Feasibility Investigation of Fiber Lasers for Mid-IR applications

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In this contribution, the feasibility investigations of different fiber lasers for MID-IR applications are illustrated. Different host glasses and pumping schemes are described. In particular, the reported simulation results refer to: i) the design of an efficient pumping scheme for a Dy^{3+}:$Ga_5Ge_{20}Sb_{10}S_{65}$ PCF fiber laser which provides an optical beam emission close to 4400 nm wavelength by employing two pump beams at 2850 nm and 4092 nm wavelengths [1]; ii) an optimized optical source exploiting a Master Oscillator Power Amplifier (MOPA) configuration, the MOPA pump and signal wavelengths being 1709 nm and 4384 nm, respectively [2]; iii) a time-dependent numerical model of a dysprosium-doped ZBLAN glass fiber developed in order to design a pulsed laser emitting at about 3 μm wavelength, by employing an in-band pumping scheme [3]. In all the cases, spectroscopic parameters measured on preliminary samples of chalcogenide and ZBLAN glasses are taken into account to fulfill realistic simulations. The results are compared and discussed. Chalcogenide glasses are extremely promising for innovative applications at longer wavelengths, while ZBLAN glasses offer the possibility to develop novel lasers by employing available-on-the-market optical fibers.

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Silica microspheres as Raman scattering enhancers

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Silica microspheres (1-20 μm) are presented as Raman scattering enhancers, via two different mechanisms: serving as microlenses, producing photonic nanojet, and as cavities for light confinement, producing whispering-gallery modes. Some experimental results and achievements of enhancements from other groups for both mechanisms are shown [1], [2], [3]. Although in beginnings, own results to date are displayed, namely 2D and 3D Raman mapping pictures of the microspheres irradiated by 532 nm laser beam, where indications exist of visual confirmation of photonic nanojet. Also technical obstacles and results of determining the laser beam waist for successful coupling and irradiating the microspheres are presented.

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Optical fiber bend as a sensing element for the evanescent wave spectroscopy in the mid-IR

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Using of the evanescent wave spectroscopy for chemical analysis in the mid-IR spectral range allows effectively defining the composition of liquids. Engineering of the optical fibers, which can guide evanescent modes with large attenuation coefficients, is necessary to increase sensitivity and reduce the minimum detectable amount of an analyte. Reduction of size of the fiber-based sensing element is an important task in the problem of the method optimization. In this work, we are dealing with engineering of a fiber shape to obtain large attenuation coefficients of evanescent modes. As an example, we consider a single-index multimode fiber with a permanent bend. Such U-shaped or loop-shaped optical fibers can be used as compact sensing heads of the evanescent wave spectroscopic sensors [1]. In experiment, transmittance of such a sensing head immersed into diesel oil with a fuel additive has been measured. The sensing heads were fabricated from chalcogenide fibers made of the $Ge_{26}As_{17}Se_{25}Te_{32}$ glass by using the technology described in [2]. A heat source radiation was launched into the fiber endface coaxially with the fiber.

For analysis of fiber modes transformation at the fiber bend, the Wave Optics Module of Comsol Multiphysics provides an efficient tool based on numerical solution of Maxwell's equations by using the finite-element method. For the fiber bend, the solution is presented as a mode characterised by its complex-valued propagation constant and electromagnetic field profile in the fiber cross-section. We have shown that attenuation coefficients of the fundamental mode and low-order modes significantly increase at the bend. The sensing head functionality has been characterised with repsect to the fiber bend radius and number of the loops.

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WGM for the measurement of absorption and scattering loss in UV-irradiated photosensitive fibers

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The UV-assisted inscription of photosensitive fibers is the most employed method to fabricate fiber Bragg gratings and long period gratings. The exposure of a fiber to UV-radiation induces a change in the refractive index, which is associated with a variation of the absorption coefficient, and may induce mechanical deformations. In this work we present a technique to measure the increment of the absorption coefficient due to the fabrication process. The technique also allows to discriminate between the absorption and scattering contributions to the overall losses. The increment of the absorption coefficient is measured employing the thermal sensitivity of the whispering gallery modes (WGMs). A section of a UV-irradiated fiber plays the role of a microresonator. The WGM resonances are excited at a given point (axial resolution: 200 μm) using a 2 μm auxiliary tapered fiber, which can be swept along the resonator [1]. An infrared pump signal of moderate power (~1W) is used in order to produce a temperature variation (detection limit 0.03ºC). The thermal profile of an irradiated Fibercore PS980 (5 mm) illuminated with a signal at 1550 nm and 1 W is measured, Fig. 1(a). We observed that the irradiated section suffers a higher temperature increment than the non-irradiated section. This is directly related with an increment of the α^{abs}. Following the analysis developed in [2] is possible to relate the ratio between the temperature increment and the ratio of the absorption coefficients, $\Delta T_2/\Delta T_1 = \alpha_2^{abs}/\alpha_1^{abs}$. The ratio of the studied fiber is $\alpha_2^{abs}/\alpha_1^{abs} = 36.9 \pm 0.7$ for a irradiation value of 150 J/mm^2.

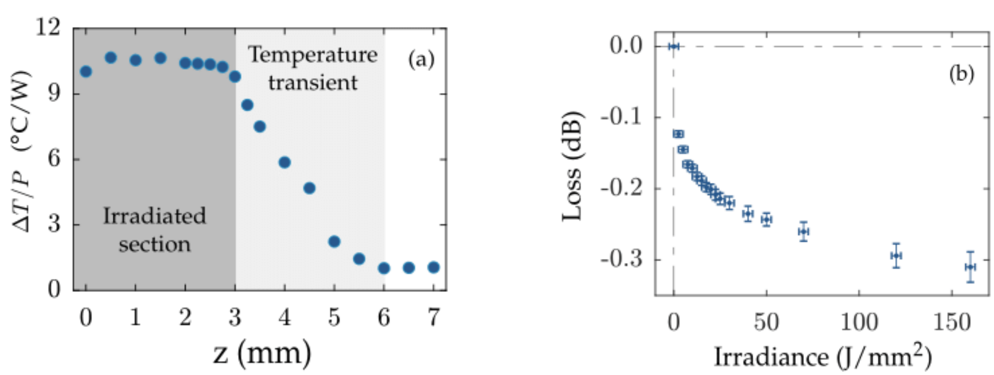

Fig. 1: (a) Typical thermal profile of an irradiated section of PS980. (b) Direct measurement of the losses as the fiber is irradiated (irradiated fiber length: 5 cm).

To discriminate the contribution of the absorption and the scattering, the direct measurement of the total losses as the fiber was irradiated was carried out, Fig. 1(b). While the WGM measurement gives information of the absorption coefficient, in this case, the measured losses take into account the absorption and the scattering. The ratio of the losses is $\alpha_2/\alpha_1 = 52 \pm 3$ (the losses of the pristine fiber are 120 dB/km @1550 nm), where $\alpha = \alpha^{abs} + \alpha^{scat}$. By using the results of both measurements, we can calculate the value of the two coefficients: $\alpha_2^{abs} = 3680 \pm 20$ dB/km and $\alpha_2^{scat} = 2500 \pm 400$ dB/km.

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Towards a high concentration Yb-Er phosphate glass optical amplifier for eye-safe compact LIDAR - the "Caliber" project

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Light Detection and Ranging (LIDAR) systems offer a powerful remote sensing technique, which uses laser light to retrieve information about the environment and surroundings close to its location. The light emitter is a key element of the system and contributes to overall system performance. The quality of the sensing strongly depends on the type of source employed, in terms of wavelength, pulse width, average and peak power, which altogether define the precision and reliability of the overall system.

A flexible and advantageous approach to realize a high power LIDAR source is the master oscillator power amplifier (MOPA) configuration. A seed laser with high spectral quality is followed by a single- or multi-stage power amplifier that boosts the output power to attain the needed energy.

The aim of the CALIBER project is to combine high repetition rate and high peak power in a compact and lightweight LIDAR source, that can be placed on small Unmanned Aerial Vehicles (UAVs) or in specific locations of premises where a small footprint equipment is required. The proposed laser source includes two novel components, a high peak power eye-safe microchip laser and a compact Er:Yb power amplifier, arranged in a MOPA configuration.

Following project requests of a high degree of compactness, while retaining high performances and low cost, the optical amplifier will be an Er:Yb co-doped phosphate glass based waveguide. Multicomponent phosphate glasses are recognized to be an ideal host material for engineering the amplification stage of a pulsed MOPA as they can be doped with large amount of rare earth ions (up to 10^{21} ions/cm^3) without clustering. This enables the realization of an active medium with high optical gain in short length (> 5dB/m) and thus mitigating nonlinear optical effects. Moreover, the phosphate glass possesses good thermo-mechanical properties, high emission cross-sections, high optical damage threshold and immunity to photodarkening.

In this work we report on the design and fabrication of a series of Yb/Er-doped phosphate glasses to be used as active materials for the core of a waveguide amplifier. The manufactured phosphate glasses were thoroughly investigated. First of all they were thermo-mechanically characterized, then the glasses underwent optical characterization such as refractive index measurement, FTIR spectroscopy and rare earth emission spectroscopy resolved in time and frequency. Suitable cladding compositions were explored in order to manufacture the first waveguide amplifier prototype.

The reported activity was carried out in the framework of the NATO Science for Peace and Security project "Caliber" (grant no. SPS G5248) and partially supported by COST action MP1401.

Fiber-optic biosensor for oligonucleotide-hybridization based on a narrowband long period grating

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In this work we present the use of nanometric barrowband Long Period Gratings (LPG) for the detection of the hybridization of DNA. The detection of the DNA hybridization process is of particular interest, due to their specific capability to detect particular DNA sequences that might be of interest for environmental, biological or health applications, epidemic controls, diagnosis, drug research, etc. Several approaches have been reported up to date to measure the DNA-hybridization based on different photonic devices [1-3].

The 3-dB bandwidth of the LPG employed in the experiments is around 1 nm, which is one order of magnitude lower than that of standard LPGs at 1500 nm. This unusual bandwidth was obtained by means of the selection of the proper fabrication parameters (high numerical aperture, relatively high order mode and large length) [4].

The operation principle of a LPG acting as a biosensor relies on the sensitivity (S) of the evanescent wave of the cladding modes, to variations of the refractive index of the external medium: as the external refractive index increases, the notches in the spectral response of the LPG shift in wavelength. The LPG was characterized as a refractometer and S was experimentally measured for modes $LP_{0,17}$ and $LP_{0,18}$: -32.8±1.5 nm/RIU and -77±2 nm/RIU, respectively, when the external refractive index was varied around 1.33 (the refractive index of an aqueous solution). Despite S is smaller than that reported for dual-peak LPGs [3], the reduction in the bandwidth leads to the improvement of the detection limit (DL) of the sensor.

The surface of an LPG (3-dB bandwidth: 1.5 nm) was functionalized following the procedure described in [3]. When the biosensor was immersed in a 2 µM solution of the complementary DNA strand, the $LP_{0,18}$ resonance of the LPG shifted in wavelength 0.50nm, see Fig. 1.: thus, S = 250 pm/µM. We evaluated the performance of our biosensor in terms variations of the transmittance at the slope of the resonance. If we assume that the resolution is a thousandth part of the normalized transmittance at the point of maximum transmission slope (this is, 0.1%), the detection limit is 10 nM. This value is better or comparable to other results for fiber optic biosensors for hybridization of DNA [1-3].

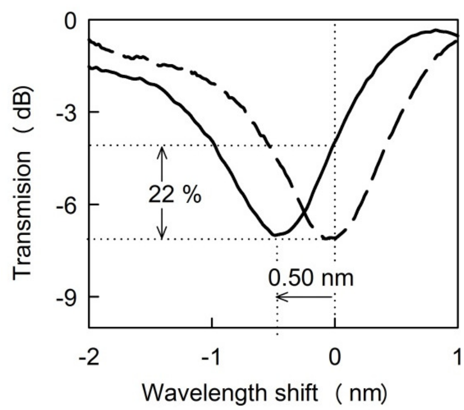

Fig. 1. Spectra of the LPG before (continuous line) and after (dashed line) of the hybridization of the DNA-complementary strand.

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Study of the response after irradiation of aluminum doped silica preforms.

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Aluminum-doped fibers are an example of fibered materials sensitive to radiation. This property was revealed by the use of aluminum in erbium doped silica fiber used as amplifier: exposed to radiation, this device showed an enhanced radiation induced attenuation (RIA) with respect to the common phosphorus or fluorine doped fibers[1]. After irradiation, Al impurities present in silica glass are converted in optically-active point defects. From optical absorption measurements one can observe optical bands corresponding to Al centers like AlOHC and AlE' in the UV-Visible[2]. The obtained RIA is very high and is due mostly to the AlOHC centers. The RIA observed in the near infrared (NIR) could be seen as being due to tail of the AlOCH center at 2.3 eV but this only contribution is not sufficient to explain the induced loss in this region. In our work we want to extrapolate some informations about the relation between AlOHC center and the RIA in the NIR range and study the Thermally Stimulated Luminscence (TSL) response of the irradiated sample. We characterized an aluminum doped silica preform made by the MCVD technique. After irradiating the sample up to 14kGy, one can observe the optical band related to the aluminum center. Performing a post-irradiation photobleaching of the centers one subsequently observes the annealing process. The TSL response grows almost linearly with the total ionizing dose showing a peak at 70 ^{o}C, and no dose rate effects are observed. This property can be useful for dosimetry applications.

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Power Threshold for Non-linear Applications in Optical Microcavities

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Abstract

Whispering gallery mode resonators (WGMR) can provide the strong nonlinear effects and can be used for sensing application. The goodness of exciting non-linear effects determines by the lowest power that corresponding to ration between squared Q-factor and mode volume. Also, it depends on the material with which microcavity was made of. So the nonlinear gain of chalcogenide glass is of up to 2-4 orders larger than that of silica. In this work, the power threshold has been calculated for silica and chalcogenide classes and compared.

Fiber-based mid-IR lasers and applications

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Summary

We review recent progress in ultrashort pulse generation in the mid-IR wavelength range between 2 µm and 4 um based on fiber and solid-state lasers and amplifiers, highlighting the most recent achievements in the Laser Physics Group at NTNU such as a high pulse energy (up to 60 nJ) Cr:ZnS oscillator [1], femtosecond/picosecond Ho-fiber MOPA [2,3], and Yb- and Tm-fiber MOPA based OPGaP frequency combs [4]. The shortest pulses that we could recently generate around 4 microns reach only three optical cycles in duration.at the highest reported output power of 250 mW and 50 % efficiency [4].

The built-in tunability of femtosecond pulses in Tm-fiber laser, high pulse energies in excess of 1 microJoule, high quality frequency combs as well as the ability to produce supercontinua directly from the laser are making this novel mid-IR laser technology particularly attractive for industrial applications demanding either high quality and fine material processing or ultrahigh sensitivity measurements. The application areas include, but are not limited to microelectronics, photovoltaics, THz generation, confocal nonlinear microscopy and neurosurgery, as well as environmental, oil and gas sensing. In this talk we will discuss a few most interesting applications that benefit from the ultrashort pulsed mid-IR femtosecond laser sources, focusing on fine material processing of semiconductors in general and silicon [5] in particular, as primary future application of ultrafast lasers operating above 2 microns [6].

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“Development of femtosecond laser devices in specialty optical fibers for sensing and fibre laser applications”

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Presentation: oral

Abstract

Femtosecond lasers are well known for their applicability to sub-micron inscription and modification of transparent materials and have been used by research centres and companies for more than a decade. Femtosecond laser-inscribed optical filters, such as fibre Bragg gratings (FBGs), typically have high thermal stability (up to 1000 ^{o}C) and offer a robust design as there is no requirement for fibre stripping and recoating. The application of conventional femtosecond-laser inscription methods for Bragg grating filter inscription in optical fibres, such as the point-by-point and the phase mask inscription methods, offer advantages and disadvantages. In order to address some of the disadvantages, the Cyprus University of Technology has recently developed a new inscription method, the *plane-by-plane* method, which improves the controllability of the Bragg grating inscription parameters regarding the period, refractive index modulation, spatial dimensions of the grating, coupling length and order.
The flexibility offered by the particular inscription method leads to the possibility for producing advanced femtosecond laser-inscribed FBGs, such as apodised FBGs, and a means to limit the excitation of higher order modes in multimode fibres, the inscription of fibre laser cavities in different active material fibres for monolithic lasers and the development of various optical comments for applications in the sensing and fibre laser domains.
Our company is exclusively licenced by the Cyprus University of Technology, to use their patent and specialised on the development of custom-made optical fibre sensors.

UV inscribed Bragg grating on ytterbium and germanium doped nanostructured core silica fiber for laser applications

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For the first time successful inscription of high reflectivity Bragg grating in nanostructured core active fiber is presented. Nanostructurization of the fiber core allows to distribute the active and photosensitive areas all over the core avoiding unfavorable clustering between germanium and ytterbium particles. Discrete glass areas with feature size smaller than λ/5 compose the nanostructured fibre core with effectively continuous refractive index profile [1][2].

For fabrication of nanostructured core we used 1320 doped with ytterbium and 439 doped with germanium silica glass rods arranged in a regular lattice designed for effective step-index profile. The average germanium doping level within the core was only 1.1% mol but it allowed to inscribe efficiently the Bragg grating with preliminary hydrogen loading with the excimer laser at 248 nm. The nanostructured core was 8.6 µm and the internal cladding was 112 µm in diameter coated with low index polymer to achieve the double-clad structure. In the first proof-of-concept in the laser setup we achieved 35 % of slope efficiency in relation to launched power for the fiber length of 18 m. The output was single-mode with spectrum width below 1 nm. The maximum output power limited by pumping diode was 2.3 W.

The nanostructurization opens new opportunities for development of fibers with a core composed of two or more types of glasses. It allows to control simultaneously the refractive index distribution, the active dopants distribution and photosensitivity distribution in the fiber core providing opportunities for novel optical fibre designs.

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Assessing the optical properties of chalcogenide glasses

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Refractive index dispersion is one of the critical parameters that influences the design of optical components. Measurements on prisms in our laboratory can determine the mid-infrared refractive index of chalcogenide glasses to a standard deviation of precision of less than 0.002. However, shortcomings of this technique are that it requires multiple light sources and intensive sample preparation. The modelling of transmission spectroscopic data [1] is an attractive alternative and was extended by us into the MIR region by introducing a two-term Sellmeier equation [2]. This approach determines the refractive index dispersion of chalcogenide glasses to an accuracy of better than 0.4 %. In the presentation we will review this method, and discuss its recent extension to the evaluation of thermo-optic coefficients.

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Eye safe broadband emission and lasing in germanate double-clad optical fibers co-doped with rare-earth

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Laser and ASE (amplified spontaneous emission) optical fiber sources emitting radiation in the eye- safe range (>1.5 µm) have attracted extensive interest because of their applications in surgery, remote sensing, lidar and atmospheric pollution monitoring. Key issue in construction of new active optical fibers is a of low phonon and thermally stable glass, which can be applied in optical fiber technology. The most popular silica fibers are characterized by low losses, but due to high phonon energy the efficiency of donor – acceptor energy transfer in e.g. Yb^{3+}/Ho^{3+}, Tm^{+}, Er^{3+} co-doped optical fibers is limited. Among oxide glasses, germanates have attracted a considerable interest for constructing RE- doped optical fibers. Their good thermal stability, low phonon energy (800 cm^{-1}) and high transparency in a wide wavelength range make them a good candidate as a host for RE ions. Germanate glasses doped with Er^{3+}, Tm^{3+} and Ho^{3+} enable to achieve 1.5-2.1 µm emission corresponding to radiative transitions of Er^{3+}: $^4I_{13/2}\rightarrow{}^4I_{13/2}$, Tm^{3+}: $^3F_4\rightarrow{}^3H_6$ and Ho^{3+}: $^5I_7\rightarrow{}^5I_8$. All mentioned active ions can be sensitized with Yb^{3+}. Superposition of luminescence bands resulting from radiative transitions gives possibility to obtain ultra-broad emission spectrum .

The presentation will show ultra-broad luminescence in low phonon germanate glasses and double – clad optical fibers. Luminescent properties of Tm^{3+}/Ho^{3+}, $Yb^{3+}/Tm^{3+}/Ho^{3+}$ and $Er^{3+}/Tm^{3+}/Ho^{3+}$ doped germanate glasses and double - clad optical fibers are analyzed. Special attention has been paid on possibility of profiling luminescence spectra and analysis of mechanisms influencing on emission spectra of glasses and optical fibers. Lasing properties of Tm^{3+}/Ho^{3+} under 796 nm have been also presented.

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Author Form - COST Meeting in Warsaw

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Your first name: Florian

Your last name: Lindner

Your title (Prof., Dr., etc.): Dr.

Your status (Student, Ph.D. student, Early Carrier Investigator, Researcher, Dr., Prof., etc.): Researcher

Sex (Male/Female): male

Your affiliation: Leibniz Institute of Photonic Technology (IPHT), Albert-Einstein-Str. 9, 07745 Jena, Germany

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Title 1: "Gas phase deposition of Al/RE-doped preform prepared by modified chemical vapor deposition (MCVD)"

List of Authors with affiliations:

F. Lindner*, C. Aichele*, A. Schwuchow*, M. Leich*, A. Scheffel*, K. Schuster*, K. Wondraczek*
* Leibniz Institute of Photonic Technology (IPHT), Albert-Einstein-Str. 9, 07745 Jena, Germany

Tentative abstract to be submitted by October 10 (please reuse Jena template http://www.aflaser.eu/wp-content/uploads/2017/07/COST-Jena-template.docx)

Presentation: oral/~~poster/any~~

Targeted section - please select one or more from the following list (multiple targets allowed):

1. **WG1 Materials, Fibres, Components and Technology,** Chair: Kay SCHUSTER, Vice-Chairs: Maurizio FERRARI, Hrvoje GEBAVI, Virginie NAZABAL **X**
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6. **STSM** activities, Chair Trevor Benson

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Stefano, Trevor, Hanna, Lidia, & Marian

Active polymeric optical fibers doped by lanthanides and organic dyes

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New organic dyes and lanthanides can be successfully incorporated into the polymeric host to obtain new luminescent properties. Polymer optical structures, including planar and cylindrical optical fibers, are finding wider and wider applications in optoelectronic constructions [1, 2]. This is mainly due to the fact that they have a number of advantages, such as high elasticity, making it possible to produce "flexible" optical fibers with significantly larger diameters (up to several mm), high numerical aperture, lower manufacturing costs and wide-ranging possibilities of doping with functional compounds (organic and inorganic). The high absorption cross section of organic dyes and antenna effect observed in organometallic complexes of lanthanides allow to efficient excitation and luminescence in polymeric fibers. This is also why there are continuously new applications based on this material in the construction of compact light sources, optical amplifiers and metrology systems being developed [3,4]. Beside well-known phenomena of spectral attenuation and reabsorption, the energy transfer between luminescent compounds can be used for effective luminescence profile modification in optical fibre structure. The poly(methyl methacrylate) fibres co-doped with organic dyes (Perylene – Rhodamine 6G), lanthanides (Tb^{3+} - Eu^{3+}) and organic dye – lanthanide (Tb^{3+} - Rhodamine B) will be shown. The luminescence spectrum modification vs. the fibre length will be investigated. Different mechanism of luminescence modification (spectral attenuation, reabsorption, energy transfer) will be presented to obtain specific luminescent properties in the visible spectrum range.

The project was funded by the National Science Centre (Poland) granted on the basis of the decision No. DEC-2017/01/X/ST8/00595. The COST Action MP1401 "Advanced fibre laser and coherent source as tools for society, manufacturing and life science" is also acknowledged.

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Recent achievements in preparation of REE-doped chalcogenide glass fibers

Vladimir Shiryaev[#], Ella Karaksina, Tatyana Kotereva, Gennady Snopatin

G.G. Devyatykh Institute of High-Purity Substances of the Russian Academy of Sciences, 603951, 49 Tropinin Street, Nizhny Novgorod, Russia

Experimental results on the development of high-purity chalcogenide glasses and optical fibers for active mid-IR fiber optics were presented. Research was carried out in the following directions: 1) search of optimum glass compositions for active mid-IR optics, 2) development of purification methods of glasses, 3) development of optical fibers capable to withstand the high power of the laser pumping and having specified luminescence characteristics in the 2-6 μm spectral range.

Methods for the synthesis of high-purity Ge-As-Se-Ga, Ge-As-Se-In-I glasses, host and doped with (0.05-0.3 wt.%) Pr(3+), Er(3+) and Dy(3+) ions have been developed [1-3]. Glasses with a low tendency to crystallization, different glass transition temperatures (Tg=220-356°C), and a high luminescence yield in the mid-IR were produced. On the basis of prepared glasses, single-index and step-index optical fibers were fabricated. Their optical losses and emission characteristics were studied. The influence of the laser pump power at the wavelengths of 1.55 and 1.97 μm on the emission intensity for the REE-doped glass fibers was studied. For the first time, the ability of core-clad chalcogenide Se-based glass fibers to withstand pump power up to 1600 mW was demonstrated. Luminescence spectra were recorded for fiber samples having lengths which correspond to the values required by the numerical models for fiber laser characteristics calculated for chalcogenide fiber materials.

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[3] E.V. Karaksina, T.V. Kotereva, V.S. Shiryaev, J. Lumin. 204 (2018) 154-156

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NANOCOMPOSITE OPTICAL FIBERS DOPED WITH RARE EARTH IONS AND NANOPARTICLES FOR PHOTONIC APPLICATIONS

Jacek Zmojda[a], Marcin Kochanowicz[a], Piotr Miluski[a], Agata Baranowska[a], Darisz Mazur[a] Karol Czajkowski[a], Maciej Sitarz[b], Dominik Dorosz[b], Joanna Pisarska[c], Wojciech Pisarski[c]

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Recently, nanocomposites glass materials embedded with silver particles and lanthanide ions are widely investigated. The main interest is a surface plasmon resonance (SPR) phenomenon which as a result of nanometric particles interaction with external electromagnetic wave led to the enhancement of rare-earth luminescence. In most works, metallic nanoparticles are created in photonic glass by annealing with various time and temperature, but the pretty poor discussion is dedicated to the practical use of plasmonic effect in optical fibers. In this paper, an effect of silver ions on luminescent properties of europium ions in antimony-germanate-borate SGB glass fibers is presented. The glass was synthesized by standard melt-quenching technique and glass fiber was drown at the temperature of 580°C. The analysis of Ag+ ions content, as well as heat-treatment (hT) time, show almost 36% increase in emission at 616 nm for glass fiber co-doped with $0.1Ag^{+}/0.2Eu^{3+}$ ions after the 2h annealing process. In the experiment, the interaction mechanism was investigated in terms of localized SPR in each step of the glass fiber fabrication process. Moreover, we demonstrate that self-assembling of silver nanoparticles on glass fiber surface exist only for fiber co-doped with $0.6Ag^{+}/0.2Eu^{3+}$ ions. The non-conventional bottom-up technique of thin film of Ag nanoparticles was analyzed by SEM measurements.

The project was funded by National Science Centre (Poland) granted on the basis of the decision No. DEC-2016/21/D/ST7/03453. The COST Action MP1401 "Advanced fibre laser and coherent source as tools for society, manufacturing and life science" is also acknowledged.

Effects of protons irradiation on Yb^{3+}, Er^{3+} co-doped phosphate glasses

Laura Mihai[1#], Dan Sporea[1], Laura Nita[2], Rajannya Sen[3], Laeticia Petit[3], Ion Burducea[4], Mihai Straticiuc[4]

[1]Institute for Laser, Plasma and Radiation Physcis, Center for Advanced Laser Technologies, Magurele, Romania
[2] Universitatea Politehnica, Bucuresti, Romania
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[4]Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Magurele, Romania

There is a high interest in developing new materials to increase the capabilities of optical fibres and optical fibre systems that could be used for multiple applications, including space missions. The highest percent of ionizing radiation from space is formed by protons particles. In this paper, phosphate glasses within the system (98-x) ($0.50P_2O_5$-$0.40SrO$-$0.10Na_2O$) -$0.5Er_2O_3$-$1.5Yb_2O_3$-xZnO with x=1.25 and 2.5 have been prepared using standard melting process in air. After polishing, the glasses have been exposed to a fixed fluency of 10^{15} p/cm^2 and two different energies of protons particles in order to check their resistance to this type of ionizing radiation. UV-NIR spectroscopy was combined with THz spectroscopy to evaluate the damage/ resistance of this type of samples. Parameters such as UV-NIR absorbance and absorption coefficients, refractive index and the real and imaginary part of dielectric constant in the range 0.06 – 1.2 THz were investigated for all samples prior to and after irradiation. The results showed that lower proton energies have higher effect on the samples than the highest one.

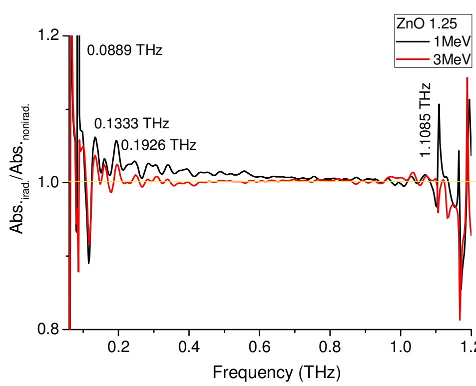

Fig. 1 The changes of absorption coefficients for a doped phosphate glass samples having 1.25 w% of ZnO irradiated with two energies of protons particles.

Acknowledgement

Laeticia Petit would like to acknowledge the financial support of the Academy of Finland (Academy Project-308558). Romanian authors acknowledge the financial support of the Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI), under the contract 24 PED/2017, project “Photonics devices under extreme operating conditions”— PHOENIX.

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Your last name: **KRZYSZTOF**

Your title (Prof., Dr., etc.): **Professor**

Your status (Student, Ph.D. student, Early Carrier Investigator, Researcher, Dr., Prof., etc.): **Researcher**

Sex (Male/Female): **Male**

Your affiliation: **Wroclaw University of Science and Technology**

Your e-mail address: **krzysztof.abramski@pwr.edu.pl**

Title 1:

Advances in research on fiber lasers in the Wroclaw's "Laser and Fiber Electronics Group", in the frame of COST 1401

List of Authors with affiliations:

K.M. Abramski, J. Sotor, G. Sobon, D. Stachowiak, P. Kaczmarek, K. Krzempek, G. Dudzik, M. Pawliszewska, J. Boguslawski,

Tentative abstract to be submitted by October 10 (please reuse Jena template http://www.aflaser.eu/wp-content/uploads/2017/07/COST-Jena-template.docx):

During the last four years of the COST Program, a group of Laser and Fiber Electronics (Wroclaw University of Science and Technology) has significantly developed several important research and application threads. The presentation will include a description of achievements such as:
- optical combs based on fiber lasers with non-linear elements such as graphene and other topological isolators, working on 1550 nm (based on Er-doped fibers), and around 2 microns (based on Thulium-doped and Holmium-doped fibers),
- differential frequency generation of different fiber lasers in MIR (DFG 1064/1550nm comb, 1550nm/2µm comb),
- supercontinuum generation in photonic optical fibers by comb lasers,
- phase-locking of laser beam arrays from fiber optic amplifiers.

Presentation: oral

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Your first name: Amiel

Your last name: Ishaaya

Your title (Prof., Dr., etc.): Prof.

Your status (Student, Ph.D. student, Early Carrier Investigator, Researcher, Dr., Prof., etc.): Prof.

Sex (Male/Female): Male

Your affiliation: Ben-Gurion University of the Negev

Your e-mail address: ishaaya@bgu.ac.il

Title 1: Femto-second inscription of optimized FBG output couplers

List of Authors with affiliations: Z. Montz, A. Shirakov, U. Ben-Ami, S. Genish, and A. A. Ishaaya, Department of Electrical and Computer Engineering, Ben-Gurion University of the Negev, Israel

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Stefano, Trevor, Hanna, Lidia, & Marian

An intra-cavity method to measure dispersion properties based on pulse shape variations in a tunable fiber laser

T. Tiess, A. Hartung, M. Becker, M. Rothhardt, H. Bartelt, and M. Jäger

Leibniz Institute of Photonic Technology (IPHT) Jena, Albert-Einstein-Straße 9, 07745 Jena, Germany

The dispersion properties of fibers govern the pulse evolution through an optical system. This is of particular importance in mode-locked fiber lasers, defining the pulse regime, as well as in supercontinuum generation in specialty fibers. In order to design such systems properly, the dispersion properties of the involved fibers and components need to be determined. While common methods based on free-space coupled spectral interferometry set the benchmark in terms of resolution, sensitivity and spectral bandwidth, they are prone to environmental influences and employ elaborate analysis procedures to retrieve the dispersion features from the indirect measurement. On the other side, a direct method in the time domain, measuring the pulse delays at different wavelengths, requires long fiber lengths of hundreds of meters to kilometers due to the limited sensitivity [1]. In this work, we present a novel direct intra-cavity measurement for the dispersion properties of fiber optical elements based on evaluating pulse shape variations along the tuning range of a fiber laser [2]. The concept relies on a tunable theta-cavity fiber laser (TCFL) as shown in Fig.1a [3]. Working with a fixed physical resonator length for each wavelength of the FBG array tuned laser, dispersion effects introduce marginal shifts in the pulse round trip time that are quantified based on asymmetric pulse steepening. The concept is demonstrated by analyzing 2 fiber samples (Nufern PM980-XP) and comparing it to a reference method based on spectral interferometry [4] with an excellent agreement (see Fig. 1b). Due to the pulse formation over multiple round trips, an enhanced sensitivity is obtained with this direct approach in the TCFL, requiring fiber lengths of less than 100m.

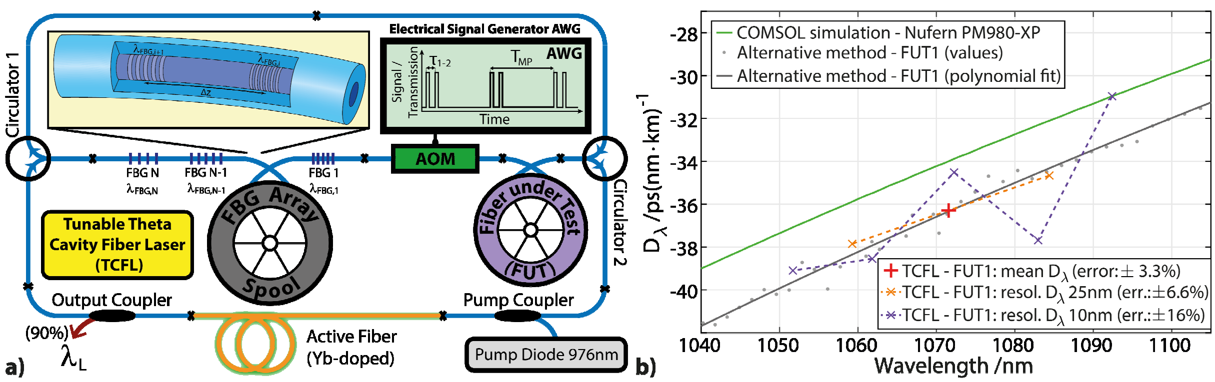

Fig. 1: Part a) shows the setup of the tunable theta cavity fiber laser (TCFL) that provides the basis for the dispersion measurement. The fiber under test (FUT) is spliced inbetween circulator 2 and the acousto-optic modulator (AOM). Part b) shows the achieved experimental results measured for the FUT Nufern PM980-XP. The results with the TCFL are compared to another experimental method based on spectral interferometry [4] and simulations conducted with COMSOL. The experimental results agree within a 1.3% deviation (error bar: ±3.3%).

corresponding author: tobias.tiess@leibniz-ipht.de

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Pulsed Dual-Wavelength Pumped 3.5 µm Erbium-doped Mid-Infrared Fiber Laser

Nathaniel Bawden,[1] Hiraku Matsukuma,[2] Ori Henderson-Sapir,[1,3#] Elizaveta Klantsataya,[1] Shigeki Tokita,[2] and David J. Ottaway[1]

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The wavelength of rare-earth doped fiber laser has recently been pushed beyond 3 µm. This offers exciting opportunities for new applications in medical diagnosis, remote sensing of trace gases, defense and material processing [1]. Importantly, fiber lasers operating at wavelengths longer than 3 µm can cover the fundamental light absorption features of vibro-rotational transition of the C-H, N-H and O-H chemical bonds.

Medical and remote sensing applications require short-pulse lasers to effectively operate, and until recently there were no pulsed, fibre based laser that operated at wavelengths longer than 3 µm. The first demonstration of a watt level rare-earthed doped fibre laser that operated at 3.5 µm was achieved using dual-wavelength pumping in erbium doped ZBLAN fibre. These first demonstrations only operated in CW and QCW modes. [2,3]

Numerical simulations suggested that Q-switching at 3.5 µm was possible. We report on experimental results using a hybrid fiber and open resonator configuration using an acousto-optic modulator as the Q-switch. Stable Q-switching was achieved at repetition rates of 20 kHz to 120 kHz. Our latest results will be presented.

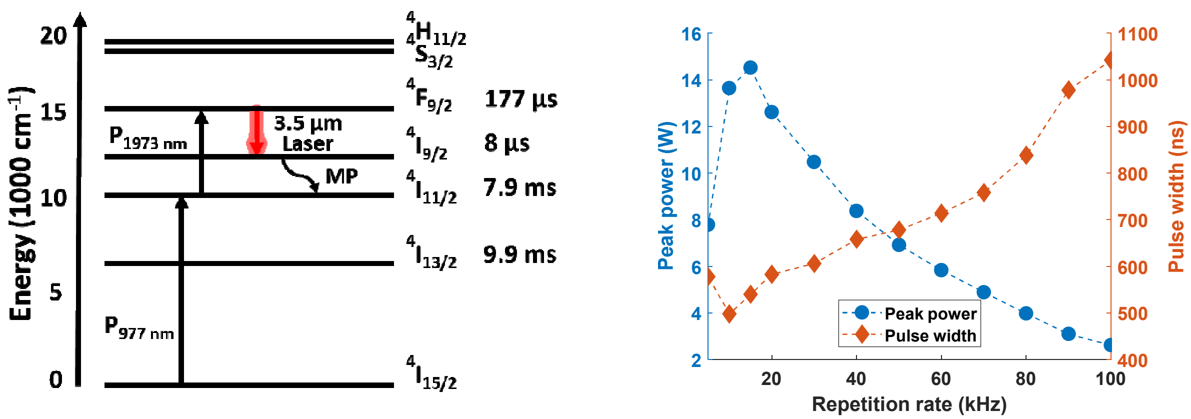

Figure 1 – Energy level diagram of Er3+ doped ZBLAN (left), Peak 3.5 um power and pulse width (right).

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Modelling of long wavelength fibre lasers

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Modelling and design is essential to the development of novel fibre lasers. In the recent years the main research focus has been on the development of fibre lasers operating at wavelengths exceeding 2000 nm. This research effort included both experimental and modelling activities. This therefore has been also reflected in the activities of the COST action, whereby extensive experimental activities where accompanied by numerical modelling effort. Two particular modelling tasks were followed, namely numerical calculation of the output power of a dysprosium ion doped chalcogenide glass based fibre laser and of an erbium ion doped ZBLAN fibre laser. In this contribution we present the most recent results obtained by the participants of this action.

Figure 1 shows example numerical results obtained using Method of Lines for the ZBLAN fibre laser at the pump power of 10 W. The operating wavelength of the laser is 2800 nm whilst the pumping wavelength is 976 nm.

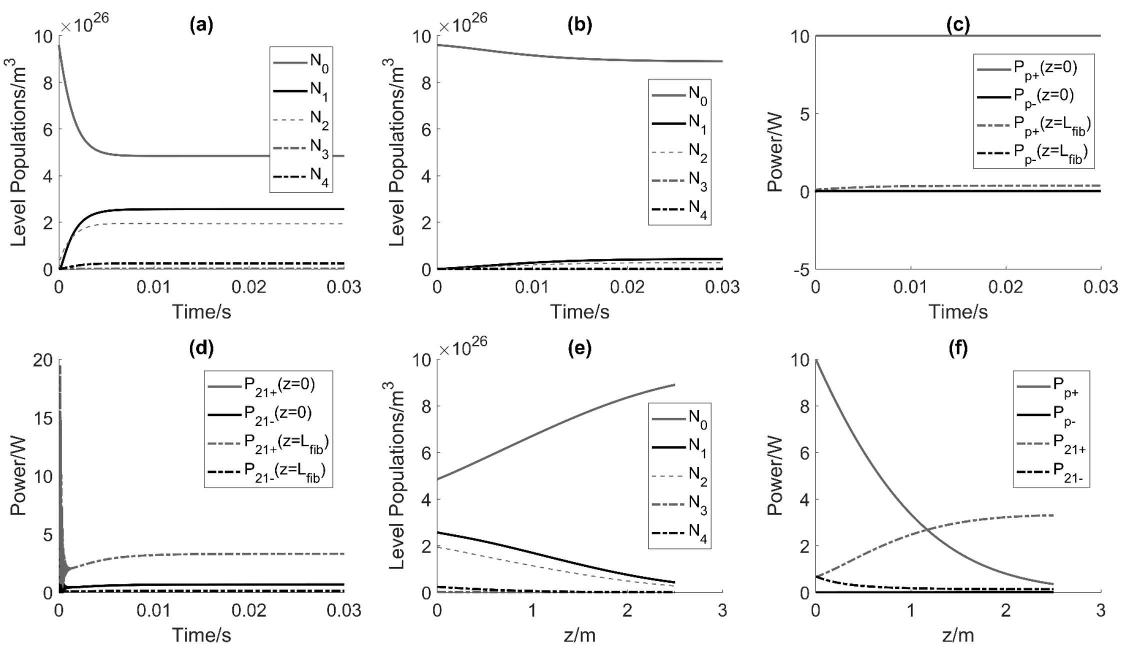

Fig.1. The numerically calculated dependence on time of (a) level populations at pumped side; (b) level populations at end side; (c) pump powers and (d) signal powers at selected positions; and spatial distributions for (e) level populations and (f) pump and signal powers. The fluoride glass fibre laser operates at 2800 nm. The pump power is 10 W.

Mid-IR, Tm:YLF /KGW external-cavity Raman laser

Salman Noach[1], Uzziel Sheintop[1]

[1] *Department of Applied Physics, Electro-optics Engineering Faculty, Jerusalem College of Technology, Havaad Haleumi 21, Jerusalem, Israel*

This letter presents a dual-wavelength KGW Raman laser with an external-cavity configuration at the mid-IR region. The Raman laser is pumped by an actively Q-switched Tm:YLF laser emitting at 1880 nm [1], and has two different output lines at 2197 nm and 2263 nm. The two lines emit energy pulses up to 0.4 mJ and 0.15 mJ and exhibit pulse durations as short as 21 ns and 5.4 ns, respectively. To the best of our knowledge, this is the first time that the KGW medium [2] is used in a Raman laser in the 2-µm region; hence, it appears to be a promising candidate for efficient wavelength coverage in this spectral range [3,4,5].

The Raman laser output spectrum is shown in Fig. 1. The two lines are observed for orthogonal orientations of the fundamental polarization to each other at the KGW crystal. Fig. 2 present the output energy and peak power of the Raman laser as functions of the pulse energy of the fundamental pump laser at a 1-kHz repetition rate, respectively.

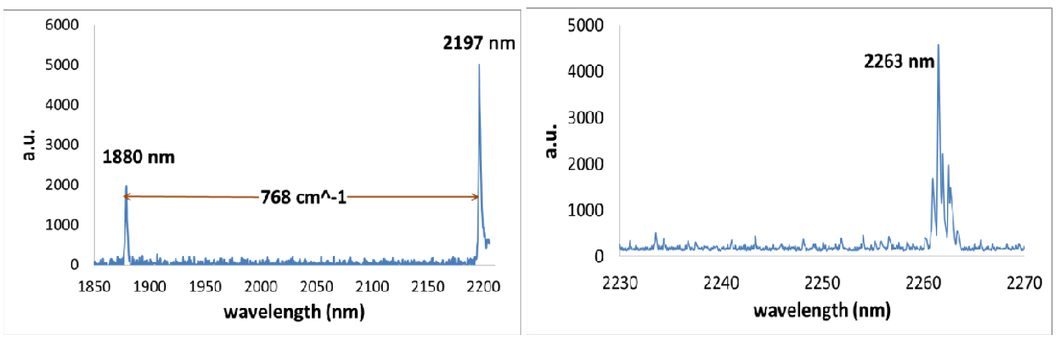

Fig. 1. Spectrum of fundamental and 768 cm−1 line (top) and 901 cm−1 line (bottom)

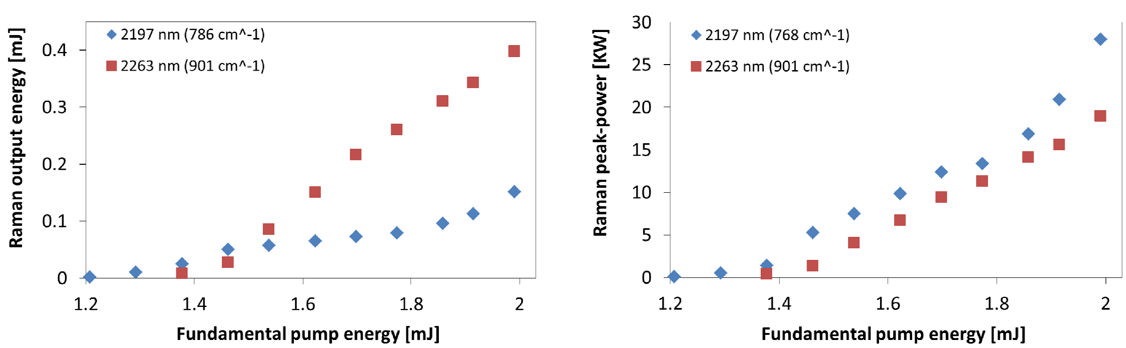

Fig2. Output energy and peak power of the Raman laser as functions of the pulse energy of the fundamental pump.

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Corresponding author: salman@jct.ac.il

Selective transparency in photonic crystals and its impact on grating inscription in photonic crystal fibers

Tigran Baghdasaryan[1], Thomas Geernaert[1], Karima Chah[2], Christophe Caucheteur[2], Kay Schuster[3], Jens Kobelke[3], Hugo Thienpont[1], Francis Berghmans[1]

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It is known that photonic crystals can behave similarly to isotropic and transparent media when their feature sizes are much smaller than the wavelength of light. We have found that photonic crystals can also behave as a transparent and isotropic medium in an anomalously high range of normalized frequencies up to 0.9, i.e. in a region where the crystal's feature sizes are comparable with the free space wavelength of light.

We have demonstrated – using traditional photonic band theory – that the isofrequency curves for triangular lattice photonic crystals and for TE polarized light can be circular in the region above the first stop band, which is indicative of the isotropy of the lattice. In addition, by simulating how efficiently a tightly focused Gaussian beam propagates through the photonic crystal slab, we could judge on the photonic crystal's transparency rather than on isotropy only. This allowed identifying a wide range of photonic crystal parameters that provide for this anomalous or selective transparency.

We have applied this result to femtosecond laser micromachining, by demonstrating what we believe to be the first point-by-point grating inscribed in a multi-ring photonic crystal fiber (PCF). The lack of diffraction and scattering in a specially designed selectively transparent microstructured cladding of a PCF allowed tight focusing of IR femtosecond laser pulses to the fiber's core. This led to the first ever inscription of a fiber Bragg grating by means of femtosecond laser point-by-point micromachining in a dedicated pure silica multi-ring hexagonal lattice PCF [1].

The above opens perspectives for designing PCFs with a cladding that is transparent for transversely propagating light and that can be designed to serve applications ranging from fiber lasers to fiber sensing and lab-in-fiber. Our findings also indicate the possibility to scale up the features of photonic crystals and to extend their operational wavelength range for applications including optical cloaking and graded index guiding [2].

This work is a joint effort involving Vrije Universiteit Brussel (Brussels, Belgium) and the Leibnitz Institute of Photonic Technology (Jena, Germany), partially supported by COST MP1401.

[1] Baghdasaryan T., et al. (2018) Scientific Reports, 8, 5470.

[2] Overton G. (2018) Laser Focus World, 8, 9-10.

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Author Form - COST Meeting in Warsaw

Honourable COST Colleague,

To plan technical activities efficiently we need an input from you regarding your technical contribution. We kindly ask to return this form to M.Marciniak@itl.waw.pl at your earliest convenience, or by September 30. Keep the form for your records!

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Your first name: **Mary**

Your last name: **Konstantaki**

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Your status (Student, Ph.D. student, Early Carrier Investigator, Researcher, Dr., Prof., etc.): **Researcher**

Sex (Male/Female): **Female**

Your affiliation: **Institute of Electronic Structure and Laser (IESL), Foundation for Research and Technology- Hellas, (FORTH), Greece**

Your e-mail address: **mkonst@iesl.forth.gr**

Title: Optical Fiber Bragg Grating Sensors for Torque Induced Strain Monitoring in Filament Wound Composite Shafts

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Tentative abstract to be submitted by October 10 (please reuse Jena template http://www.aflaser.eu/wp-content/uploads/2017/07/COST-Jena-template.docx)
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*****************THANKS for returning this form to M.Marciniak@itl.waw.pl !!!******************

Stefano, Trevor, Hanna, Lidia, & Marian

Erbium doped fiber laser: sensing and complex networks

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Fiber laser for sensing

In a Fiber Bragg laser (FBL) the active medium is an erbium-doped optical fiber, delimited by two fiber Bragg grating (FBG) mirrors with identical pitch directly inscribed on the fiber, which constitute a Fabry-Perot cavity. When pumped with 980 nm radiation, laser oscillation can be obtained with an emission peak around 1530 nm. Fiber Bragg lasers are fabricated by imprinting two FBGs, with identical peak wavelength on a single-mode photosensitive erbium doped fiber by using an excimer (KrF) UV laser. The reflectivity of the FBG mirrors are regulated for the best laser operation (typically > 99% for the total reflecting mirror, > 90% for the output coupler mirror). The emission power ranges from 100 μW up to 1 mW. Variations of the FBG pitch, of the cavity length, and of the fiber effective refractive index n_{eff}, induced by strain, temperature and pressure, produce a shift of the FBL emission wavelength.

Sensors based on optical fibers have well known advantages: they offer electrically passive operation and immunity from electromagnetic fields, very small dimensions and have multiplexing capabilities for a quasi-distributed measurement configuration. Remote measurement is also possible. Indeed, the very low signal attenuation (~ 0.3 dB/km) of the fibers in the region around 1.55 µm makes it possible to place the opto-electronic control unit very far from the measurement point. Moreover, high sensitivity and wide dynamic measurement range can usually be achieved.

Complex networks

Complex optical networks containing one or more gain sections are investigated, and the evidence of lasing action is reported. The chaotic diffusion and amplification leads to an emission statistic with characteristic heavy tails and an experimental demonstration of Lévy statistics expected for random lasers. A novel scheme is presented: the lasing network (LANER) [2]. It consists of a complex active optical network, whose connectivity induces a form of topological disorder and can display laser action. The great majority of lasers share the same structure with a single gain section in a simple linear or ring cavity, supporting regular sets of optical modes. A somehow opposite case is the random laser, where the propagation of rays in a disordered gain medium leads to light amplification. The LANER generalizes to strongly connected multiple gain setups and could also be considered as a discrete random laser with a controllable complexity.

[1] Bagnoli P. E., Beverini N., Falciai R., Maccioni E., Morganti M, Sorrentino F., Stefani F., Trono C., Development of an erbium-doped fiber laser as a deep sea hydrophone, (2006) Journal of Optics A: Pure and Applied Optics, 8 No 7.

[2] Lepri S., Trono C. and Giacomelli G., Complex active optical networks as a new laser concept (2017) Phys. Rev. Lett. 118, 123901.

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Unconventional Lithography with Plasmonic Metasurfaces

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A two step nanotechnology is proposed to fabricate periodic holes or pillars over a large surface. The first step utilizes nanosphere lithography to produce a metasurface composed of bow-tie antenna elements. Colloidal chemistry can manufacture a large variety of dielectric nanospheres. Such nanoparticles can be self-assembled with the Langmuir-Blodgett technique on a photoresist covered glass substrate to form a single layer of nanoparticulate film. Metal deposition through the monolayer film as a mask results in a periodic structure of bow-tie shaped metallic nanoparticles formed in the interstices between the hexagonally packed dielectric spheres. Then the spheres can be removed by dissolution. Thus, on the top of the photoresist layer bow-tie antennas, which are arranged in a space group P6mm array can be formed Then the mask is removed and the metasurface is illuminated with light. Due to plasmonic effects, the bow-tie antennas can focus the exposing light even at wavelengths where the dielectric nanospheres of the mask are no longer able.

It is shown by numerical simulations that properly designed metasurfaces of bow-tie elements can extend the limits of optical lithography to produce deep subwavelength periodic structures. Figure 1. presents the setup and the concept of the proposed unconventional lithography.

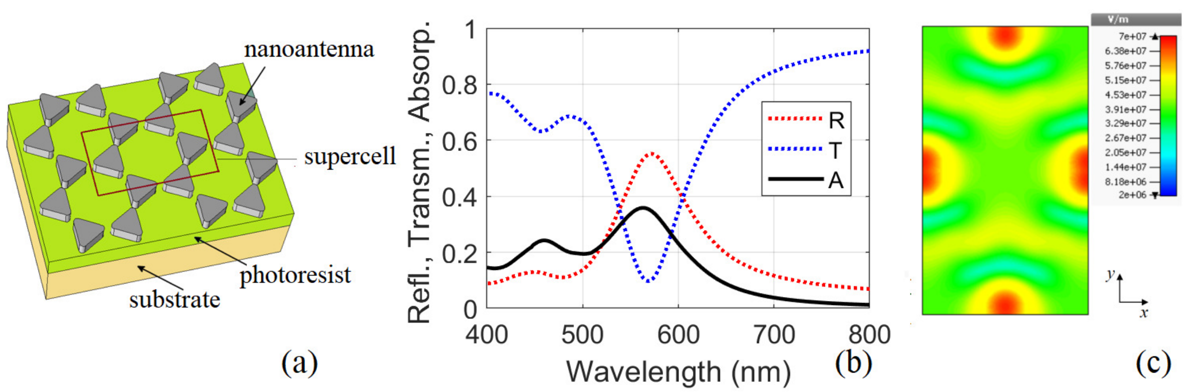

Fig. 1 The setup of the unconventional lithography is presented in (a). The calculated transmission T, reflection R and absorption A spectra are shown in (b). The maximum absorption occurs at the wavelength of 563 nm and the corresponding averaged electric field distribution at the bottom of the photoresist layer is shown in (c). The field enhancement in the region of the gaps is substantially stronger than in other parts of the supercell. This intensity contrast suggests that the photoresist is properly exposed and after dissolution deep subwavelength nanopatterns can be obtained.

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