Strain Distribution in Silica-Clad Crystalline-Germanium-Core Fiber

Dongyang Wang, Na Chen*, Ziwen Zhao, Zhenyi Chen and Tingyun Wang

Key Laboratory of Specialty Fiber Optics and Optical Access Networks, Shanghai University, 149 Yanchang Road, Shanghai 200072, China

*E-mail: na.chen@shu.edu.cn

Abstract: In this paper, we fabricated the crystalline germanium core silica cladding fiber with rod-in-tube method. Its strain distribution inside the fiber was analysed using Raman spectroscopy. The results reveal that the core of the prepared fiber has relatively high degree of crystallization and a relatively uniform strain distribution inside the germanium core.

1. Introduction

The merger of germanium with its high nonlinearity, high Raman gain, infrared transparency and rich optoelectronic functionality into optical fiber opens the door to a nascent and cutting-edge filed.

These good features attracted many researchers starting to study the manufacture of the germanium core optical fiber. Some excellent method, such as molten-core method [1], high-pressure micro-fluidic chemical vapor deposition (HPMFCVD) [2] and powder-in-tube method [3] have been used in the semiconductor core fiber fabrication. In these methods, HPMFCVD is easy to introduce reaction intermediates. Powder-in-tube method is preferred to form an oxide. Due to the big difference of the core and cladding materials, large strain is usually induced during the fiber drawing process, and this will affect the fiber properties a lot. In this paper, we present a highly crystalline germanium core fiber with a uniform strain distribution fabricated by the rod-in-tube method.

Although many ways were presented to produce the fiber, more problems still exist to be solved. Some challenging question, such as how to reduce the transmission loss or analysis the crystal characteristics of the optical fiber, inspired the researchers to devote themselves into these research. After years of unremitting efforts, a lot of methods have been put forward to solve these problems. By annealing [4] or tapering [5], the degree of crystallization of the core can be improved. Through changing the core size [6] or improving the purity of the fiber core, the transmission loss was reduced. But few people studied the strain distribution of the fiber core. One of the difficulties of fabrication is that the thermal expansion coefficient of the cladding material and core material does not match. In this paper, we present a study on the strain distribution inside the highly crystalline germanium core fiber fabricated by the rod-in-tube method.
2. Fiber fabrication
Firstly, we fabricated Ge-core silica-clad fiber with rod-in-tube method. The high-purity single crystal Ge rod with an outer diameter 2.5 mm was put into a silica tube, of which an inner diameter slightly larger than 2.5 mm. The outer diameter of the silica tube is 20 mm. In order to melt the Ge rod evenly during the fiber draw, the silica tube had been pre-draw and shaped. It is also for this reason that we can get a uniform distribution of strain in the core. Using graphite furnace, we can obtain the uniform hot zone with the temperature higher than 2200°C that the pre-fabricated fiber preform needed. Throughout the drawing process, the temperature and the drawing speed are monitored and controlled by the drawing tower. Stable external environment and constant stretching speed are more conducive to create a uniform strain distribution and high crystalline core.

As is shown in microscope (Fig. 1), we found that in the fiber center emerged a perfect round core and the interface between core and cladding is smooth without micro-cracks or gaps, which ensure the performance of fiber. The diameter of Ge core is 19 μm.

![Fig. 1. Optical micrograph of the germanium core cross-section](image)

3. Strain analysis
Fig. 2 shows the Raman spectra of the single crystal Ge rod that we used as the core material and the drawn fiber core. Comparing both spectra, we find that the peak of Ge rod (red line) is 300.994 cm\(^{-1}\), and the peak of fiber (black line) is 300.321 cm\(^{-1}\), while the FWHM of Ge rod and the fiber are both 2.609 cm\(^{-1}\). This indicates that the fiber has a high crystalline Ge core, but it may be due to the stretching strain that the Raman peak of Ge-Ge slightly shifts toward lower wave number.
For detecting the strain distribution, we obtained the Raman spectra at the points A, B and C, on the flat end face of the fiber. In Fig. 3 the Raman shift of Ge gradually shift to a higher wavenumber from A of 300.363 cm\(^{-1}\) to C of 301.346 cm\(^{-1}\), contrastively the silica shift to a lower wavenumber from B of 488.995 cm\(^{-1}\) to C of 489.134 cm\(^{-1}\). It shows that stretching strain has been formed in the core compared with the pressure strain in the cladding. The intensity of Ge Raman shift in the core is obviously stronger than that of the cladding, which is in line with the actual situation. From the Raman spectra analysis, we also found that the line width of the Raman peak is narrower in the core than in the cladding. This reflects that from interface to center the crystallinity of Ge is tend to be single-crystalline, while the core presents stretching strain.
Using Raman spectroscopy, we performed a mapping on the end of the fiber. We scanned 50 μm × 49 μm area with the step size 1 μm. The results are shown in Fig. 4.

![Fig. 4. (a). Strain distribution; (b). FWHM distribution.](image)

From the peak position distribution of measurement points, we can obtain the shifts of the peak position. Thus the strain change of the fiber can be conveyed. From Fig. 3 (a), we notice that there is no obvious peak drift inside the core. And near the interface, core has a clear red shift, which is the performance of the pressure strain. In the core, the peak concentrates upon 301 cm⁻¹, which exactly is the peak of Ge rod. It is because the silica tube and Ge rods have a mismatch thermal expansion coefficient.

Likewise, we analysed the full width at half maximum (FWHM) of each point, there was no significant saltation in the core as shown in Fig. 3 (b). The FWHM just goes wide when close to the interface. In the core, the FWHM is 2.609 cm⁻¹. This indicates that Ge in the core tends to be single-crystalline. The results of the above analysis are consistent to the result of peak analysis.

4. Conclusion
In conclusion, we fabricated the Germanium core optical fiber using the rod-in-tube method. A smooth junction formed between the core and the cladding. The Raman spectrum reveals uniform strain distribution of Ge core that is overall highly crystalline. This study may give a good insight for the future manufacture of the Ge core fiber.

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