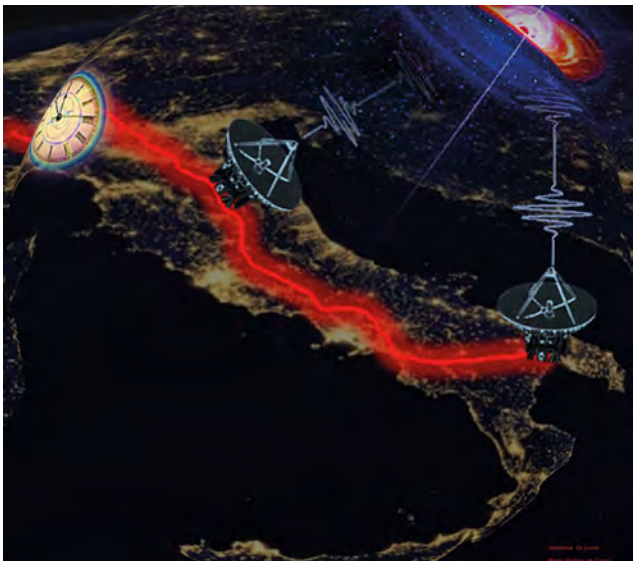
Photonics in Italy

Italy can boast a very diversified and lively panorama of educational, research and industrial activities pivoted about Optics and Photonics. Significant advancements in laser technology, optical communication, and optical materials are driving innovation in healthcare, manufacturing, agrifood and generally in promoting digital transition. The National Recovery and Resilience Plan is expected to greatly enhance the country competitiveness on a global scale.



A pictorial view of the VLBI experiment between Matera and Medicina using the Italian Meteorological Institute (INRIM) clock on the Italian Quantum Backbone https://doi.org/10.1364/OPTICA.393356
Credits: Valentina Di Sarno (CNR) and Mario Siciliani de Cumis (ASI)

https://doi.org/10.1051/photon/202412519

Emiliano Descrovi[1]*, Roberta Ramponi[2], Luca de Stefano[3]

[1] President-elect of the European Optical Society, and Politecnico di Torino
[2] Vice-President Photonics21, President AEIT-CORIFI; Politecnico di Milano
[3] President of the Italian Society for Optics and Photonics (SIOF); CNR-ISASI

***emiliano.descrovi@polito.it**

Historical notes

Starting from the early works of Francesco Maria Grimaldi on the diffraction of light in the XVII century, optics has played a significant role in the development of scientific culture in Italy. In the post-World War I period, and more prominently, after World War II, Italy has witnessed a strong boost in both fundamental and applied research in optics. In 1927, the Regio Istituto Nazionale di Ottica was founded, based in Arcetri, Tuscany. Beside carrying out research activities, the new institute played a key role in spreading and disseminating knowledge on optical technologies across the Italian industrial environment at the beginning of the century. In the same period, the Consiglio Nazionale delle Ricerche (CNR), the largest public research institution in Italy, was founded in Roma. After several decades, the Istituto Nazionale di Ottica (INO), with headquarters in Sesto Fiorentino, merged into CNR in 2005, along with the Istituto per i Processi Fisico-Chimici of Pisa and the Centro su Bose-Einstein Condensation of Trento. Nowadays, CNR-INO is active on several sites, including Brescia, Lecco, Napoli, Pisa, Trento and Trieste.

In early 60s, Orazio Svelto started his pioneering works on the development of solid-state and ultra-short pulse laser sources at the Politecnico di Milano. Following the growing interest in the emerging field of laser technologies, the Center for Quantum Electronics and Electronic Instrumentation of CNR was then established and later integrated within the current Institute for Photonics and Nanotechnologies (IFN) together with the Institute of Solid State Electronics of Rome, a CNR Center for material science in Trento, a Centre for ultrafast spectroscopy in Milano and two Innovation Laboratories (in Padova and Bari) belonging to the Istituto Nazionale di Fisica della Materia (INFM). Meanwhile, a growing scientific interest in optics and photonics has led to consolidating research lines in the Physics and Engineering departments in various universities spread across the country, the most prominent being La Sapienza in Roma, the University of Napoli Federico II, the University of Pavia, Padova, Brescia, the University of Trento, University and Politecnico of Bari, as well as the Universities of Pisa and Firenze. At the latter, in early 90s, the European Laboratory for Nonlinear Spectroscopy (LENS) was established, targeting activities mainly focused on biophotonics, materials for optics, and, more recently, quantum technologies.

Thanks to such a solid background, Italy has emerged as a worldwide recognized country performing excellent

research in the science of light, also providing a fertile ground for innovation and technological development in the fields of optics and photonics.

Photonics research and education in Italy today

Nowadays, research in photonics is very diversified in Italy, covering all traditional topics whilst continuously expanding toward new investigation and application areas. Through a network of world-renowned research institutes, cutting-edge universities, and international collaborations, thousands of Italian scientists are currently contributing to advance knowledge in crucial sectors such as quantum photonics, optical communications, biophotonics, nanophotonics, ultrafast photonics and laser technologies (including laser material processing and manufacturing). Such a vibrant activity relies on the indispensable technological support from large clean-room facilities such as PoliFab in Milano, Fondazione Bruno Kessler (FBK) in Trento, Inphotec in Pisa and NanoMicroFab (CNR facility) in Roma, and the expertise developed in semiconductor physics, material science and nanotechnology on the one side, developed in institutes such as the CNR Istituto Officina dei Materiali (IOM) and the Istituto di Struttura della Materia (ISM). With robust support from the national and regional governments, the European Union and several other funding agencies, photonics research in Italy continues to thrive, fuelled by scientific curiosity, a marked creativity, and commitment to addressing global challenges through advanced optical solutions.

Environments facilitating the cooperation among institutions such as CNR, universities, public-private organizations under a common roof are big fund attractors and play a prominent role on the national and international scene. As a remarkable case, the Milano area is witnessing an intense growth of sparkling research and entrepreneurial activities pivoted around Politecnico di Milano, CNR-IFN, Italian Institute of Technology (IIT) and University of Pavia, mainly focused on optoelectronics (with a prominent role played by STMicroelectronics), laser technologies (e.g. the CUSBO centre, part of the LaserLab Europe network), integrated photonics, nanophotonics, sensors and quantum optics. A bit more than a hundred kilometres west from Milano, the Politecnico di Torino, together with the Links foundation represents an excellence pole for optical communications. Still in Torino, the National Institute for Metrological Research (INRiM) is active in the fiber-based distribution of optical time-frequency references to various end-user such as LENS. INRiM has built the Italian Quantum Backbone, a 1800 km long fiber-based infrastructure covering the entire national territory, from Matera to the French border.

In North-east Italy, a significant research activity in optics and photonics is carried out at the Universities of Padova and Trento, the latter being particularly interesting because of the successful collaboration with FBK on optical materials, photonic devices and sensor technology. In Trieste, the Area Scientific Park hosts the ELETTRA synchrotron, the FERMI source (Free Electron laser Radiation for Multidisciplinary Investigations) and CNR-IOM.

Tuscany has a long tradition in optics too: the Scientific Pole in Sesto Fiorentino, close to Firenze, hosts vast infrastructures for institutes such as LENS, the CNR Istituto di Fisica Applicata (CNR-IFAC), the above mentioned CNR-INO and the Physics department of the University of Firenze. In Pisa cutting-edge research on integrated light sources, semiconductor heterostructures, THz emission, optomechanical systems is performed at the NEST Laboratory (joint infrastructure involving Scuola Normale Superiore, Scuola Superiore Sant'Anna, CNR-Nanoscienze, IIT) and the University of Pisa. Non-linear optics, optoelectronics, quantum optics and complex media photonics are some of the topics investigated by research institutions in the Rome area, including La Sapienza, Roma Tre, Istituto Sistemi Complessi (CNR-ISC) and CNR-Nanotec. In 2006, the Lazio region funded The Centre for Hybrid and Organic Solar Energy (CHOSE), with the strong involvement of the University of Roma Tor Vergata. Within the CNR "Area di Ricerca Tor Vergata" photonics is within the activity portfolio of institutes such as CNR-IFN, ISM and IMM.

Optical biosensing, structured light and digital holography are among the most relevant core expertise specifically developed, at the Institute of Applied Sciences and Intelligent Systems (CNR-ISASI) and the University Federico II, in the Napoli area. Fundamental research of polaritonics, at the edge between semiconductor physics and photonics, is carried out at CNR-Nanotec in Lecce. The University of Catania is an excellence centre for Silicon photonics and optoelectronics, also thanks to the synergic collaboration with STMicroelectronics (whose facilities have been recently empowered).

Last but not least, we mention research centres and institutes carrying out research and development in Optics and Photonics at different levels, from materials (Istituto per lo studio dei Materiali Nanostrutturati CNR-ISMN), to space applications (Agenzia Spaziale Italiana ASI; the Istituto Nazionale di Astrofisica INAF).

At Italian universities, Optics and Photonics are widely addressed in many teaching programmes, mainly within Physics and Engineering tracks. Generally, a fundamental scientific background is provided at the Bachelor level (Laurea Triennale), while the educational offer becomes more specialized at the Master level (Laurea Magistrale). Worth to mention a bachelor-level degree called Laurea in Ottica ed Optometria, available at several institutes such as the University of Torino, Milano Bicocca, Roma Tre, Firenze, Padova, Napoli Federico II, Perugia, Palermo and the University of Salento. At a higher level, education in Optics and Photonics is offered either as specialized tracks of the Master of Science (sometimes called "curricula") within Physics, Engineering Physics, Electronic Engineering, Telecommunication Engineering majors, or self-standing

post-laurea masters, such as the Optics and Quantum Information master at the Sapienza, University of Rome. Master lectures are often given in English, with international student cohorts resulting from agreements in the framework of university networks and mobility programs such as the Erasmus Mundus.

As third-level or post-secondary education is concerned, in addition to traditional 3-year PhD tracks within research groups at universities or research centres, industrial PhD options have been recently introduced, after the boost from PNNR (Piano Nazionale di Ripresa e Resilienza), launched in 2021.

In order to further reduce the gap between universities and industries, several careers counselling initiatives are often organized at a local (often, regional) level. Worth to mention the participation of the Politecnico di Milano to the EU-funded consortium CARLA (2020-2023) and its updated version CARLA 360 (2024-2027), wherein outstanding research/educational institutes, innovation hubs and scientific societies facilitate the creation of new opportunities for the development of early-stage careers in Photonics at the European level.

National initiatives and networks

In recent years, several relevant actions have been undertaken by the central government to support university missions (i.e. research, education, knowledge dissemination and transfer), to facilitate collaborations with research institutes (e.g. CNR) and promote the creation of new entrepreneurial initiatives.

The Fondo Italiano per la Scienza (FIS) supports basic research in the framework of excellent research program replicating an application scheme from the European Research Council. FIS has made available 50 MEUR in 2021, that have increased to 150 MEUR yearly, starting from 2022. Other funding opportunities include the Fondo per gli Investimenti nella Ricerca Scientifica e Tecnologica (FIRST) and the periodic calls for proposals under the PRIN program (Progetti di Rilevante Interesse Nazionale). For example, in PE areas, about 865 MEUR have been provided across two calls in 2022.

The program named Dipartimenti di Eccellenza represents an innovative intervention with a strong financial support started in 2017, aiming at identifying and funding, on a five-year basis, the top 180 departments in public universities. These are departments distinguished by the quality of research produced and the quality of the development project, assessed according to quantitative parameters. In the period 2018-2022, 1.36 billion euros have been distributed. Among the beneficiary departments exhibiting a significant activity in optics and photonics, we recall the Physics departments at the University of Padova, Pavia, Pisa, Roma La Sapienza, Milano Bicocca and the department of Industrial, Electronic and Mechanical Engineering at the University of Roma Tre, collecting estimated funds amounting to about 7.9 MEUR overall.

Starting from mid-2021, the Italian Government has launched the implementation of one of the most massive funding and investment programs in the last decades, the so-called PNRR, supervised and coordinated by the Ministry of Economy and Finance. PNRR constitutes the Italian implementation of the Next Generation EU program, targeting the attenuation of the socio-economical impact of COVID-19 pandemic. Among the extremely varied and diversified investment portfolio, photonics plays a prominent role in the several initiatives.

The Photonic Platform for Quantum Technologies within the new National Quantum Science and Technology Institute (budget 116 MEuro) promotes fundamental research on the interaction between non-classical light and matter, in order to design single-photon sources, and new schemes for quantum-light manipulation and detection. Applications include the whole spectrum of QST applications from quantum communication to the simulation of quantum chemical and physical systems.

Photonic and Quantum technology constitute the core of I-PHOQS, a network of important national research infrastructures providing a unique integrated, interdisciplinary, and multifaceted approach to address complex scientific and technological issues. I-PHOQS offers full access to national and international users from the academic and industrial world, designed to promote interdisciplinary research in most areas of science.

Lastly, within the RESTART program (budget 118 MEuro), the largest national partnership for research and innovation in telecommunications, the spoke called “Pervasive and Photonic Network Technologies and Infrastructures” focuses on radically new technologies and paradigms for ultra-fast optical transport in the metro-core network, programmable, green, and ultra-fast interconnections between sites supported by optical transport and the design and fabrication of novel components and photonic integrated circuits for the optical networks domain.

Innovation and Industry

Optical technology and photonics are among the most widely used technologies in our daily lives, with countless applications. Photonic technologies trigger innovation in traditional production processes in various sectors: healthcare, manufacturing, agri-food, mobility and energy, security, space and defense, and digital infrastructure. In 2022 Italy has reached a record number for published patent applications to the European Patent Office (EPO), with a 5% increase with respect to the previous year (UnionCamere and Dintec data report). Since 2016, the number of filed patent applications is constantly growing, reaching a net increase of about 33%, a number that confirms a remarkable creative activity at the national scale. Furthermore, 20% of the 2020 Italian patents relate to enabling technologies, advanced manufacturing in particular. A significant growth of the photonics domain is also reported, with 74 patents filed in 2020.

EPR	A61	G01	C07	C12	H01	G06	B01	C08	A01	H04	B60	H02	G02	C01	A23
Consiglio Nazionale delle Ricerche - CNR	101	472	462	383	132	275	71	192	195	80	43	11	6	83	59
Politecnico di MILANO	96	272	371	78	40	110	165	99	76	24	130	124	49	51	29
Agenzia Nazionale per le Nuove Tecnologie, l'energia e lo Sviluppo Sostenibile - ENEA	100	19	96	24	14	44	11	33	5	13	2	9	9	4	32
Politecnico di TORINO	95	175	186	0	9	66	108	46	15	23	57	80	74	9	6
Fondazione Istituto Italiano di Tecnologia	120	313	99	54	50	54	41	17	37	12	4	0	16	38	27
UniversitÃ degli Studi di BOLOGNA	76	238	107	76	120	26	45	48	67	88	24	11	14	3	9
UniversitÃ degli Studi di PADOVA	27	338	96	83	120	66	67	16	12	31	43	4	55	8	8
UniversitÃ degli Studi di ROMA "La Sapienza"	60	293	129	89	159	49	38	25	12	16	32	12	20	18	26
UniversitÃ degli Studi di MILANO	82	289	63	180	95	14	23	32	39	40	3	0	0	0	3
UniversitÃ degli Studi di PISA	61	128	84	61	25	21	30	9	24	12	4	4	4	8	0
UniversitÃ degli Studi di GENOVA	23	113	63	66	32	5	12	17	18	6	9	6	17	2	2
UniversitÃ degli Studi di FIRENZE	48	133	91	51	31	24	20	2	0	13	17	15	3	18	0
Scuola Sup. di Studi Univ. e Perfezionamento S.Anna di PISA	93	247	51	5	12	3	27	3	2	5	18	17	11	4	0
UniversitÃ degli Studi di TORINO	28	218	58	24	80	0	17	8	11	10	8	0	0	0	0
UniversitÃ degli Studi di MILANO - BICOCCA	16	115	50	86	33	54	29	21	41	12	5	28	4	8	4

In the table above, the number of patents filed in various Intellectual Property Classification (IPC) areas is shown for the 15 largest Italian research institutions (source, Patiris-MISE). The IPC code G02 refers to "Optics" and certainly represents an underestimation for the whole Photonics domain.

According to the Market Data and Industry Report 2020 (source Photonics21, Tematys), photonics embraces about 200 companies in Italy with 150000 employees overall. As a mere illustrative and non-exhaustive list, we mention Think Quantum, OST-Optical Sensing Technologies, CareGlance, EYE4NIR, NIREOS, Cambridge Raman Imaging, Dynamic Optics, PioNIRS, Optosensing, PhotonPath, Julight, L-pro Antares Vision Group, OptoSmart, IPG Photonics Italia, Bright Solutions, Officina Stellare, Nirox, LithiumLasers, MicroPhotonDevices, Optoprin, Prima Industrie, Adige S.p.A. (BLM Group), Kirana, SM-Optics, Quanta System, ElEn, iGuzzini, TASI (Thales AleniaSpazio Italia), Ericsson, SAES Getters, Convergent Photonics, Laser Point, OPI Photonics, Cordon Electronics Italia, Univet.

Industrial production is estimated as 5.2 billion euros, constituting a 5% share on the European total production. Major sectors of Photonics production are: (1) Defence & Security, with Leonardo playing a major role, also in aerospace; (2) Laser machines and systems for imaging and optical measurement in industrial environment, such as barcode scanners and related equipment provided by Datalogic, the third-largest manufacturer in this segment; (3) Environment, energy and lighting, with many lighting companies producing LED-based lamps and modules; (4) Mobility, in particular automotive lighting, wherein Hella and Marelli Automotive Lighting have prominent role; (5) Healthcare, for example, spectacle lenses and contact lenses provided by Hoya and Essilor, plus many SMEs focused on imaging systems.

Beside big industrial actors promoting partnerships with universities and research centres (worth recalling the agreement of EssilorLuxottica and Politecnico di Milano for the first joint Smart Eyewear Lab, providing initial investments of over 50 MEUR), there are dozens of incubators and start-ups accelerators spread across the whole country. In this complex scenario, a new initiative called Fotonica District has been recently launched as an industry association with the mission of promoting the excellence of Italian Photonics. In particular, it aims at gathering all national innovative photonics SMEs, giving them support in terms of services and fund raising opportunities. Additional support for innovation is provided by the European Union, through successful initiatives such as PhotonHub and having Confindustria Toscana, CNR, Scuola Superiore Sant'Anna, CNIT, El.En (Italy's leading laser technology company), and Leonardo as Italian partners.

Currently, a significant boost to industrial innovation is provided by the above mentioned PNRR plan, through the creation of so-called Innovation ecosystems. A total investment of 1.3 billion euros is made available to facilitate networks of universities, public research institutions, local public bodies and other highly qualified public and private entities to operate in technological areas consistent with the regional vocations. As an example, the Innovation Infrastructure QMPI - Innovation Infrastructure on Quantum, advanced Materials and Photonics coordinated by Scuola Superiore Sant'Anna will be realized at the Sant'Anna Campus in San Giuliano Terme over about 3800 square meters equipped with a large clean room, laboratories and offices. Being rather pervasive in many different PNRR projects dealing with innovation and business creation, the Photonics sector is expected to grow sensibly in the next few years.

Coordination activities and scientific dissemination

In the complex scenario depicted above, coordination activities are of paramount importance to keep tight contact with funding agencies and to disseminate results toward the scientific community and the general public.

AEIT-CORIFI (COordinamento Ricerca Innovazione Fotonica Italia) was founded in 2014 as the national mirror of the European Technology Platform Photonics21. It gathers individual members, both from academia and public research institutions and from industries and collaborates with professional societies in the field of Optics, Photonics and Laser Manufacturing. In synergy with Photonics21, it contributes to the promotion of research and innovation in Photonics at the European and National level, participating at the preparation of European vision papers and strategic research agenda, interacting with national and regional/local institutions, and organising topical events to bring together photonics scientists and industrial players with end-users, policymakers, and general public.

The IEEE Photonics Italy Chapter was founded in 1997, then as LEOS Italian Chapter. It currently has 130 members and an Executive Committee of 17 members from universities, research centers and industries in Northern, Central and Southern Italy.

Every year it carries out dozens of activities aimed at promoting photonics, such as seminars, workshops and conferences, professional development activities, awards for young people, and dissemination activities.

The Italian Society for Optics and Photonics (SIOF, Società Italiana di Ottica e Fotonica) was founded in 1991 with the goal of promoting the research activities in the field of optics and photonics and coordinate them all over the national territory by favouring the spread of knowledge and the organization of scientific events, schools, conferences, and workshops, with a special emphasis on the formation of young scientists. SIOF is governed by a council of 12 members elected, and active members are currently over 300 distributed all over Italy with members also from abroad. SIOF is in charge of one of the most important conferences in Italy, the Italian Conference on Optics and Photonics (ICOP), organized every other year with the support of IEEE Photonics Society and other organizations.

In addition, there are several organizations and associations of students and researchers connecting optics and photonics scholars and facilitating the creation of networks of scientists. Societies such as Optica, SPIE, EPS and EOS support activities through local chapters in Napoli, Roma, Trento, Padova, Milano, Messina, Pisa, and Torino.

Future directions

As witnessed by the complex scenario depicted above, Photonics is probably one of the most powerful engines for innovation of this century. In order to fully deploy its potential and create a beneficial impact on the national economy and society, in the perspective of a sustainable growth, Italy needs to build one (or more) symphonic ecosystem(s) where education, research, innovation and knowledge transfer are seamlessly interconnected. The unprecedented investments enabled under the PNRR are an exceptional opportunity to achieve this ambitious goal and fill the competitivity gap with major industrial players on the global scene.

Being one of the six Enabling Technologies, Photonics has a basically ubiquitous role in achieving the missions Italy has set for its future development, which are on: Health; Digital and Aerospace Industry; Energy, Climate and Mobility; Natural Resources; Agriculture and Environment. At the time being, the implementation of the above-mentioned extended partnerships, national centres and innovation ecosystems is smoothly running according to the scheduled roadmap (source BOZZA IV RELAZIONE ATTUAZIONE PNRR – 21_02_2024). Whilst it is probably too early to provide precise projections on the expected socio-economical impact in 2026, when the PNRR is planned to end, but we can certainly forecast a very intense period of hard work for many Photonics experts and researchers in Italy.

AEIT-CORIFI
COordinamento Ricerca Innovazione Fotonica Italia

corifi

SIOF Società Italiana di Ottica e Fotonica