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Mid IR Applications of Chalcogenide Based Microstructured Fibres

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Abstract *– Soft glasses like tellurite, bismuth- oxide-based glasses, and* ***CHALCOGENIDE*** *glasses have intrinsic nonlinearities from 10 to 100 times than those of silica glass. Among these soft glasses the Raman gain coefficients of chalcogenide glass fibres are almost 300 times higher than that of silica fibres, and the Brillouin gain coefficient is more than 2 orders of magnitude more than that of silica-based fibres. In addition chalcogenide shows low linear absorption, low two-photon absorption, and fast response time because of the absence of the free- carrier effects. As a result, optical fibres made of chalcogenide glasses, are efficient a] for generating mid-IR nonlinear phenomena, b] fabricating short active fibre devices and c] achieving fibre Raman and Brillouin lasers. In particular, biomedicine and sensing will be strongly aided by these devices. New communication and remote sensing systems operating in unexplored atmosphere wavelength windows could become a reality. This paper reviews the deployment potential of* ***chalcogenide*** *along with the application trends and improvements that are underway.*

Keywords*: Signal processing method, precise estimation of* L_{eq} *,Nonlinearity, wide bandwidth, high power delivery*

I. Introduction

Elements such as sulphur, selenium or tellurium, are called chalcogen and stable glasses that can be made from these elements combined with other elements such as arsenic, germanium, antimony, gallium, are called Chalcogenide. Chalcogenide can come in a variety of colours depending on their chemical constituents and ranging from partially transparent to completely opaque. They are quite different from Silica used for semiconductors and conventional optical fibres. Such glasses can exhibit interesting phenomena like mid infrared transparency. The composition can be adjusted to tune
a] refractive index b] melting temperature and c] nonlinearity.

Mid IR science and technology requires powerful, coherent, robust, and compact laser sources at wavelengths beyond 3 microns. Though during the last decades, a number of mid-IR laser sources have been developed but they have shown low conversion efficiency and limited beam quality besides being bulky, and expensive. The developments in optical fibre technology however have thrown enough light to remove such obstacles. The possible very compact size combined with higher lasing efficiency can make mid-IR fibre sources attractive for telecommunications, industrial, and medical applications.

II. Silica Verses Chalcogenide

Silica-based fibre lasers have proved to be both efficient and compact sources in the near-IR wavelength range. However they are not able to provide mid-IR wavelengths because of their high phonon energy and limited transparency beyond the wavelength of 2µm.
Chalcogenide glasses are a] chemically and mechanically durable b] have a low toxicity c] possess reasonably large glass-forming regions and d] can be fabricated into low-loss fibres. In addition their high refractive index (2 to3) and low phonon energy (250 to 400cm^{-1}) result in a larger radiative decay rates, high absorption and emission cross sections of radiative electronic transitions. These properties result in high quantum efficiency.

The electronic energy levels of rare-earth ions allow a number of useful transitions from 2 to 12microns. However, only a few glass hosts can efficiently activate transitions at longer wavelengths. The low phonon energy of the chalcogenide glasses enables an efficient laser transition between closely spaced electronic energy levels allowing many IR transitions. Furthermore, the high rare earth solubility into several chalcogenide glasses facilitates the fabrication of efficient rare earth doped lasers and appliers.

III. Advantages of Microstructured Fibres

The technology used to fabricate low loss single mode conventional fibres fibres in step-index configuration requires extreme care and expertise. When chalcogenide is used the different physical properties of the core and cladding glasses [with refractive index variation] may promote crystallization, bubbles, contamination at the core/cladding interface, and core ellipticity. Moreover, it is difficult to fabricate step- index fibres having very small and very large mode area, because a fine control of the refractive index of the core and cladding cannot be obtained.

In order to overcome these problems for using chalcogenide, the use of microstructured optical fibres [MOF] or photonic crystal fibre (PCF) technology is a feasible and attractive solution. In fact, it eliminates the problems induced by the core/cladding interface since a single materials is used. In addition, the single-heating step used to make the MOFs allows both the reduction of the crystallization problems and fibre losses. Lastly, the high refractive index of the chalcogenide glass enables a better confinement of the light by using only a few rings of air holes.

Rare earth elements, such as erbium, ytterbium, praseodymium, neodymium, samarium, and thulium, can be used to fabricate active fiber amplifiers operating at different wavelengths. Erbium doped fiber amplifiers (EDFAs) are nowadays available for long-haul communication systems with conventional single mode fibres.

These devices are very attractive because of their high gain, wide optical bandwidth, high output saturation, low noise, low insertion losses, high reliability and compactness, polarization independence, and possibility of choosing the pumping laser diode at either 980nm or at 1480nm wavelengths.

EDFA technology is mature and widely employed nowadays. However further researches are needed to obtain amplifiers with higher gain efficiency. The fibre design for optimizing the transverse section is a dire need to improve the amplifier performance in terms of gain, noise, and output power characteristics as well as device compactness and pump power consumption. In the rare-earth-doped devices, the fiber geometry strongly affects the pump intensity, the overlap of the pump, and the signal propagation modes with the doped core. As a consequence, it can lead to the suppression of the amplified spontaneous emission (ASE), the power scaling and the reduction of the fiber length.

In order to meet these objectives a fine control of refractive index profile of both core and cladding as well as more design flexibility of fiber cross section is required. The conventional optical fibers are not able to completely respond to these requirements, while the Microstructured fibre technology seems to be an attractive solution. A microstructured fibre is typically characterized by a transverse crystal lattice containing either air holes or glass strand running along the fiber axis. These are periodically arranged. As a consequence, these fibers differ in refractive index profile of core and cladding compared to the conventional fibres. In addition the dispersion characteristics can be easily manipulated.

The unique properties of microstructured fibres are extremely attractive for a variety of rare earth doped fibers and devices because they enable more flexibility to control the interaction of both pump and signal modes with the rare-earth-doped host. In addition, the stacking procedure used to fabricate such fibers offers the possibility to accurately confine the rare earth dopant in the central region of the fiber where the pump and signal intensity peaks occur.

IV. Wide Band Sources

The microstructure fibre technology besides endless single mode propagation and group velocity control via a proper design provides broad-bandwidth transmission to chalcogenide glasses.

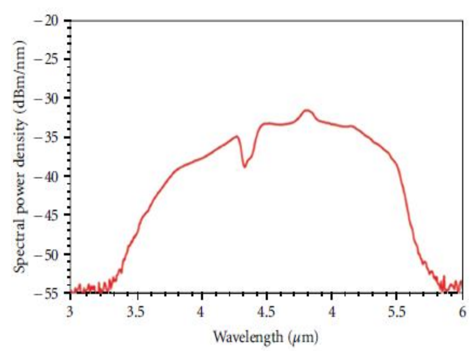

Fig 1 Wide bandwidth with chalcogenide sources

In addition, the high quantum efficiencies of the mid-IR transitions make rare-earth-doped chalcogenide fibers attractive alternatives to obtain black-body sources for 3–5 μm wavelength range.

Microstructured optical fibres are particularly attractive since they offer the possibility to significantly enhance the nonlinearity of the bulk medium by means of a strong light confinement of the electromagnetic field. Another advantage is the ability to tailor the material dispersion

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by adjusting the waveguide dispersion design. Consequently, a wide range of applications has strongly benefited from these remarkable features to generate octave-spanning optical supercontinuum for biology or optical metrology, to process nonlinear effects with high efficiency and compactness, and even to levitate particles.

V. All Optical Signal Processing

Equations should be placed at the center of the line and provided consecutively with equation numbers in parentheses flushed to the right margin, as in (1). You must use Microsoft Equation Editor or Mathtype.
The growing wavelength division multiplexing [WDM] systems demand aggregate rate in excess of terabit per second. Adding more wavelength channels is not the complete solution to future capacity demand, as each channel results in increased equipment costs and added network complexity. Hence increasing the data rate of each individual channel through optical time division demultiplexing might be the means by which the capacity of future transmission systems will be expanded.
In order to operate at bit rates as high160 gigabits per second and beyond optical communications systems will need to process signals entirely in the optical domain to overcome the speed limitations associated with opto-electronic conversion. All-optical signal processing involves the control of light by light, and this is only possible in a nonlinear optical material.

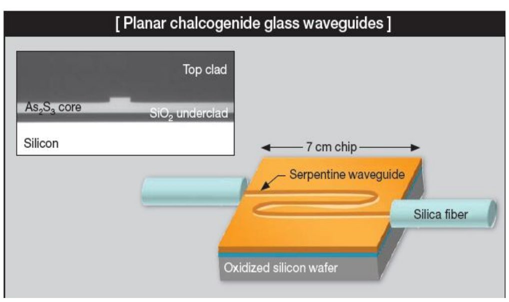

Fig 2 Planar waveguide – basis for a photonic chip

Many nonlinear optical materials have been studied like semiconductor optical amplifiers, nonlinear fiber, and lithium niobate. However the essential requirements of a] large ultrafast nonlinear response b] low nonlinear absorption are not met by any including Silica.

Chalcogenide glass planar waveguides are a new contender in this race. These glasses meet the requirements for all-optical signal processing and are leading to a number of useful results.
Fig2 shows the possible photonic chip based on chalcogenide materials.

VI. High Power Delivery

While solid-core PCF can be exploited for both optical amplification and nonlinear applications, hollow-core photonic-bandgap-chalcogenide fibres can be effectively deployed for higher power mid-IR laser transmission.

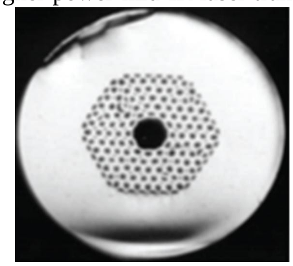

Fig 3. Hollow core chalcogenide microstructured fibre

Fig 3 shows prototype reportedly made already. Moreover, the optimization procedure of both the cladding structure and the core size to obtain the overall losses lower than the material ones, lies in the realization of a hollow-core PCF having multi rings of hole.

VII. Medical and surgical applications

In medical and surgical applications the output source properties like power and wavelength are important. Moreover, other laser characteristics such as beam quality may be important for applications requiring precise and efficient ablation of hard and soft biological materials.
The recent technological progress in the development of lasing materials, in the fabrication of sophisticated optical fibers, and in the fabrication of beam-shaped high-power diode laser has positioned the infrared fiber laser as one of the most promising technologies in bioscience and medicine. Following are the major segmentations applications:
In surgery: cardiology bloodless operations, on abdominal and thoracic organs, skull and brain microsurgery, corneal surgery.
In diagnostics: endoscopic investigations, and optical coherence tomography.
In therapy: the treatment of cancer, spider veins, and vascular dysfunction. In cosmetics and aesthetic medicine: smoothing wrinkles, resurfacing the skin, and bleaching tattoos.
Therefore, due to their inherent flexibility of physical principles and design, fiber lasers have enormous potential to bring new opportunities to biophotonics and biosciences. Generally, a lot of medical applications require the mid infrared wavelengths, in the range 2 to 10 μm. In particular, laser emitting in the 2-3 μm range has gained, in recent years, strong attention for coagulating of soft and hard biological tissues. Moreover, mid-IR laser is a promising technology for the study of biomolecules because most of these ones have a specific absorption in the mid-IR wavelength range, and the

photon energies are an order of magnitude lower than those of UV lasers.

Significant efforts have been done to develop mid-IR fiber lasers and amplifiers, but the high cost of fabricating fibers with sufficiently low losses in such wavelength range has slowed down the research efforts in this field. This is probably due to a lack of host materials having wide optical transparency, good drawing ability and low phonon energies of the glass matrix, good rare-earth solubility, suitable environmental durability, and mechanical properties. Advances in the development of rare-earth-doped optical fiber based on chalcogenide glasses have dramatically pushed progress in mid-IR laser devices. In particular, the good midinfrared transparency permits them to scan the entire spectral range of biomolecules and the chalcogenide glass resistance to the chemical corrosion results in good biocompatibility with biological components.

VIII. Supercontinuum Generation in MID IR

Nonlinear optical processes such as four-wave mixing and supercontinuum generation require high nonlinearity and zero or low group velocity dispersion for applying in the efficient low power, short- length fibre devices. The group velocity dispersion in an optical fibre is decided by both the material and waveguide dispersion. Generally because of the high refractive index, the dispersion of chalcogenide glasses originates mainly from the material dispersion and the zero-dispersion wavelength lies in the IR region, at longer wavelengths compared to silica and far from the wavelengths of conventional fibre based pump lasers. As a result the use of nonsilica fibres to develop supercontinuum sources having an efficient spectral broadening up to the mid-IR often requires expensive and high-power pump lasers.

The Microstructured fibre technology seems to be a potential solution to these drawbacks since the design flexibility of the microstructure in the transverse plane can help the tuning of the chromatic dispersion, dispersion slope, relative dispersion slope, and zero-dispersion wavelength in a way which cannot be achieved by using conventional fibres. In fact, the number of holes, their sizes, shapes, orientations and placements as well as the nature of the bulk dielectric material and the refractive index of the inclusions can provide a number of possible variations enabling a fine control of the waveguide dispersion characteristics. In this way, the zero-dispersion wavelength can be tuned below 2 μm where cheaper diode-pumped solid-state lasers are commercially available.

In other words it is possible to extend a supercontinuum beyond 2μm through chalcogenide fibre.

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