SOLID OPTICAL FIBERS CONTAINING PbS QUANTUM DOTS FOR FIBER LASER APPLICATIONS

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Abstract: Quantum dots (QDs) embedded in glass have not been translated to optical fibers to date. In this paper, we report the fabrication of PbS QD containing optical fibers from silica glass containing PbS QD precursors by melt and draw technique. Interestingly these fibers containing QDs have shown absorption spectra with an excitonic peak and emission in a very wide range from 1000 nm to 2400 nm. These fibers could be utilized for fiber laser applications in future.

Keywords: Quantum dots, PbS, Optical fibers, Emission, Absorption.

Introduction: Optical fiber lasers, due to their high output power, excellent beam quality and precise and compact nature remain the most efficient solid state lasers to date and have been a subject of tremendous research since decades due to their enormous applications ranging from material processing, telecommunication, spectroscopy and medicine to military domain [1]-[4]. It is observed that the gain material in such fibers still remain confined to rare earth doped glasses [5]-[7] with a narrow range of wavelengths making them inapplicable for a vast field of unconventional wavelength applications such as drug delivery [8], bioanalysis and diagnostics [9], [10]. Consequently, the growing demand for unconventional wavelength fibers and lasers has lead to ventures leading to fiber lasers with a spectrum of wavelengths. Keeping this in view, quantum dots seem to be a good choice as a dopant material due to their conveniently tunable band gap and photoluminescence profile with the size and size distribution, high PL quantum yields, broad absorption spectra, narrow emission spectra and non linear properties [11]-[15].

During the last few decades there has been a consistent effort for incorporating quantum dots (QD's) in optical fibers by various techniques [16]-[20]. To date solid QD fibers have not been fabricated by using glass containing quantum dots. In this paper, we report the fabrication of solid PbS QD fibers, fabricated by utilizing PbS QD precursor containing glass, and melt and draw technique. Glasses containing QDs have been fabricated since decades but have not been converted to optical fibers due to the deterioration of nanoparticles at high fiber drawing temperatures. Although QD containing glass have been thought of a potential candidate to be drawn into optical fibers, but to date there has been no report on any such fabrication. In this paper, optical fibers containing PbS nanoparticles without cladding have been fabricated. By pumping a 1 cm length with a continuous laser emitting in the absorption spectral band of the particles, the emission was successfully obtained and analyzed in the infrared region.

Experimental: The glass specimen with a nominal composition of $50SiO_2$-$25Na_2O$-10BaO-$5Al_2O_3$-8ZnO-2ZnS-0.8PbO (in mol %) was prepared by melt-quenching method. Starting powders were mixed and melted at 1350 ^{o}C for 30 minutes in alumina crucible with cover under ambient atmosphere. The melt was poured into a brass mold to prepare the glass rod with diameter of 1 cm and length of 10 cm (Fig. 1). The brass mold was preheated at 300 ^{o}C to avoid crack formation in the glass preform. The glass rod thus made was annealed at 350 °C for 3 hours to reduce thermal stress. First set of fibers was fabricated with this glass without any cladding layer. This was done in order to obtain an idea of melting temperature of glass and also to study the behavior of unclad nanoparticle fibers. The fiber draw was possible due to compatible cylindrical geometry of glass containing precursors for QDs with the drawing furnace as shown in Fig. 1. The fiber draw takes place at ~ 800 °C.

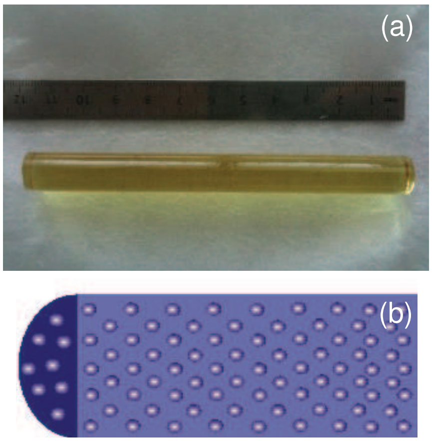

Fig 1: (a) Image of a 10 cm long silicate glass preform containing precursors for PbS QDs synthesis (b) Schematic of the as prepared QD fibers cross sections without cladding.

Results and Discussion: Optical fibers containing quantum dots have been fabricated, without any cladding layer by using quantum dot containing glass as preform as shown in Fig. 1a. Fig 1b represents a schematic of the fabricated fibers. The left over preform, drop off and the fabricated fibers are shown in Fig. 2a. The black color of fibers confirms PbS quantum dot formation. Good quality of quantum dots is confirmed by the TEM micrograph of fibers (Fig. 2b). It was observed that the size of quantum dots obtained from TEM was ~ 2.6 nm. The absorption spectrum further verifies the semiconducting nature of the quantum dots as shown in Fig. 3a. The absorption edge is largely blue shifted as compared to 0.26 eV band gap of PbS confirming quantum confinement effect and hence proving quantum dot formation in fibers. The observation of the excitonic peak shows good quality of PbS quantum dots.

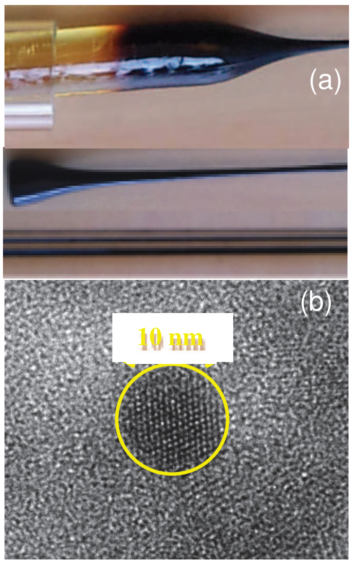

Fig 2: Images of (a) the preform after fiber drawing and the drop-off and the resulting black fibers with different outer diameters, (b) TEM image of the fiber after fiber draw.

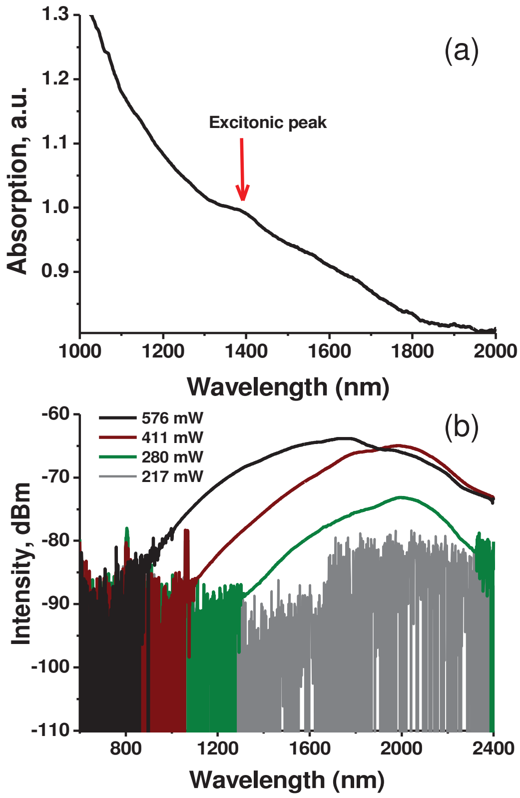

Fig 3: (a) Absorption spectra of a section of PbS quantum dots containing unclad silica fibers (b) Emission spectra of a 10 mm length fiber at different laser powers

Moreover, due to high absorption of these nanoparticles for wavelengths less than 2000 nm the corresponding emission spectra were obtained by using a green 532 nm CW-laser coupled into a section of 0.5 mm diameter fibers. At the fiber-end output, spectrometer and a CCD camera was used for optical characterization. The maximum power injected is 576 mW. Thanks to the silicate glass which could sustain such high power as compared to the liquid core fibers.

A stable emission centered at 1800 nm is observed corresponding relatively to the electronic bandgap of the particles and then amplified with the increase in pump power as shown in Fig. 3b. The range of emission is broad from 1000-2400 nm. It is observed that with the increase in laser intensity the emission intensity of fiber increases with a blue shift of maximum emission wavelength. The blue shift at maximum pump power is due to temperature dependent band gap of PbS nanoparticles.

Conclusions : PbS QD fibers were successfully fabricated from QD precursor containing glass for the first time ever. Unclad PbS QDs dispersed in silica were fabricated and their absorption and emission characteristics investigated.

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