〈초청논문〉

반도체 양자점이 함유된 비선형 광섬유의 개발
Development of nonlinear optical fibers containing semiconductor quantum dots

한 원 택
Won-Taek Han

광주과학기술원 정보통신공학과
Departments of Information and Communications, Kwangju Institute of Science and Technology
Oryong-dong 1, Buk-Gu, Kwangju, 500-712, Korea
Tel : +82-62-970-2215, Fax : +82-62-970-2204, E-mail : wthan@kjist.ac.kr

Abstract: Optical fibers containing PbTe semiconductor quantum dots for nonlinear optical application were developed using modified solution doping method in MCVD Process. The formation of the PbTe nano-sized particles in the core was identified by the resonant absorption peak near 1050nm and the quantum dots were found to precipitate as spherical particles with 5 nm in diameter.

1. Introduction

Recently, much attention has been paid on development of nonlinear optical glasses for application to all-optical devices. Semiconductor doped glass (SDG) was of interest because of it's nonlinear optical properties due to quantum confinement effect by nano-sized semiconductor quantum dots (SQD) dispersed in glass matrix [1,2]. However, most of SDGs are fabricated as a bulk type by the melt and quenching process and a film type by the sputtering or the sol-gel process. No silica fibers containing SQD were developed, to our knowledge, especially for optical communication applications. Nonlinear optical fibers with non-oxide glass compositions have also been developed, but those glasses suffer from unstable mechanical properties and incompatibility with silica glass fibers.

The operating wavelength of optical devices using SDG containing SQD is determined by the band gap energy of the semiconductors and the size of the semiconductors[3]. PbTe was selected as a candidate semiconductor material and nano-sized PbTe particles were incorporated into the core of the optical fiber. We have successfully developed optical fibers containing PbTe nano-sized particles dispersed in the core for nonlinear optical applications at wavelength near 1550 nm. In this paper, the fabrication method of the fibers, their linear and nonlinear optical properties, and microstructure were presented.

2. Fabrication of optical fibers containing PbTe

PbTe was supplied into the core of the preform as a form of ions in doping solution. The doping solution was made by dissolving reagent grade PbO and Te powders in HNO_3 solution to be 0.05M each. The preform tube with partially sintered deposition layers with germanosilicate glass composition was soaked in the doping solution. After draining the doping solution, the preform was dried, sintered, and collapsed. After drawing the fibers based on such conventional solution doping process, optical spectrum was measured. Unfortunately, no optical absorption bands were found, which was expected from resonant absorption from PbTe quantum dots precipitated in the core.

There are two possibilities of having no absorption, extremely low incorporation of the semiconductors and evaporation of the semiconductors during the MCVD process. Since it is known difficult to dope rare-earth ions more than 0.23mol% in fiber core region with 0.1M solution using the general solution doping technique, which consists of the soaking and the drain process [4], we tried to eliminate the drain process during the solution doping process. Both ends of silica tube were partially collapsed, so that the large amount of dopant could be incorporated as shown in Fig. 1. Then the partially sintered core region, which was formed during the MCVD process, was soaked with the solution and dried. To prevent possible evaporation of the dopants, additional core layer was deposited onto the solution-doped layers. Finally these layers were sintered and collapsed. Then the preform was drawn into fibers using the drawing tower.

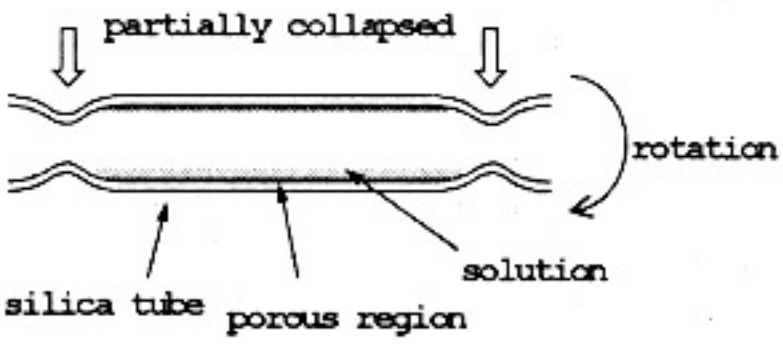

Fig.1. Silica glass tube for modified solution doping

3. Linear and nonlinear optical properties

To identify the precipitation of PbTe quantum dots, optical absorption spectrum of the optical fibers was measured using cut-back method with optical spectrum analyzer (OSA). Fig.2 compares the optical absorption spectrum of the optical fibers fabricated by the conventional solution doping method and by the modified one we developed. The absorption peak clearly appeared near 1050nm and it is attributed to resonant absorption due to PbTe semiconductor quantum dots in the fiber core.

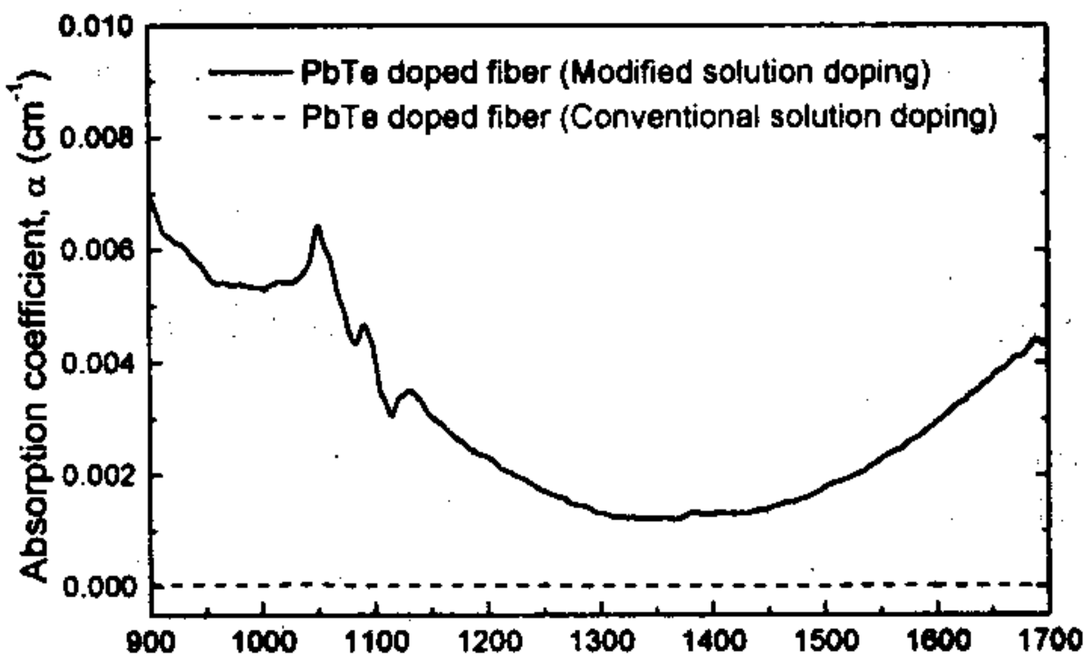

Fig.2. Optical absorption spectra of the PbTe doped optical fibers

The PbTe SQD seemed to be formed during the MCVD process and the fiber drawing process. The fiber core containing dopants through the solution doping process would have sufficiently experienced heat treatment during the MCVD process for the preform and during the drawing process for the fiber. Since the temperature of both processes was above 2000°C, formation of the PbTe particles as precipitates from the Pb ions and Te ions in the glass matrix must have taken place during the fiber preparation.

To examine nonlinear optical property, a new method of optical nonlinearity measurement was employed. Nonlinear refractive index, n_2, was measured using a long-period fiber grating (LPG) pair. The developed fiber containing the PbTe quantum dots was spliced between the LPG pair and interference fringe shift upon pumping with laser diode at 980 nm was measured. The nonlinear refractive index was measured to be ~ 4 x 10^{-15} m^2/W at 1544 nm.

4. Microstructures

To confirm the existence of the nano-sized PbTe quantum dots, the origin of the observed resonance absorption peak near 1050 nm, the microstructure of the core was examined by transmission electron microscopy (TEM). The thin samples were prepared by ion milling of the preform core and the PbTe particles precipitated out of the glass matrix were examined. Fig. 3 shows the microstructure of the core and the PbTe quantum dots were found to precipitate out of the glass phase as spheres with 5 nm in diameter.

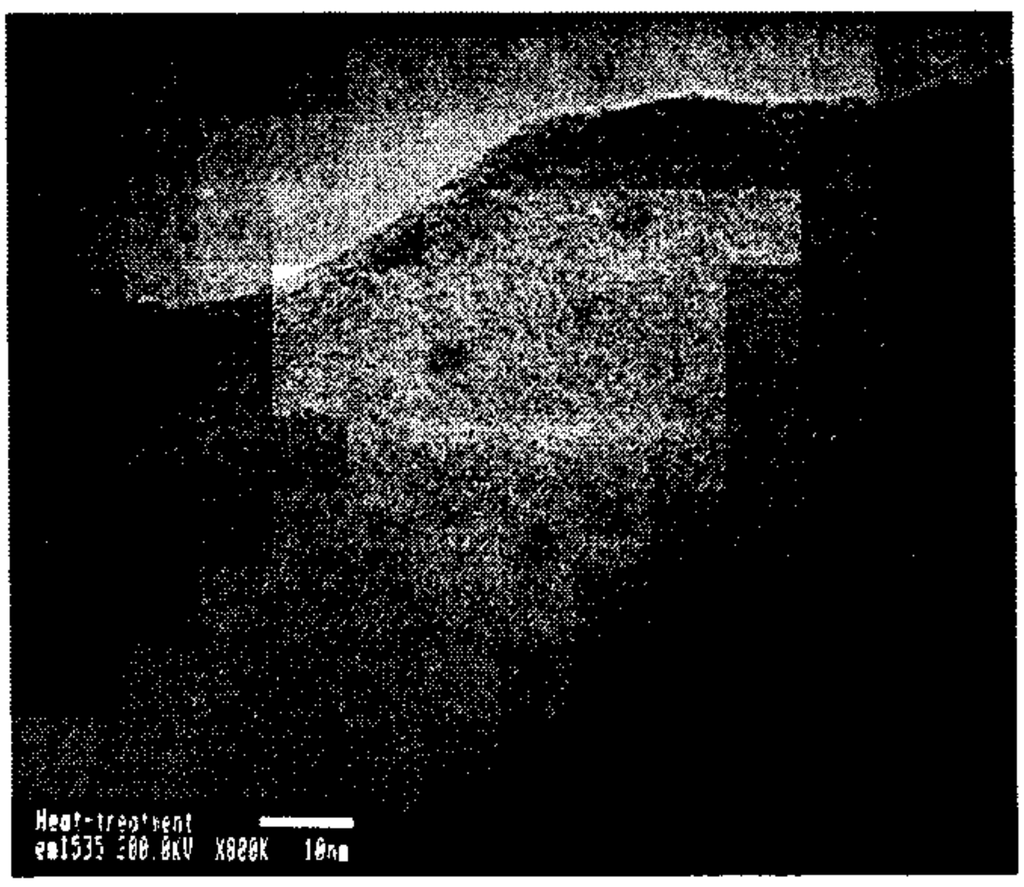

Fig. 3 PbTe quantum dots in the core of the preform by TEM

5. Conclusion

We fabricated the resonant type nonlinear optical fibers containing the PbTe semiconductor quantum dots in the core region. Absorption peak was found near 1050nm and it was attributed to the optical resonance due to the PbTe quantum dots precipitated in the core of the fiber. The PbTe quantum dots were examined by TEM and found to be spherical in shape with 5 nm in diameter. The nonlinear refractive index was measured to be ~ 4 x 10^{-15} m^2/W at 1544 nm.

This work was partially supported by KOSEF through UFON, an ERC program of K-JIST and by the BK-21 IT Project, MOE, Korea. Prof. C.J.Kim at Gyeongsang National University is greatly appreciated for the TEM measurement.

References

[1] U. Woggen, *Optical Properties of Semiconductor Quantum Dots,* (Springer-Verlag 1997).

[2] Y. K. Yoon, W.-T. Han, "Temperature dependent optical resonances of quantum confined CuCl nanocrystals in borosilicate glasses," *Journal of Applied Physics*, Vol. **82**, 2584-2589 (1997).

[3] V. C. S. Reynoso, A. M. de Paula, R, F. Cuevas, J. A. Medeiros Neto, O. L. Alves, C. L. Cesar and L. C. Barbosa, "PbTe quantum dot doped glasses with absorption edge in the 1.5 μm wavelength region," *Electronics Letters*, Vol. **31**, No, 12, 1013-1014 (1995).

[4] J. E. Townsend, S. B. Poole, D. N. Payne, "Solution doping technique for fabrication of rare-earth-doped optical fibers," *Electronics Letters*, Vol. **23**, No. 7, 329-331 (1987).