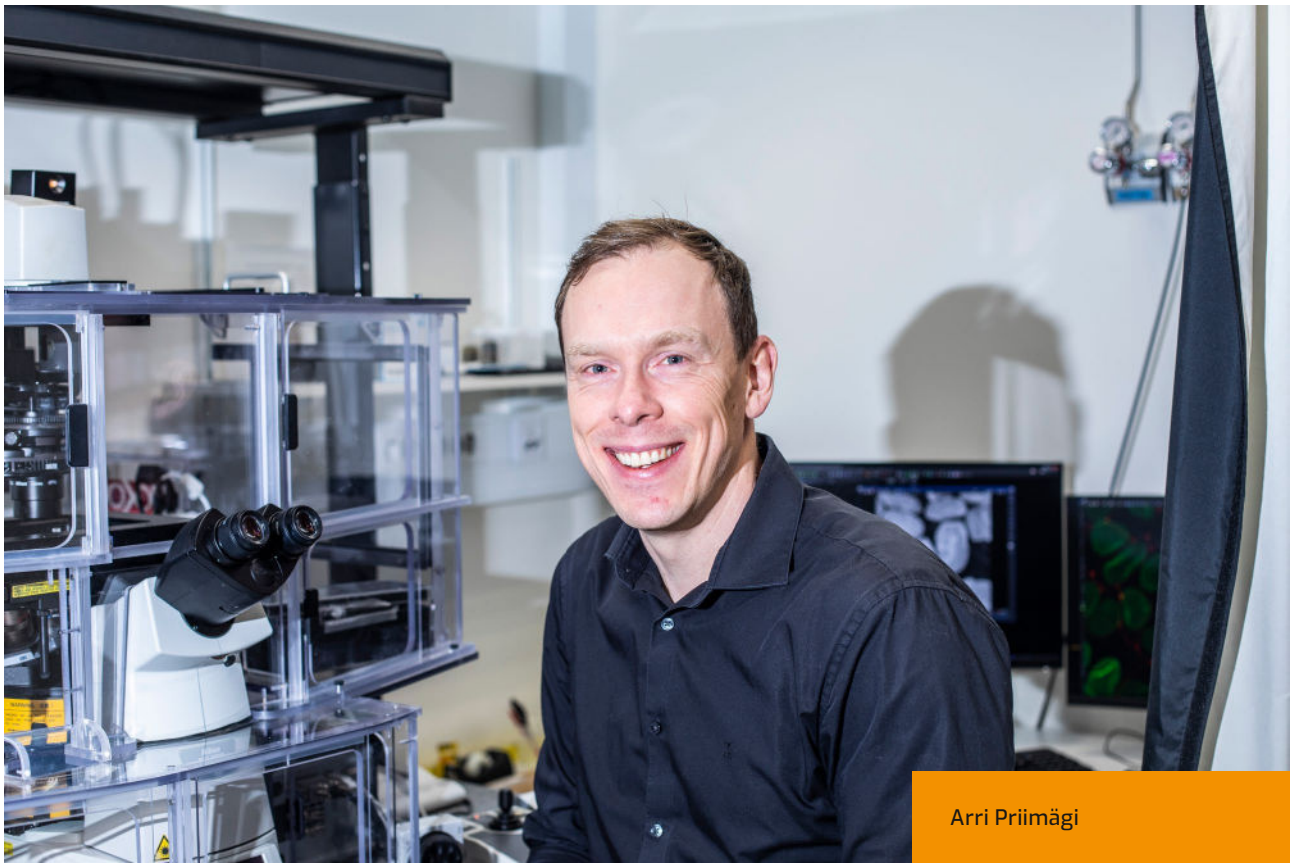
Päivi Törmä from Aalto University for the project Correlations in multiband quantum systems. The project targets to discover how the non-trivial multiband nature of a periodic lattice system affects bosonic correlations. The project combines quantum many-body theory research with optical experiments in nanostructured materials. Optical processing could offer low-energy-cost solutions for information technology whose global energy consumption is growing at an unsustainable rate, but advances have remained hindered partly by the weakness of matter-mediated effective interactions between photons. The key idea of the project is that the multiband lattice design may allow even weak photon-photon interactions to lead to strong effects on the system behavior. The expected breakthroughs are fundamental knowledge revealing how bosonic correlations can be enhanced by the lattice design, and the demonstration of the results in an optical system. The results can open the door for full-scale utilization of photons in all-optical classical and quantum information processing.

ICT project funding

In November 2022, the Academy of Finland granted funding to projects researching the sustainability and energy efficiency of future ICT solutions. The ICT 2023 programme is a joint effort between the Academy of Finland and Business Finland. The Academy of Finland has granted funding to ten projects researching the sustainability and energy efficiency of future ICT solutions. of which two photonics research projects are related to PREIN.

Humeyra Caglayan from Tampere University heads the CHIST-ERA consortium that studies novel technologies that enhance the capacity of communication networks. The project will develop a breakthrough miniaturised emitter suitable for power-efficient operation, adaptive modulation and massive production at low cost. The emitter will serve as an enabling factor for the next generation of smart free-space optical communication and light-fidelity (LiFi) networks.

Zhipei Sun from Aalto University heads the Bio-material-based photonics and optoelectronics for sustainable ICT systems consortium, Bio-Base project. The project is a collaboration with **Nonappa Nonappa's** group in Tampere University. According to the project description, photonics is widely used in our everyday lives and industry, significantly protecting our well-being, health, environment, and resources. The project aims to develop sustainable and renewable biomaterials (mainly cellulose- and nano-cellulose) based photonic devices for sustainable ICT solutions (e.g., imaging, communication, and sensing).



Arri Priimägi

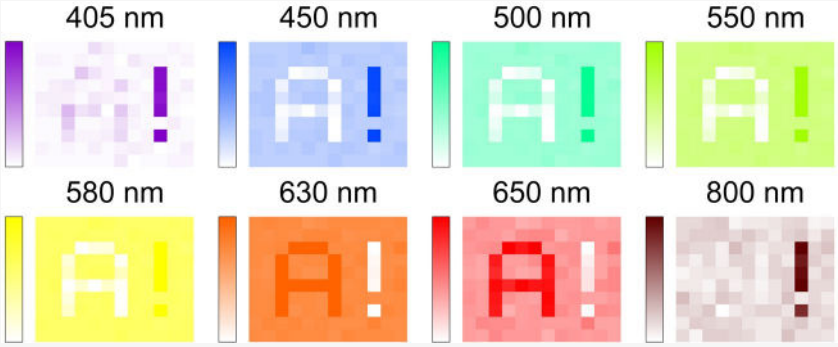
Green and Digital Transition funding

The Academy of Finland decided on funding for twelve consortia under the 2022 call for research on key areas of green and digital transition. Two of the consortia involves a PREIN research group.

Zhipei Sun from Aalto University is partner in the joint project Bright- Biotic Damage Mapping with Ultrawide Spectral Range LiDARs for Sustainable Forest Growth carried out in collaboration with the Finnish Geospatial Research Institute (FGI) in the National Land Survey of Finland and University of Helsinki. The project aims to increase the influence of healthy forests to the entire ecosystem, which is critical for the EU's climate-neutral aim by 2050. Climate-changing is increasing the amount and intensity of forest stress agents, such as drought, insect pests, and pathogens. Remote sensing techniques for forestry inventories advanced remarkably in the last decades but are still not enough to efficiently monitor the biotic damage to forests. To fully address the current remote sensing challenges, after combining the complementary skills and expertise (Integrated photonics and high-sensitivity miniaturized spectrometer in Aalto, hyperspectral LiDAR (HSL) technologies in FGI, and forest ecology in UH), this consortium will (1) advance mobile ultrawide HSLs with the integrated photonics, (2) use the advanced HSL to investigate tree health mapping, (3) develop accurate and fast modelling and mapping method assistant with artificial intelligence (AI) for sustainable forest growth.

Caterina Soldano from Aalto University is a partner in a larger Aalto University project titled "Intelligent wallpaper - Enabling sustainable wireless systems with organic electronics" involving different research groups. Reconfigurable Intelligent Surface (RIS) is a promising solution for manipulating the propagation of radio signals, with potential to improve the energy efficiency of wireless communication systems. RIS can also be used in various new applications ranging from sensing and imaging to health and biomedical monitoring. However, current RIS technology suffer from two main challenges: Firstly, there is a need to dynamically control the RIS beam-forming which requires active transceiver to be installed at the RIS increasing its complexity, cost, and energy consumption. Secondly, RIS can by physically large leading to sizeable amount of e-waste at the end of its life-cycle. In this project, we develop and demonstrate zero-power RIS which can be produced from recyclable or biodegradable materials using additive manufacturing methods

Aalto: Spectral images of the Aalto logo "A!" with the spectrometer. The red uppercase alphabet and the blue exclamation mark are distinguishable from the background. Each image represents a spectral image reconstructed at different wavelengths that cover the visible to the near-infrared range, highlighting the advantages of spectral imaging over conventional RGB colour imaging. (Image: Aalto University)



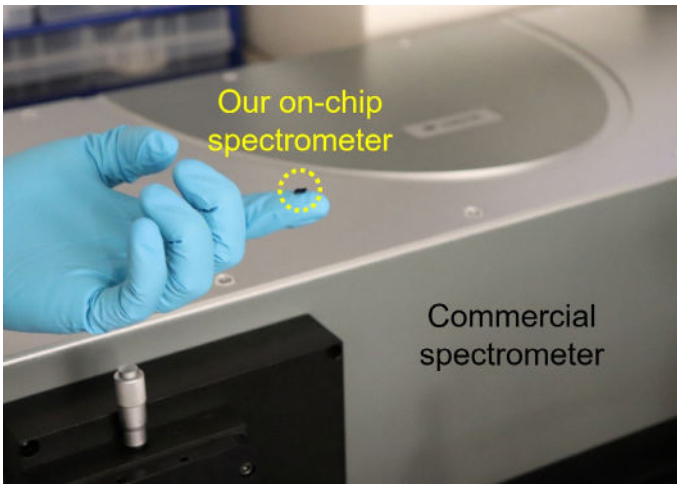
on cellulosic or recyclable thermoplastic substrates. We use optical link and organic light sensitive transistor to implement the RIS control link.

Post-doctoral Researchers

New Academy of Finland funded Post-doctoral researchers in Natural Sciences and Engineering. The Academy of Finland's Research Council for Natural Sciences and Engineering decided to fund 44 new posts as Postdoctoral Researcher, of which were linked to PREIN.

Hoon Hahn Yoon from Aalto University for the research Single-Junction Broadband Spectrometer project which aims to develop the world's smallest spectrometers with performance far beyond the current state-of-the-art miniaturized spectrometers. Futuristic spectrometer miniaturization and on-chip applications are of great benefit for applications to a wide range of innovative technologies (e.g., sub-micrometer-scale in-situ inspector, semiconductor manufacturing equipment, security sensor, military product, biomedical imager, human healthcare system, environmental monitoring tool, hyperspectral space satellites, etc.). If successful, the world's smallest high-performance spectrometers will bring a huge impact on the quality of people's daily life in many ways: healthcare, wellbeing, food, environment, security.

Mikko Partanen from Aalto University for the project titled Unified theory of optical force fields and its engineering applications. The project aims at extending the recently developed mass-polariton theory of light to inhomogeneous materials like photonic crystals and metamaterials. This will enable theoretical analysis and simulations of optical forces in micro- and nanoscale structures and the eventual design of new optomechanical devices. We will also develop the quantum field formulation of the mass-polariton theory of the spin and orbital angular momenta of light. This project will provide a solid theoretical platform for further development of spin photonics of light. We will also contribute to the optomechanical measurement of the orbital angular momentum of light and to the theoretical design and simulations of experiments probing the field-medium dynamics resulting from various optical force components.



Chip: A fingertip-sized on-chip spectrometer in the foreground compared to a commercial benchtop-size spectrometer in the background. (Image: Aalto University)

Johannes Haataja from Aalto University for the project Voltage-controlled photonic materials based on non-equilibrium liquid interfaces. The ever-increasing demand for electronic consumables and on the other hand increasing global and ecological plight creates pressure to develop

more sustainable and energy efficient display technologies. This requires new innovations in the field of dynamic nano systems and photonics. The objective of this research project is to create fast tunable photonic materials by using immiscible liquids that under favorable conditions can self-organize to light scattering structures by controlling the strength electric field. This research project will accelerate the investigations of structural photonic materials, and thus the replacement of fading and inorganic pigments with sustainable materials and development of new display technologies. This in turn increases the consumption of sustainable materials, such as cellulose, and thereby strengthens sectors like wood industry and Finnish economy.

Hongshuang Guo from Tampere University for the project Dynamic, Environment-Adaptive Light-Triggered Actuators (DELTA). Guo works in the fields of chemistry and materials science at the Faculty of Engineering and Natural Sciences. In his project, Guo investigates new methods for developing bioinspired soft robotic materials. The goal of the DELTA project is to build a new materials platform that shows self-adaptation to different environments. DELTA will produce robotic protypes, such as amphibious robots, a reconfigurable micro-gripper, and a cooperating robot team.

Rafael Ferreira Pinto do Rego Barros from Tampere University for the project Quantum frequency conversion driven by classically non-separable light. In his project, he investigates the frequency conversion of quantum states driven by classically non-separable vector beams, a novel process that can be termed Hybrid Quantum Frequency Conversion (HQFC). The process will pave a new way for controlling non-linear processes for quantum photonics applications, and it aims at revealing the thin line between classical non-separability and genuine quantum entanglement. He works in photonics at the Faculty of Engineering and Natural Sciences.

European Research Council Funding

PREIN related researchers have been awarded significant funding from the European Research Council, in November. Funding to photonics researchers linked with PREIN was granted in the Starting Grants and as an additional decision in the Proof of Concept category.

The ERC Starting Grant is for top researchers with 2 to 7 years of experience since completion of their PhD. A total of 2696 proposals were submitted in response to the ERC 2023 Starting Grant Call of which 1151 were in Physical Sciences and Engineering.

The ERC Proof of Concept Grants aim at facilitating exploration of the commercial and social innovation potential of ERC funded research and are therefore available only to PIs whose proposals draw substantially on their ERC funded research.

Hao Zeng from Tampere University received an ERC Starting Grant for the project "From light fueled self-oscillators to light communicating material networks." The 1.5-million-euro funding is directed to developing interactive stimuli-responsive materials and micro robots and a general design route to obtain communication between inanimate materials.

Arri Priimägi from Tampere University received ERC Proof of Concept grant to develop dynamic and light-responsive cell culture platforms in a collaborative project between research groups in the Faculty of Medicine and Health Technology and the Faculty of Engineering and Natural Sciences combining photonics, chemistry and bio-medicine.

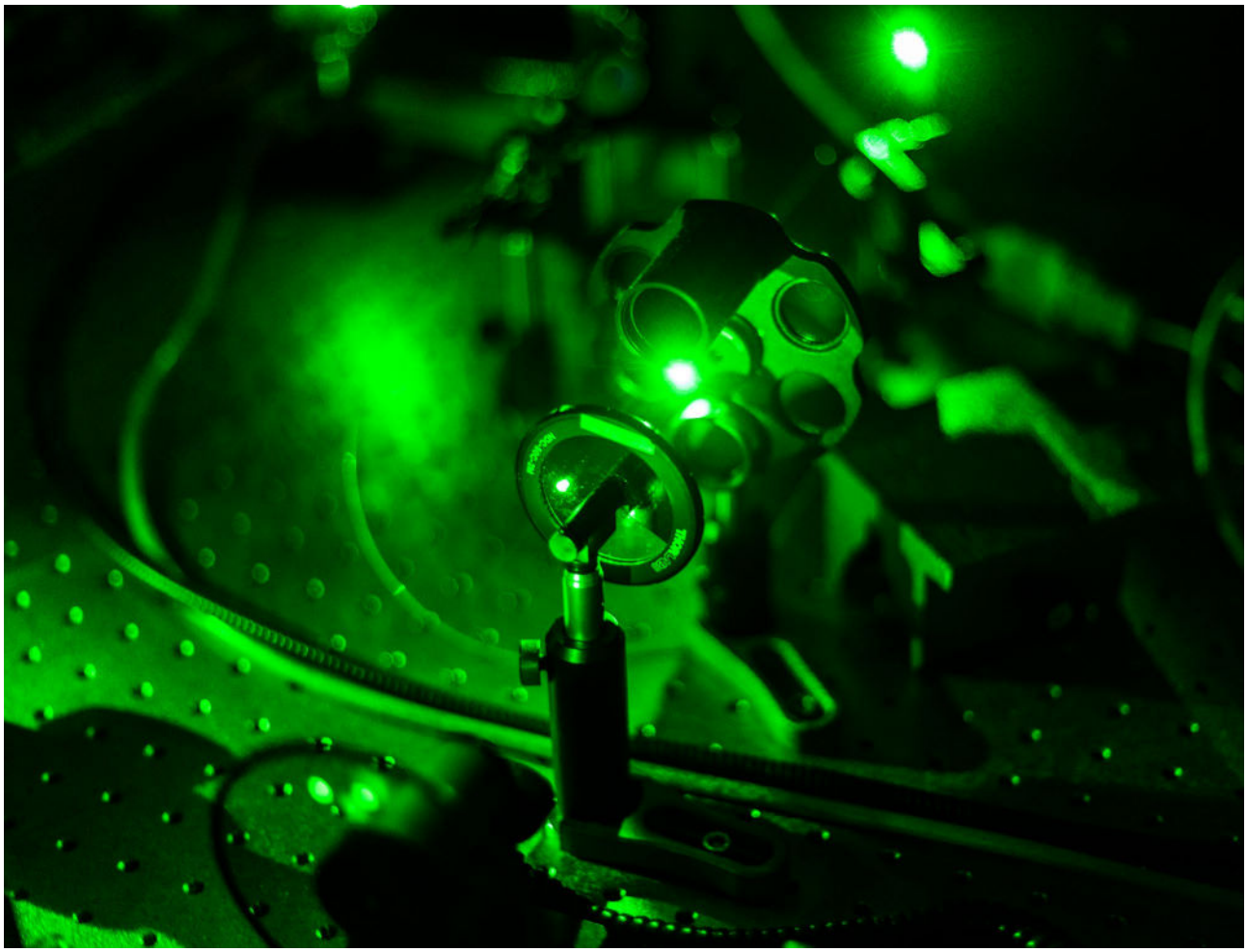
Finnish Research Infrastructure Funding FIRI

In 2022 there were two FIRI funding decision.

In February 2022, the Academy of Finland has decided on nearly 16 million euros in funding for the building and upgrading of national and international research infrastructures.

In December 2022, the Academy of Finland granted funding to 19 research infrastructure projects. The projects will be carried out in different parts of Finland and will have impact both locally and regionally. The funding supports the upgrading or construction of local research infrastructures and puts emphasis on targets related to the green and digital transition. The funding was granted based on Finland's national Recovery and Resilience Plan (RRP).

The funding was divided between five research infrastructures. The joint infrastructure of Otanano between Aalto and VTT was funded in the first decision and the UEF photonics related infrastructure project in the second call.



OtaNano – Otaniemi micro- and nanoscience and -technology

The joint infrastructure on Aalto University and VTT Technical Research Centre of Finland Ltd received funding for the COMQURE- project, which aims to strengthen OtaNano's state-of-the-art services for academia and industry nationally and internationally. Specifically, this project aims to tackle the growing complexity, resolution and control requirements in following areas:

1. high resolution microscopy for nano- and 2D materials science and technology
2. measurement capabilities for advanced quantum technology
3. process analytics for improved quality of complex nanostructured devices

The practical implementation of the project focuses on strategic investments, which allow characterization, measurement and monitoring of growingly complex nanoscale structures, systems and processes.

University of Eastern Finland Photonics and Materials Research Infrastructure: Printable Luminescent Materials

Infrastructures are essential in the research and education in natural sciences such as physics and chemistry. The rationale of the Printable Luminescent Materials infrastructure (PRILUMAT) is to replace existing, out-of-the-date pieces of equipment and to get new research started on the 3D printing of tailored luminescent materials. The research will aim to various novel applications in lighting, luminescent solar concentrators, waveguide-based sensing, and switching in optical data transfer. These solutions will support both digitalization and green transition, the ultimate goals of Horizon Europe. Furthermore, the equipment and services enabled by them will be available for the local companies via the existing infrastructure organization of the University of Eastern Finland.

Innovation

The results in scientific, societal and educational impact in 2022 have been on a high level with significant developments gained during the year. Funding for scientific research topics and groups received in 2022 shows that the scientific level and its impact is extremely high in the flagship. Photonics researchers and research groups linked to PREIN were highly successful in the 2022 Business Finland, Academy of Finland and European Research Council funding applications demonstrating also economic impact. There were several projects running for the commercializing of research in 2022. The number of invention disclosures was 27 in 2022 and there were 6 filed patent applications in 2022.

Business Finland Research to Business funding

Research to Business (R2B funding is intended for researchers and research groups in universities and other research organizations who want to build new business based on their research and commercialize their idea. The project must have several commercialization options – the entity who commercializes the idea cannot be known at the start or during the project. The actual product and business development occur after the project either within a new company being established, or as a new business activity in an existing company.

In 2022 R2B funding was granted to **Zhipei Sun** from Aalto University for the project A-GATE. The project aims to research high-efficiency miniaturized hyperspectral imaging sensors for commercialisation preparation. The impornatnce of the project lies in the fact that hyperspectral imaging technologies are expected to be used in our daily life in applications in astronomy, agriculture, molecular biology, biomedical imaging, geosciences, physics, and surveillance.

Industry Collaboration

Economic impact and industrial collaboration are increased mainly through a tight collaboration with Photonics Finland as PREIN and Photonics Finland continue to increase and tighten their cooperation.

Zhipei Sun

New Photonics Start-ups

Photonics Center – Collaboration for Business and Research, based in Joensuu

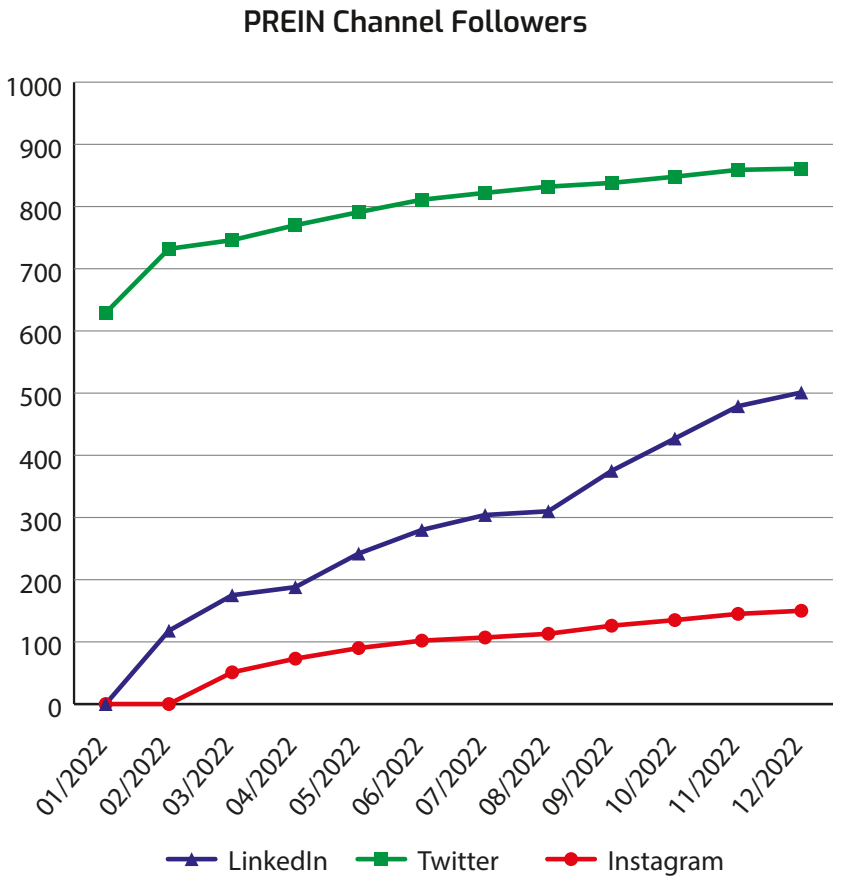
One of the major infrastructural investments from the PREIN partner University of Eastern Finland and its regional partners has been the new Photonics Center Oy (a non-profit company) in Joensuu. The parties of the Photonics Center Agreement are the City of Joensuu, Business Joensuu, University of Eastern Finland, Karelia University of Applied Sciences, Riveria Training Consortium, University Properties of Finland, and the Regional Council of North Karelia. The Center was officially opened in 2022.

Societal Impact

PREIN's communication activities aim to increase the visibility and understanding of general public on the importance of photonics in Finnish education and industry. As the current trend of the ways of receiving and following news is very much scattered, it is important to be present in the most relevant online channels. In addition to previous social media channels (website, Twitter), PREIN also introduced PREIN channels in Instagram, LinkedIN and YouTube in 2022.

Most news were promoted shortly in Twitter, LinkedIN, Instagram and linked to more extended news stories in the PREIN website. Some individual news was published also in the printed media, such as Fotoni and Helsingin Sanomat Teknologialiite.

In 2022 PREIN Twitter followers increased by 27%, YouTube views were nearly 2000, the Instagram channel gained popularity especially among students, LinkedIN followers got up to over 500 from zero the audience including mainly researchers (24%), people working in education (12%), engineering (11%), business development (11%) and the rest of the followers from several various fields.



OUTREACH 2022

The aims to increase the visibility of photonics and educate the public about the possibilities light-based technologies can offer are important for PREIN and therefore PREIN participates in events targeted at the general public and arranges activities targeted at children and youngsters. In these activities PREIN partners with the outreach experts in the partner organizations and the photonics industry's umbrella organization Photonics Finland.

There are certain outreach activities which have become reoccurring and part of the annual activities of both PREIN and its partners. In addition, there are events organized by other organizations in which PREIN participates in. The target groups of each event also vary. In 2022 the Week of Light event in May was targeted at pre-school and primary school students, whereas Shaking up Tech and the Researchers' Night were aimed at students in secondary school.

Week of Light Events 2022

To celebrate the International Day of Light on May 16, PREIN and the LUMA collaboration partners, Juniversity, Aalto Junior and LUMA Center Eastern Finland organized several on-line events. The thematic week called "Valon viikko" was directed at children, young people, schools and teachers. The event was a part of the official program of the International Day of Light, IDL 2022 to increase the national visibility. All the LUMA partners promoted the activities to their contacts and to local schools. Juniversity organized Hehkun Värikkäät tunteet -workshop for pre-schools. Aalto Junior provided a workshop on building your own spectroscope intended for primary school children. LUMA Eastern Finland produced a workshop on light and color for pre-school groups. The workshops were organized on-line reached almost 700 participants during the week.

Suomi Areena 2022

Suomi Areena 2022

PREIN and Photonics Finland participated in Suomi Areena, one of the most popular events on politics, society, culture and sports in Finland. The panel discussion hosted by **Kirsi Alm-Siira** live in Pori on July 11, 2022, was also broadcasted on MTV3 network and channel. The topic of the panel discussion was Light cures! – Break-through technology photonics revolutionizes healthcare (Valo hoitaa! – Läpimurtoteknologia fotoniikka mullistaa terveydenhuollon). The main theme was focused on applications of photonics in preventive healthcare, well-being monitoring and cancer treatments.

Speakers of the panel discussion included
Antti-Pekka Elomaa, Specializing physician, KYS Neurocenter neurosurgeons
Jukka-Tapani Mäkinen, Optics lead, Oura Health Oy
Paula Risikko, Member of Parliament, National Coalition Party (Kokoomus)
Petteri Uusimaa, CTO, Modulight Oy

Tutkijoiden yö (TAU) – Researchers' Night

In September The Researcher's Night event of Tampere University was organized in collaboration with PREIN and Juniversity. The Tampere University event held in Nokia Arena included workshops and demos for upper secondary and high school students. On this occasion, workshops and demos were organised by PREIN researchers showcasing photonics and related applications. Professor Juha Toivonen was the speaker in the Researcher's Cafe discussion event closing the event. There were over 200 enthusiastic participants in workshops, pop-up demos and presentations.

Shaking up Tech

Shaking up Tech was organized in November 2022 in Aalto University. The goal of the Shaking up Tech event is to indicate that young women have more than enough expertise and skills to study technology. The partners of the event include a range of businesses that share the same goal. Technology is the field of the future and there is already competition in the labor markets for competent women. Aalto University organized a photonics themed workshop "What can you define with the light?" at the Shaking up Tech event.

Sponsoring StarT Competition for Schools

In 2022 PREIN collaborated with LUMA Suomi in the national StarT science competition. PREIN sponsored the prize for light-related competition submission. PREIN gave with a monetary prize and donated a Photonics Explorer Kit to the winning school whose competition work utilized light.

Photonics Explorer Kit Campaign

The Photonics Explorer Kit campaign launched on the International Day of Light in 2020, continued also in 2022 and PREIN and Photonics Finland renewed their commitment of donating one kit each for all the private or company donations made.

Professor Juha Toivonen in the Researcher's Café -discussion.

PRIZES AND ACKNOWLEDGEMENTS

In 2022 there were several significant prizes awarded to PREIN members and PREIN members were nominated for honorary positions and elected to significant representative roles internationally. On the national level, prizes for scientific and industrial achievements were given at the Optics and Photonics Days. In addition, several researchers received poster awards in international conferences and were awarded funding from foundations.

Photonics21 representatives

Two PREIN-related representatives were elected in 2022 as new members into the Board of Stakeholders of Photonics21. The Board of Stakeholders consist of a hundred members and is the main decision-making body of the platform and it has a significant input in decision-making regarding EU funding for the industry. The new members Professor **Jyrki Saarinen** and **Juha Purmonen** represent University of Eastern Finland and Photonics Finland. **Tauno Vähä-Heikkilä** from VTT continues as the third Finnish member in the Board.

Science Academy of Finland nominations

The Finnish Academy of Science and Letters is a broad-based learned society the members of which are invited based on scientific merits. In 2022 The Science Academy of Finland announced 31 new members. Professor **Zhipei Sun** from Aalto University and **Nikolai Tkachenko** from Tampere University were invited as new members in the field of natural sciences.

European Optical Society EOS Fellowship

The European Optical Society is a non-profit society, and an umbrella organization for all national optical societies around Europe. Professor **Goëry Genty** from Tampere University was nominated EOS fellow, the highest category of membership, for his achievements in ultrafast photonics and remarkable experiments on nonlinear phenomena in optical systems.

Finnish Photonics Company of The Year and Best Doctoral Dissertation

The national annual prizes were awarded at the Optics and Photonics Days in September 2022 in Tampere.

Dispelix Oy was named the Company of the Year. Dispelix Oy is an advanced waveguide designer and manufacturer producing visual solutions for consumer as well as enterprise AR and MR wearables. Dispelix product development and a large part of its operations are based in Finland. The company has grown rapidly and recruited experts in the photonics field not only in Finland but also internationally. In addition, Dispelix has actively participated in the advancement of the Finnish photonics community.

The doctoral thesis of Antti Moilanen titled "Bose -Einstein condensation in plasmonic lattices" Aalto University was chosen as the photonics dissertation completed in 2021. The best dissertation is selected by Photonics Finland's academic advisory board with all universities conducting photonics research in Finland are represented. Moilanen's dissertation was the only one that received full marks from all evaluators for the scientific impact of the work.

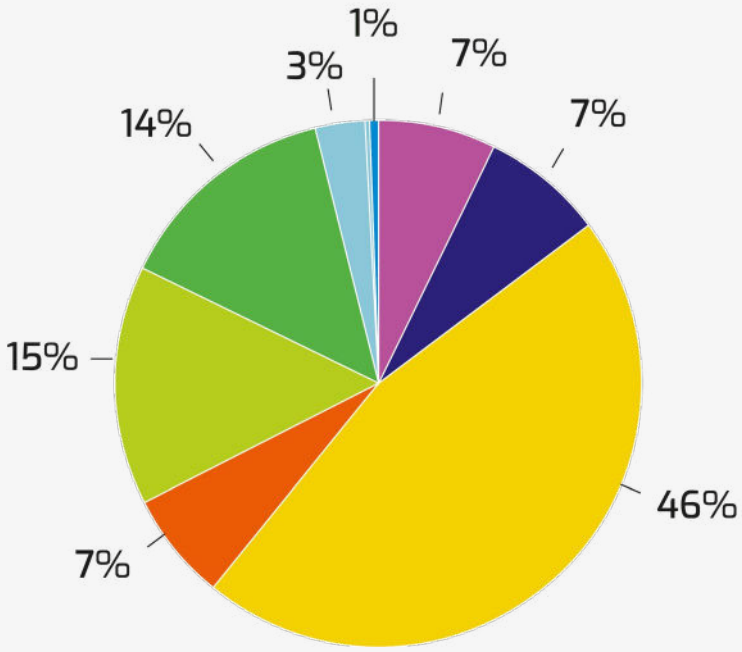
Juha Toivonen and Juha Purmonen representing PREIN and Photonics Finland awarded Antti Sunnari, the CEO of Dispelix the Company of the year award.

FUNDING 2022

The total funding of PREIN in 2022 reached its all-time highest level with 54,5 million, of which 50 million euros was from other sources and 4 million from the Academy of Finland Flagship program funding. The main source of funding for the Flagship is the institutional funding from the partner organizations constituting almost half of the total funding (46%). The proportion of institutional funding has declined slightly as PREIN has been able to secure more external funding. There are no major changes in the funding sources but the growth during the program period has been steady. The proportions of other Academy of Finland funding and EU funding have remained on a stabile level, whereas funding from Business Finland slightly decreased in 2022. The most significant change is the increase in company funding rising to 7,4 million and 14% of the overall funding in 2022. Funding is reported based on the utilized funds.

FUNDING SOURCES	
Academy of Finland Flagship Funding	4 M€
Other Academy of Finland funding	4.1 M€
University/research institute's funding	25.2 M€
Business Finland	3.6 M€
EU	8.0 M€
Business companies	7.5 M€
Other Finnish	1.7 M€
Other foreign	0.1 M€
External in-kind contribution to the flagship	0.3 M€
Total	**54,5 M€**

2022 funding sources



- ACADEMY OF FINLAND FLAGSHIP FUNDING
- OTHER ACADEMY OF FINLAND FUNDING
- UNIVERSITY/RESEARCH INSTITUTE'S FUNDING
- BUSINESS FINLAND
- EU
- BUSINESS COMPANIES
- OTHER FINNISH & FOREIGN
- EXTERNAL IN-KIND CONTRIBUTION TO THE FLAGSHIP

PREIN

Photonics Research
and Innovation

prein.fi

prein-photonics-research-and-innovation-flagship

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FLAGSHIP PROGRAMME

ACADEMY OF FINLAND