SINGLE CRYSTALS GROWTH AND CRYSTALS PERFORMANCE FOR OPTICAL AND LASER APPLICATION

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Crystalline materials have always been the basis of major technological changes. They play an important role in the design, implementation and use of manufactured products in the field of optics such as lasers, scintillators and phosphors and the electronic field of semiconductors and superconductors. This talk will develop the recent results obtained on crystalline materials with different geometry for optics applications.

Monocrystalline fibers are the subjects of intense recent studies because of their particular characteristics. In general, any elongate material in a direction with a diameter varying from a few microns to mm is called fiber. This geometry can be achieved by growing from the liquid phase. The development of single-crystal fibers opens perspectives quite promising new components design for a variety of applications. The availability of single crystal fibers with properties already mastered as YAG ($Y_3Al_5O_{12}$) and LuAG ($Lu_3Al_5O_{12}$) [1] or lithium niobate (LiNbO3) noted LN and sapphire (Al2O3) [2] allows new architectures of optical components.

Except monocrystalline fibers, another attractive region of recent research is on large diameter sapphire. Sapphire crystals are used for a wide range of applications: clock and watch industry, synthetic jewellery, optical components for micro-electronics and laser systems. There is an increasing demand, for undoped sapphire wafers as substrates for GaN and ZnO thin films and for Ti^{3+} doped sapphire for ultra-short and high power laser systems. Sapphire doped with Ti^{3+} ions, indeed, is now recognized as the solid state laser material which allows the direct generation of the shortest laser pulses and as the basic amplifier medium for most of the future high power laser chains at the petawatt level. In the world, there is a strong international competition to get the high power laser generation and, only few countries have developed CPA laser chain. Undoped and titanium doped sapphire crystals are now considered as very strategic materials. A lot of work remains to be done to grow and provide high-quality large-size highly-doped single crystals with reproducible performance [3].

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DESIGNING NANOPARTICLES DURING THE DRAWING STEP

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Nanoparticles in the core of optical fibres are widely studied due to the opportunity they give to tailor spectroscopic properties. Such fibres are usually obtained by drawing at high temperature a preform containing nanoparticles [1]. This study focuses on the effect of the fibre drawing on nanoparticles. We fabricated an MCVD optical preform by doping the porous layer with nanoparticles. The optical fibre was studied by a FIB/SEM tomography [2].

Figure 1 is the volume reconstruction of the core of the optical fibre. The yellow phase represents nanoparticles inside the core of the optical fibre. This reconstruction shows evidences of break-up, elongation and coalescence of particles [3]. These features will be discussed according to phenomena well known from the rheology of emulsions and polymers [4]. It comes from a competition between viscous stresses of the flow and surface tension.

Observation of these size-controlling phenomena occuring during fibre drawing offer new perspectives to tailor the size of nanoparticles and are therefore of great interest for light scattering issues.

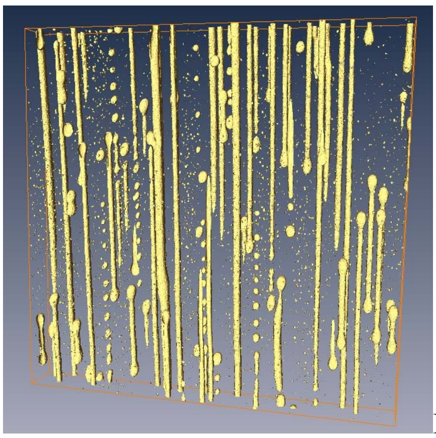

Figure 1: 3D rendering of the particles in the core of the optical fibre. The drawing direction is vertical. Width of the volume reconstructed by the FIB/SEM process is 5 µm.

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Fabrication and characterization of step-index tellurite fibers with varying numerical aperture for near- and mid-infrared nonlinear optics

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Development of broadband supercontinuum (SC) laser sources in the mid-infrared (MIR) was widely studied during the last two decades for its high application potential in various fields such as spectroscopy, defense, medical science and others. TeO_2 based vitreous materials appear to be good candidates for the development of fiber-based SC sources emitting in the MIR thanks to their 1-6 µm transparency widow and relatively high nonlinear optical properties. However, at the moment, few studies report spectral broadening spreading further than 3 µm in tellurite fibers [1, 2, 3]. Most of those results were obtained using microstructured optical fibers (MOFs) in which an ageing process, inherent to the micrometric architecture and due to water contamination, has been identified for chalcogenide [4] and silica [5] glasses. MOFs allow the shifting of the zero-dispersion wavelength (ZDW) toward the near-infrared, where compact high-peak-power laser sources suitable for SC generation are commercially available. Nowadays, comparable pumping configurations are accessible around 2 µm with the development of thulium-based fiber lasers. In those conditions, less drastic dispersion tailoring is required, especially for tellurite materials, which exhibit ZDW located around 2 µm.

We report aging experiments performed on tellurite MOFs suggesting SC generation might also be limited by this kind of phenomenon. Consequently, all-solid step-index fiber profiles are considered for preventing water steam diffusion inside the waveguide in order to anticipate transmission degradation due to ageing. We then present results on the manufacturing of step-index tellurite, germanate and germanate-tellurite fibers including their linear and nonlinear characterizations. Three different step-index profiles with varying refractive index difference are explored. To this end suitable compositions are associated leading to step index fibers through a fabrication method combining built in casting and rod in tube processes. The potential of our fibers for nonlinear optics is next reported through SC generation experiments, by using a femtosecond fiber laser at 1.56 µm. SC spectra covering the 1.3-2.0 µm region were obtained for each fiber. Finally, we extend our study to the fabrication of step-index tellurite fiber made from purified glass. Nearly complete elimination of OH-related absorption bands of the vitreous materials is proven through attenuation measurements performed on several meter-long large-core multimode fiber. The beneficial impact of glass purification on SC generation towards the MIR is confirmed in a low-OH 3.5-µm-core tellurite step index fiber pumped above 2 µm resulting in SC spectra extending beyond 3µm.

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INVESTIGATION OF THE QUANTUM CUTTING PROPERTIES OF Tb^{3+}/Yb^{3+} CO-DOPED SILICA-HAFNIA GLASS AND GLASS-CERAMICS OBTAINED BY SOL-GEL TECHNOLOGY

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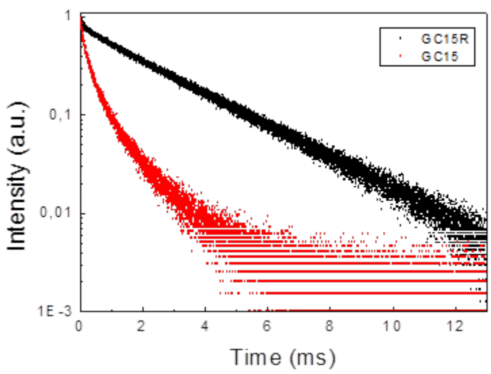
The optical properties of quantum cutting systems, able to produce two or more near-infrared photons from a blue incident photon, could have applications in high efficiency light emitters, lasers and photovoltaics. In this work, we report the synthesis of Tb^{3+}/Yb^{3+} co-doped silica-hafnia glass and glass-ceramic waveguides by sol-gel technology and their structural and optical characterizations. In particular, the quantum cutting properties of the system has been investigated in the glass and glass-ceramic environment as a function of the rare earth concentration, demonstrating the possibility to approach the theoretical limit of 200% quantum efficiency.



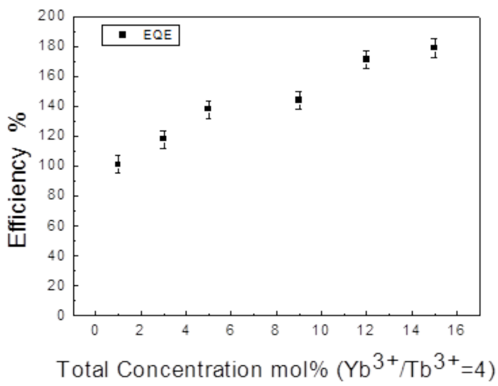


Figure left: photoluminescence intensity decay at 543.5 nm for 3 mol% Tb^{3+} excited state without and with the presence of 12 mol% Yb^{3+} ions. **Figure right:** quantum efficiency values as a function of rare earth total concentration, keeping constant the rate Yb^{3+}/Tb^{3+}=4.

Dy^{3+} doped ZBLAN fiber for efficient laser emission at 3 μm

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The mid-infrared (mid-IR) spectral region of 2–20 μm (500–5,000 cm^{-1}) is a domain of interest to many areas of science and technology. A large number of molecules undergo strong characteristic vibrational transitions in this domain, thus making mid-infrared spectroscopy a univocal way to identify and quantify molecular species, including isotopologues, in a given environment. The development of tunable, compact, and high power laser sources for the mid-infrared (IR) region still remains a major challenge. Mid-IR emission can be achieved using semiconductor lasers, such as lead salt compounds or gallium-antimonide, and quantum cascade lasers. At around the 3 μm emission wavelength, however, these devices feature low output power and limited tuning range. Non-linear optical techniques, namely difference frequency and optical parametric generation, also can be used to produce mid-IR light, at the expense of an increased complexity of the optical source.

Impurity (transition metal or rare earth ions) doped crystalline as well as rare earth doped glasses lasers constitute another important route for mid-IR generation. Rare earth doped glasses are particularly interesting because they allow the exploitation of the fiber-laser technology. Fiber lasers are efficient, powerful and versatile sources in a small and low-maintenance format providing enormous flexibility in the characteristics and quantity of light that can be generated. In the last years a great effort has been devoted to the development of glasses that extend the emission wavelength of fiber lasers from the near infrared to the mid-infrared “fingerprint” region. Dysprosium ion when doped into a ZBLAN glass matrix can produce a broad emission centered around 2.9 μm ($^6H_{13/2} \rightarrow {}^6H_{15/2}$) upon pumping any of its higher energy levels such as $^6H_{7/2} + {}^6F_{9/2}$, $^6H_{9/2} + {}^6F_{11/2}$, $^6H_{11/2}$, of which first two are closely spaced energy levels providing broad absorption bands centred at 1097 nm and 1328 nm.

Here we present a full characterization of Dy-doped ZBLAN fiber as an active medium for efficient laser emission at around 3 μm.

Integrated photonic device by top down fabrication processes

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Different photonic devices will be described together with their fabrication processes. In particular all optical switches and logic gates, electro-optical switches and photon sources based on Quantum Dots (QDs) and Photonic Crystal (PhC) nanocavities.
All the fabrication processes have been carred out in the Micro and Nanofabrication Facility at CNR Institute of Photonics and Nanotechnologies, site of Rome.
Integration between the standard microelectronics, based on silicon CMOS technology, and micro scale optical devices are a necessary condition for high-speed optical on board communication and it is acting today as driving force for developing silicon photonics platforms. Couplers, splitters, amplifiers, low loss waveguides, light emitters, adders and filters [1] on silicon have been demonstrated, but a micro scale low power dissipating and high rate modulators are still challenging goals. In order to realize an electro optical modulator on silicon chip, one has to overcome the weak electro optical interaction in silicon [2]. Some have dealt with this issue by producing very long structures [1], others have made short devices using a ring resonator which has a high finesse and narrow spectral response. Different kind of devices [3,4] will be described as examples of how top down fabrication techniques can be employed in nanophotonics. Moreover a quantum system based on the deterministic coupling between a PhC nanocavity and a single QD will be described.

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Opto-Electronic Devices and Sensors Based on Nanostructured Silicon

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Silicon nanomaterials, known as one of the most important types of nanomaterials, feature a number of unique merits, such as excellent electronic/mechanical/optical properties, huge surface-to-volume ratios, and facile surface modification [1]. Fast development of silicon nanomaterials with well-defined structures and required functionalities has vastly promoted the advancement of silicon nanotechnology. Structuring surface and bulk of (poly)crystalline silicon on different length scales can significantly alter its properties and improve the performance of opto-electronic devices and sensors based on silicon. Different dominant feature scales are responsible for modification of some of electronic and optical properties of silicon. We present several chemical methods for easy structuring of silicon on nano and micro-scales, based on both electroless and anodic etching of silicon in hydrofluoric acid based etchants, and chemical anisotropic etching of silicon in basic environments. We show how successive micro and nano structuring creates hierarchical silicon surfaces, which can be used to simultaneously exploit the advantages of both structuring feature length scales. We present some final results of application of silicon nano structuring in development of SERS substrates [2] and silicon/organic heterojunctions for IR light sensing [3].

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Novel tuning scheme for fiber lasers using a theta cavity design for constant repetition rates

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Fiber lasers provide the perfect basis to develop broadly tunable lasers with high efficiency, excellent beam quality and user-friendly operation as they are increasingly demanded by applications in biophotonics and spectroscopy. Recently[1], a novel tuning scheme has been presented using fiber Bragg grating (FBG) arrays as fiber-integrated spectral filters containing many standard FBGs with different feedback wavelengths. Based on the discrete spectral sampling, these reflective filters uniquely enable tailored tuning ranges and broad bandwidths to be implemented into fiber lasers. Even though the first implementation of FBG arrays in pulsed tunable lasers based on a sigma ring resonators works with good emission properties, the emission wavelength is tuned by a changing repetition rate, which causes problems with applications in synchronized environments.

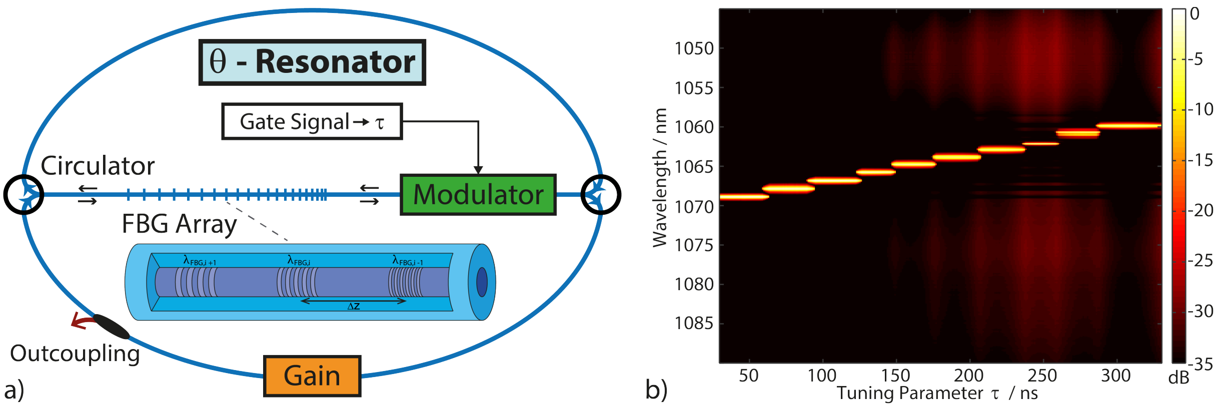

Figure 1 a) Schematic of the tunable fiber laser using a θ-cavity design b) Measured optical spectra as function of the tuning parameter τ.

In this work, we present a modified resonator scheme to maintain a constant repetition rate over the tuning range and still benefit from the advantages of FBG arrays as filters. This first feature is especially important for applications requiring a synchronization of the laser source. With a theta ring cavity and two counter propagating filter passes, the delay times in the FBG array are compensated resulting in a constant pulse round trip time for each filter wavelength. Together with an adapted gating scheme controlling the emission wavelength with a modulator, the tuning principle has been realized based on an Ytterbium-doped fiber laser. We present the first experimental realization of this tuning method, demonstrating a tuning range of 25nm. The signal contrast is typically very good (>25dB) and pulse durations are about 10ns. With the prospect of tailored tuning ranges, this pulsed fiber-integrated laser may be the basis to tackle challenging applications in spectroscopy.

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Pr-doped Ga(In)-As(Sb)-Ge-Se glasses and fibers for MIR-range

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One of the problems of the preparation of RE-ions doped chalcogenide glasses for fiber lasers of the 3-5 μm region is the reducing of the concentration of the impurities limited the optical transparency, specially in the range of pump and emission wavelengths. Oxygen- and hydrogen-contained impurity compounds in these glasses lead to the increase of the optical losses and to the degradation of quantum and physical characteristics.

In this report we offer the method of synthesis of chalcogenide glasses for fiber optics of 3-5 μm with lowest concentration of limiting impurities [1]. The multistage method includes the purification procedures for all components of the glasses by using of chemical distillation processes and vapor transport reactions for the procedure of loading and purification of Ga- and In- compounds as well.

The high-pure Ga(In)As(Sb)GeSe host glasses prepared by this method were doped with Pr(3+) ions in form of Pr_2S_3. The values of the concentration of oxygen / hydrogen-contained impurities in host glasses are at the level of $\leq$ 0.1 ppmw., that is much lower in comparison with the currently available glasses of the same composition [2,3]. Small-core RE-doped fibers had been prepared from glasses of different composition and core/clad diameter ratios. These fibers demonstrated an intensive emission in the 3-5 μm range and high values of the life time of luminescence at 4.7 μm closed to theoretical ones [2].

The host glasses had been characterized by X-ray diffraction, DSC and optical microscopy methods. The optical losses of fibers, specially prepared from the glasses with higher quantum characteristics, are less than 1 dB/m at the wavelengths closed to pump (1.97 μm of Tm-fiber laser). The InIAs(Sb)Se glasses with small concentration of iodine in the glass matrix are promising for fiber active materials due to high durability to crystallization and low values of phonon energy.

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MULTICOLOUR EMISSION IN RE - DOPED FIBERS

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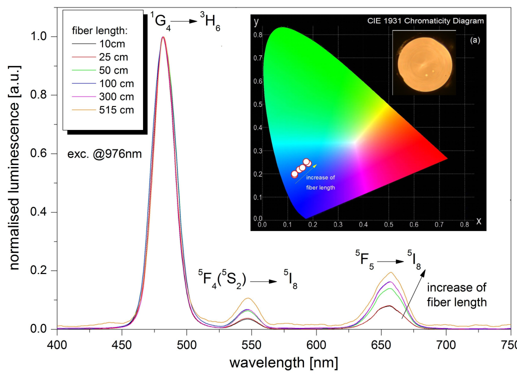
Controllable white upconversion luminescence generating by the simultaneous three primary red, green, and blue (RGB) color emissions is desired for their potential to replace conventional lighting sources in medical illumination and three-dimensional color displays [1]. In the paper multicolour upconversion (UC) emission in antimony – germanate double – clad optical fiber with two off-set cores co-doped with Yb^{3+}/Tm^{3+} and Yb^{3+}/Ho^{3+} and $Yb^{3+}/Tm^{3+}/Ho^{3+}$ - triply doped optical fiber have been investigated. Superposition of three emission bands at the wavelengths of 481nm (Tm^{3+}: blue), 545 nm (Ho^{3+}:green) and 665 nm (Tm^{3+}, Ho^{3+}: red) from two separated cores and $Yb^{3+}/Tm^{3+}/Ho^{3+}$ triply doped optical fiber was measured and analyzed.

a)



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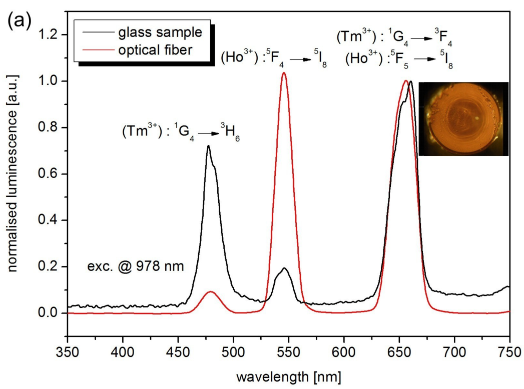

Fig. 1 UC luminescence spectra of 2 – core Yb^{3+}/Ho^{3+} and Yb^{3+}/Tm^{3+} - co- doped optical fiber, CIE coordinates and photo - inset (a), Comparison of UC luminescence spectra of $Yb^{3+}/Tm^{3+}/Ho^{3+}$ triply doped glass and optical fiber (b), (λ_{exc}=976 nm) [2, 3].

White light luminescence in glass and optical fibers was observed as a result of energy transfer with upconversion between donor (Yb^{3+}) and acceptors (Tm^{3+}, Ho^{3+}) ions under 976nm excitation. Influence of fiber length and excitation power on the colour coordinates (CIE-1931) and thus possibility of colour tuning have been also investigated.

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SPECIALTY PHOSPHATE FIBRES FOR ADVANCED LASING AND SENSING APPLICATIONS

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Phosphate optical fibres possess a large glass forming region, good thermo-mechanical and chemical properties, and they are able to incorporate a large amount of rare earth ions. These properties make them suitable for the fabrication of optical fibre lasers and amplifiers [1,2].
We report the fabrication of a special type of phosphate glass composition, which proved to be resorbable in simulated body fluid and at the same time able to guide photons in the visible, thus making it an interesting candidate for the fabrication of biosensors. The glasses for the core and cladding were fabricated by melt-quenching and then characterized in terms of thermal and optical properties. The fibres proved to be photosensitive in the UV: standard and tilted Fiber Bragg Gratings (FGBs) on the phosphate glass fibers were inscribed using a 193 nm 10 ns ArF excimer laser by means of the phase-mask technique [3].

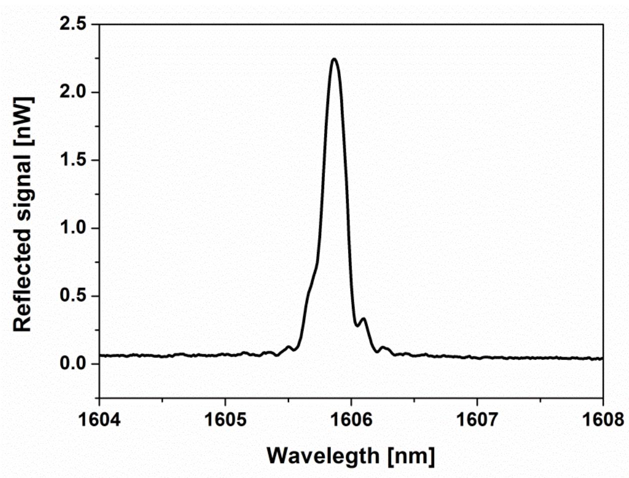

Figure 1 - Bragg grating reflection spectrum for inscription at an accumulated energy density of 6 J/cm^2

Preliminary results will also be presented on the effect of fibre dissolution on the signal of a tilted Fibre Bragg Grating. The results highlight the possibility of developing a new generation of optical sensors and sources suitable for biomedical in-vivo applications. Work is ongoing for the development of rare earth doped optical fibres for biomedical lasers.

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MODELLING OF MODES COMPETITION AND THERMAL EFFECTS IN LARGE MODE AREA PHOTONIC CRYSTAL FIBERS

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A huge industrial interest, in the last decades, has led to an increase of interest in fiber laser technologies in terms of performance enhancement. Currently fiber lasers are able to outperform other technologies with regards of brightness, beam quality, reliability, versatility and compactness [1]. Photonic-crystal fibers (PCFs) represents one of the key-enabling technologies to reach such a good improvement. In particular the use of PCFs allows to maintain the Single-Mode (SM) operation with a significant increase of fiber mode area, which is the key factor to reduce the impact of nonlinear effects. These represent the main limitation for high power operation. Nevertheless, recent experimental evidence has shown a severe degradation in high power fiber lasers operation, arguably dependent on thermal effects, whose impact become more evident with the increase of the core area. In particular the SM regime of Rare Earth-doped Large Mode Area (LMA) PCFs is compromised by the refractive index change induced by the quantum-defect heating, which causes the transition to multi-mode operation [2]. Even if the quantum defect of Yb-doped LMA PCF is quite small compared to other dopants, the impact of this thermal drift cannot be underrated.
In this contribution a new tool for deep investigation of guidance properties of Rare Earth-doped PCF under severe thermal effects is proposed. The developed technique is based on a spatial model, which describes the propagation of the modes along the doped fiber by solving the propagation and the population rate equations, while the field distributions used by the spatial model are computed with a full-vector modal solver based on the Finite Element Method (FEM). The temperature distribution, and the consequent thermally-induced refractive index change, is obtained by solving the cylindrical thermal diffusion problem along the fiber cross section [3].
To verify the reliability of the proposed model, different fiber cross sections have been taken under analysis, both the well-known Large Picth Fiber designs and the more advanced asymmetric designs, Fig. 1(a) [2]. The mode competition and its evolution along the fiber ampifier have been deeply studied Fig. 1(b).

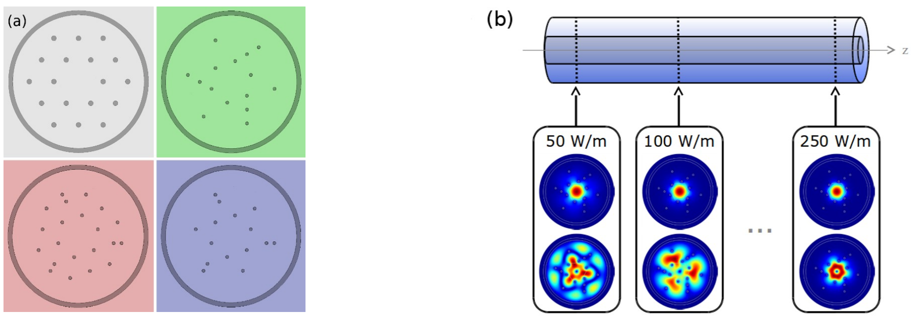

Figure 1
Fiber cross-sections (a), example of mode competition evolution along the fiber amplifier (b).

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Rare Earth Doped Silica-Based optical fibres For High Energy Physics Detectors

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Previous studies demonstrated that rare-earth doped silica glasses prepared by sol-gel route are suitable materials for the realization of scintillating optical fibers, opening their application perspectives in medical imaging systems [1, 2]. The present work is aimed at the investigation of the optical properties of Ce and Pr doped silica fibers under strong irradiation fields, in order to verify the possibility to employ them also in High Energy Physics experiments.

Photo- and radio-luminescence measurements have been coupled to optical absorption and attenuation length investigations, obtained before and after irradiation with X rays and with ^{60}Co gamma rays. Comparisons between bulk preforms and fibers have been performed in order to disclose the role of the fiber drawing process in the radiation hardness. Fibers with fluorinated glass or polymeric cladding have also been compared.

The evolution of the optical absorption spectra as a function of recovery time has been investigated in order to understand the room temperature stability of point defects acting as color centers. Moreover the samples have been treated with thermal annealing cycles up to 800 °C, to check the temperature activated carrier release from radiation-induced defects and the possibility of a complete recovery of the damage.

Eventually, photoluminescence time decays and light yield measurements have been carried out on bulk samples to better investigate the application perspectives of such kind of material as scintillator in High Energy Physics detectors.

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HIGH-ENERGY MID-INFRARED OPTICAL PARAMETRIC SOURCES USING LARGE-APERTURE QUASI-PHASE-MATCHED CRYSTALS

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High-energy sources in mid-infrared (MIR) spectral region extending between 2 µm and 20 µm are increasingly important for number of applications including minimally-invasive laser surgery, standoff detection, countermeasures and environmental gas monitoring using different modalities of LIDARs, including planned missions employing space-borne platforms. Key requirements of such missions are mid-infrared pulse energies of well-above 1 mJ coupled with wavelength-agility and, in many cases, a narrow spectral width and high wavelength stability. Optical parametric down-conversion pumped by high-energy and high-repetition rate bulk and fiber lasers so far offers the only practical route to cover this broad MIR spectral range. For such systems the pump lasers operating around 1 µm are preferable at the moment due to the fact that single-longitudinal mode, efficient and high-energy diode-pumped lasers are commercially available. In most cases, generation of pulses beyond 4 µm employ cascaded downconversion schemes, where the first stage provides high-energy radiation around 2 µm which is further downconverted to longer wavelengths using highly nonlinear materials such as $ZnGeP_2$ or orientationally patterned GaAs [1,2]. The use of intermediate stage is necessary owing to large absorption of these materials around 1 µm. The intermediate stage at around 2 µm realized with master-oscillator-power amplifiers built using large aperture periodically poled $Rb:KTiOPO_4$ (Rb:KTP) would provide high-energy, tunable and narrowband pulses for subsequent pumping of MIR optical parametric oscillators [3] or for difference-frequency mixing [3]. Development of large-aperture ferroelectric crystal structuring technology was a key step enabling such MIR systems [4]. In particular, low-concentration Rb-doping of KTP crystals was shown to have several beneficial effects such as drastic reduction of ionic conductivity, increase in the optical damage threshold at visible wavelengths and higher consistency in periodic structuring of the ferroelectric domains [5]. In this presentation we will give specific examples of nanosecond MIR systems pumped at 1.064 µm and using cascaded downconvertion reaching 18 µm. In particular the systems targeting minimally invasive laser surgery at 6 µm will be discussed, as well as ongoing developments of high-energy narrowband for MIR standoff detection and space-borne atmospheric gas sensing. Prospects of other isomorphs of KTP for fabrication of large-aperture QPM structures are being investigated. In particular, $KTiOAsO_4$ with longer MIR absorption cutoff wavelength and much lower susceptibility to color-center formation than KTP [6] is of great interest.

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Novel glass-based materials for photonics

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ORC's research activities at Tampere University of Technology have been focused on different areas such as photonic glasses, semiconductor technology, fiber optics, surface science and nanophotonics. Those research activities are perfectly linked with the activities on the development and characterization of novel materials and fundamental components (COST MP1401 WG 1)

Phosphate glasses have been extensively studied in the field of optical glasses due to their ability to incorporate high amount of dopant (as opposed to silicate glasses) [Br,00]. Because the local environment around the RE is of paramount importance for determining the optical properties, there is a constant interest in investigating new glasses with varied compositions with the aim not only to enhance their spectroscopic properties but also to increase the solubility of REs. To provide a beneficial local environment to RE ions in terms of their spectroscopic properties, glass-ceramics have been developed. Such crystallized materials combine some features of glasses, i.e. easier and cheaper processing cost than for single crystals and some advantages of rare-earth doped single crystals, i.e. higher absorption/emission cross-section and longer lifetime of luminescent levels [Da, 06]. Those glass-ceramics have been processed using the so-called glass ceramics method, which relies on the in-situ growth of nanoparticles in a glass matrix. A new route of interest consists of embedding the amplifying RE ions within oxide nanoparticles of composition and structure different from those of the glass matrix by partially crystallizing the glass.

In this presentation, we will review especially the current research activities on glasses and glass-ceramics for photonic applications. Especially, we will explain that the nanoparticles doping process cannot be systematically used to process glasses with improved spectroscopic properties due to the dissolution of the nanoparticles inside the glass. We will show that it is actually possible to process particles containing glasses which possess the spectroscopic properties of the particles when using microparticles. Then, we will present our work on Er^{3+} doped glass-ceramics. Finally, we will discuss about the influence of the glass composition on the structure and crystallization behavior of glasses with similar composition and then review the impact of the glass crystallization on the luminescence properties of erbium.

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LOCAL SURFACE ANALYSIS AND LASER MICROMACHINING FOR INTEGRATED DIELECTRIC PLATFORMS

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Scanning Electron Microscopy (SEM) imaging is a very versatile and powerful technique to unveil the morphology of micrometric and sub-micrometric systems, as well as surface topology. Moreover, the information regarding chemical composition, crystalline structure and local electrical properties of samples can also be assessed by combining different detectors. The UHV surface-sensitive Scanning Auger micro-spectroscopy (SAM) technique provides local surface compositional analyses with sub-micrometric resolution. SAM, associated to SEM imaging is capable of detecting chemical impurities, on a very wide variety of substrates, from conductors to insulators and from heavy to light atomic weight compounds. It can be applied to the study of stoichiometry and its evolution [1], local oxidation [2], diffusion and segregation of species at surfaces and grain boundaries at the nanoscale [1,3]. SAM can also be calibrated as a tool for absolute thickness measurement of graphene-related and 2D materials [4]. Therefore, as a whole it validly supports the development of material processing innovation.
The use of SEM on dielectric bulk systems is known to be a critical task. Custom recipes are necessary, usually developed on a case-by-case basis, to overcome issues related to sample charging and related artifacts.
Diamond is a promising photonic platform for sensing applications and quantum computing, due the presence of nitrogen-vacancy (NV) centers, featuring long electron spin coherence time and the ability to be located, manipulated and read out using light. We show preliminary results of SEM imaging contrast analysis applied to diamond. Specifically, SEM unveils nanoscale morphology and surface physical-chemical modifications of waveguides, written by fs-laser micromachining [5]. SEM analysis can be combined with μRaman spectroscopy and other spectroscopic methods to gain better insight into the structure, refractive index profile and transmission performances of the optical waveguides.

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PUMPING SCHEME STRATEGIES FOR MID-IR FIBER LASERS

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There is a growing interest for compact, high-efficiency and reliable optical sources in the medium infrared (mid-IR) wavelength range and the related technologies [1-7] due to a number of occurring factors. As an example, many atmosphere gases exhibit fundamental vibrational absorption in this electromagnetic spectrum region. Moreover, a number of biological molecules can be detected in mid-IR. The design of two pumping schemes for Mid-IR lasers based on photonic crystal fibers (PCFs) is illustrated. The optimized lasers are made of dysprosium doped chalcogenide glass Dy^{3+}:$Ga_5Ge_{20}Sb_{10}S_{65}$. The spectroscopic parameters considered for simulation are measured on rare earth-doped glass samples in order to carry out a realistic feasibility investigation. The first pump scheme is designed to provide an optical beam emission close to 4400 nm wavelength by using two pump beams at the wavelengths close to 2800 nm and 4100 nm, respectively [4]. In the second scheme a 1700 nm pump beam is employed to obtain laser emission close to 4400 nm wavelength [8], its efficiency is increased by including a suitable optical amplifier after the laser cavity. The two light sources are modelled via a home-made numerical model based on the coupled mode theory and solving the rare earth rate equations. A number of promising applications in different areas such as satellite remote sensing and aerospace, biology, molecular spectroscopy and environmental monitoring are feasible.

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Microsphere Based Er^{3+} Microlasers

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We will discuss the production and characterization of microlasers by coating a silica microsphere with Er^{3+} activated $70SiO_2$-$30HfO_2$ film via a sol-gel route. The pumping is achieved using a 1480 nm laser and the lasing is observed in the 1530 - 1560 nm range. The lasing is observed only at specific wavelengths corresponding to the whispering gallery modes of the microsphere.

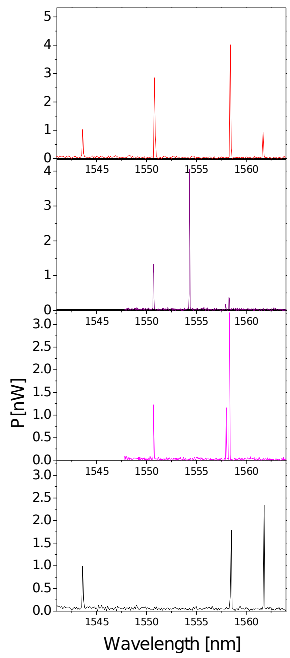

Fig 1. The lasing spectra of a microsphere coated with a Er^{3+} activated $70SiO_2$-$30HfO_2$ film

Recent applications of fibers for optical sensing and particles manipulation in lab-on-chip systems

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Opto-microfluidics consists of integrating microfluidic and micro-photonic components onto the same platform, where fluid and light are driven to interact. This combination offers new opportunities for a large variety of applications [1-4]: among the others, effective compact biosensors have attracted great attention because they combine the high sensitivity of micro-photonic devices to the properties of small amounts of fluids that surround them [5-6]. The perspective of true compact and portable Lab-on-chip platforms has driven the attention to integrate many other optical functionalities. Among the others, a novel class of optically controlled photonic devices were demonstrated to optically manipulate micron-scale objects in fluid through tightly focused external laser beams, such as optical sorter, tweezers and stretchers. Up to now, this integration is gained by developing the microfluidic circuitry on a substrate and then coupling an optical stage by external setups, mainly for delivering and collecting light. Quite surprisingly, only a few truly exploit optical fibers potentialities. Some recent examples of fibers applications will be therefore presented in the field of lab-on-chip opto-microfluidics based devices, with special care to optical manipulation and optical biosensing with perspectives towards light-reconfigurable devices and multifunctional stages.

EAGLES
International Conference on
Rare-Earth Doped Glass Materials and Fibre Lasers
MPNS COST Action MP1401
COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
COST is supported by the EU Framework Programme Horizon 2020
October 18th – 19th, 2016 | Trento, Italy

ABSTRACT

Mid-infrared (MIR) fibre lasers: progress and challenges.

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Progress and challenges in: (i) broadband mid-infrared supercontinuum (MIR-SC) fibre lasers and (ii) narrow-line MIR fibre lasers are addressed.

MIR-SC fibre lasers: the demonstration of a fibre MIR-SC from 1.4 μm to 13.3 in a specially engineered, high numerical aperture (NA), MIR step-index fibre (SIF) [1] revealed for the first time the potential of MIR fibres to emit across the MIR molecular 'fingerprint region', for prospective molecular sensing and imaging. Ultra-short fs pulses, with a central wavelength of either 4.5 µm or 6.3 µm, launched into ~ 100 mm long chalcogenide glass generated the record fibre MIR-SC, spanning 1.5 - 11.7 µm and 1.4 - 13.3 µm wavelength ranges, respectively. However, the output MIR-SC power was only a few 100s μW. As pointed out in [2], an important practical factor is that the power required to generate the MIR-SC should be relatively low - a few kW and compact, high-repetition-rate, pump sources with 10s or 100s mW of average power should be employed. OPA pumping of a 110 mm long, high NA chalcogenide SIF with a relatively low peak pulse power of ~ 3 kW and 330 fs duration pulses was shown to give rise to a MIR-SC spanning ~ 1.8 to 10 µm [2] of a few mW average power. As the Authors stated: 'similar to that of a typical MIR beamline of a synchrotron'. More recently, the group of Luther-Davies achieved chalcogenide glass SIF MIR-SC spanning 2.2-12 μm with 17 mW average power output [3]. Future challenges are: (i) to marry MIR-SC fibre lasers with Fourier transform spectrometry, for speedy acquisition of molecular spectra for sensing and imaging and (ii) development of narrow-line MIR fibre lasers for pumping MIR-SC fibre lasers, for an all-fibre, compact solution for fibre MIR-SC broadband molecular sensing and imaging.

Narrow-line MIR fibre lasers: no MIR narrow-line fibre laser has yet been demonstrated beyond 3.9 μm wavelength [4]. Chalcogenide glasses are attractive hosts for rare earth (RE-) ions, which can provide MIR emission. The chalcogenide glasses show sufficient solubility of RE-ions and have low phonon energies leading to low non-radiative emission, high radiative efficiency and transparency at the pump and emission MIR wavelengths. Broad photoluminescence (PL) spanning ~ 3.5-6 μm has been reported in Pr^{3+}-selenide chalcogenide fibre [5-7]. Encouragingly, we reported first time, long lifetimes of several ms in Pr^{3+}-selenide small-core fibres [7], demonstrating that the RE-ion local environment survives the thermal cycling to make fibre and glass devitrification did not occur. In trying to understand the radiation pathways of the excited states, we have recently observed first time excited state absorption in a Pr^{3+}-selenide fibre [8] and found evidence of saturation of the excited state [8]. Problems to overcome are: (i) some excited RE-ions in the chalcogenide fibre probably undergo a fast decay due to a non-radiative depopulation of the excited state, mediated by MIR impurity multiphotons [9] and (ii) resonant absorption of the PL signal [10] by impurities in the glass fibre in the 4-5 μm wavelength range no doubt is occurring. The challenge to be met, therefore, is to lower RE-chalcogenide fibre optical loss in order to demonstrate fibre gain and MIR fibre narrow-line lasing beyond 4 μm wavelength.

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A STUDY ON SPECTROSCOPIC QUALITIES AND MICROSTRUCTURE OF OXYFLUORIDE GLASSES AND GLASS-CERAMICS DOPED WITH SELECTED LANTHANIDE IONS

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The fabrication process, morphology, optical properties and excited state relaxation dynamics of the appropriate oxyfluoride Ln^{3+}- doped glasses and glass-ceramics have been studied. Some crystalline ordered components were obtained by the controlled heat treatment of the multicomponent oxyfluoride glasses based on silica, PbF_2 or YF_3. The materials under study were annealed in the temperature range of 600-750 ^{o}C yielding quite transparent materials. Furthermore, based on obtained materials glass optical fibers were successfully drawn. The differential thermal analysis (DTA) studies resulted in estimating both the fiber drawing temperature and the controlled crystallization temperature of glass fibers. The crystalline phases were characterized by X-ray powder diffraction (XRD). High resolution transmission electron microscopy (TEM) and selected area electron diffraction (SAED) were used to investigate glass-ceramics morphology. Optical spectroscopy methods were applied to examination of absorption and emission properties of Ln^{3+} ions as well as energy transfer phenomena and relaxation dynamic of involved excited states. It was fond that optically active ions reside into well-defined sites within the glass-ceramics. Unlike spectroscopic properties have been recognized for glasses and glass–ceramic samples, respectively. Emission intensities increased and luminescence decay curves become single-exponential in the samples containing the ordered components. Moreover, these samples are characterized by reduction of emission linewidth. Up-conversion phenomena attributed to visible anti-Stokes emission has been observed under excitation by NIR diode laser. Enhancement of visible up-converted luminescence was achieved in the glass-ceramic systems. Dissimilar spectral characteristic and relation of up-converted emissions examined in glass and glass-ceramic samples indicate that different processes relevant to this phenomena occur. Eventually, the performed investigations indicate that these optical systems may be considered as promising materials for optical amplifiers operating within wide spectral region.

Acknowledgments: This work was supported by the National Science Centre, Poland under grant number 2014/13/B/ST8/04041

Crystallization and optical properties of rare earth^{+} doped- oxyfluoride glass-ceramics for its use in optical fibers

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In recent years, rare Earths (RE) doped transparent oxyfluoride glass-ceramics have been extensively studied due to its potential photonics applications, particularly for its use in optical and lasers fibers. These materials play an important role in this field thanks to its extraordinary structural and optical properties. Indeed, oxyfluoride glass-ceramics combine the good chemical and mechanical stability of oxide glasses with the low phonon energy associated to the fluoride host that reduced the nonradiative loss resulting in an enhanced of the optical properties. Oxyfluoride glass-ceramics containing LnF_3 and $LnRF_4$ nanocrystals present unique characteristics that permit enhancing the luminescence for using in fiber laser applications. In particular, LaF_3 and $NaGdF_4$ glass-ceramics have been considered as excellent luminescent host matrices for various RE ions and are used as up- and down- converter materials. A relevant issue for obtaining optimized glass-ceramics for photonics applications is the processing route. .One of the most useful is the melt-quenching (MQ) method. Despite of the high temperatures require during this process, MQ permits obtaining bulk materials and fibers easily.In this work, LaF_3 and β-$NaGdF_4$ oxyfluouride glass-ceramics doped with different RE dopants (Nd^{3+}, Er^{3+} and Er^{3+}-Yb^{3+}) have been obtained by melting quenching method. The structural characterization confirms the nanocrystals formation after adequate heat treatments and the incorporation of the rare earths ions in the nanocrystals. The proximity between the RE ions in the nanocrystals favors the energy transfer mechanism between these ions and enhance the efficiency of the up-conversion and down conversion processes. These results suggest the possibility of using these materials as core of the optical and laser fibers.

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