Available online at www.sciencedirect.com

SCIENCE DIRECT

Thin Solid Films 483 (2005) 140–146

www.elsevier.com/locate/tsf

Mechanical strength and thermally induced stress voids of carbon-coated optical fibers prepared by plasma enhanced chemical vapor deposition method with different hydrogen/methane ratio

Sham-Tsong Shiue[a,*], Hsiu-Hsien Hsiao[b], Ting-Ying Shen[b], Hung-Chien Lin[b], Kun-Ming Lin[b]

[a]*Department of Materials Engineering, National Chung Hsing University, Taichung, 402 Taiwan, Republic of China*
[b]*Department of Materials Science and Engineering, Feng Chia University, Taichung, 407 Taiwan, Republic of China*

Received 12 May 2004; accepted in revised form 23 December 2004
Available online 2 February 2005

Abstract

Carbon coatings are deposited on the outer surface of the glass fiber using the plasma enhanced chemical vapor deposition method with six different hydrogen/methane (H_2/CH_4) ratios. As a result, the carbon coating structure exhibits a graphitic phase incorporated with a disordered phase, and the amount of the disordered phase increases with increasing H_2/CH_4 ratio. On the other hand, the roughness of carbon coatings decreases with increasing H_2/CH_4 ratio. If the H_2/CH_4 ratio is not larger than 2, the tensile strength of carbon-coated optical fibers increases with increasing H_2/CH_4 ratio, while the linear density of thermally induced stress voids decreases. Nevertheless, when the H_2/CH_4 ratio ranges from 2 to 3.33, the tensile strength of carbon-coated optical fibers slightly decreases with the H_2/CH_4 ratio, and the thermally induced stress voids are less found on the carbon coating. The method to acquire the high tensile strength of carbon-coated optical fibers and/or to minimize the thermally induced stress voids on the carbon coating is proposed.

PACS: 42.81; 97.30.H; 52.75.R; 62.40.M
Keywords: Optical fibers; Carbon; Chemical vapor deposition; Stress

1. Introduction

Optical fibers with low transmission loss and wide bandwidth have been developed, and many practical transmission systems use these optical fibers. Long-term stability is an important requirement for the optical transmission, so optical fibers must maintain the stable performance in the most severe condition [1]. The conventional optical fibers for telecommunication are usually constructed of the silica glass fiber coated with two or three polymer layers. Silica fibers with polymeric coatings provide high short-term strengths. However, when these fibers are stressed in a humid environment, long-term strength degradation occurs due to the slow crack growth. The use of hermetic coatings on silica glass fibers can greatly improve fiber reliability by preventing the mechanical fatigue, so hermetically coated optical fibers are extensively studied [2–13]. Some of these fibers exhibit high resistance to moisture attack, and some of these fibers can withstand relatively high temperatures.

The carbon material is used as a hermetic optical fiber coating, and the carbon-coated optical fiber is expected to be a key technology for optical transmission lines [2–5,7,12,13]. The coating speed of carbon on the glass fiber has been increased to a rate sufficient to supply low-cost fibers for commercial networks [4]. However, in the real application, the carbon-coated optical fibers must sustain the mechanical and thermal stresses. Once the mechanical

* Corresponding author.
E-mail address: stshiue@dragon.nchu.edu.tw (S.-T. Shiue).

0040-6090/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2004.12.059

fracture or thermally induced stress voids occur on the carbon coating, the hermetically carbon-coated optical fibers will lose their prevention of mechanical fatigue. Although the practical and commercial carbon-coated optical fibers are produced using the in-line chemical vapor deposition process, the plasma enhanced chemical vapor deposition (PEVCD) process is a simple method to prepare the carbon-coated optical fibers at a low temperature. Recently, Shiue et al. [12] prepared the carbon-coated optical fibers using the PECVD method and investigated the effect of the carbon coating thickness on the thermally induced stress voids in fibers. Nevertheless, when the carbon coatings are prepared using the PECVD method, the carbon coating properties are affected by many factors such as the mixture ratio of reactive gases [14]. Meanwhile, the tensile strength of carbon-coated optical fibers is determined by the coating structure and roughness [4,12,13]. This is the motive for this article to prepare the carbon-coated optical fibers using the PECVD method with six different hydrogen/methane (H_2/CH_4) ratios. The effect of the carbon coating structure and roughness on the mechanical strength and thermally induced stress voids of these carbon-coated optical fibers is then examined.

2. Experimental details

The experimental details proceeded as follows. First, a cylindrical stainless steel deposition chamber with the two parallel planar electrodes coupled PECVD system was employed. The carbon films were deposited on glass fibers of equal length using the PECVD method with six different H_2/CH_4 ratios. In the deposition process, the working pressure and RF power were fixed at 20 mTorr and 200 W, respectively. The deposition time was controlled such that films of identical thickness were produced for all the H_2/CH_4 ratios. Six different kinds of carbon coatings were achieved by selecting H_2/CH_4 ratios as 0, 0.67, 1.33, 2, 2.67 and 3.33, respectively, where the mass flow rate of methane was fixed at 15 sccm. Second, the thickness of the carbon coating was obtained by measuring the fiber cross-section using the scanning electron microscope (SEM). Meanwhile, the structure of coating materials was examined by Raman scattering spectrometer (RSS) with the 514.5 nm line of an Ar^+ ion laser at room temperature, and the roughness of coating materials was measured by the atomic force microscope (AFM) on the 10 μm×10 μm carbon coating surface. Third, the outer surfaces of these optical fibers were observed using the optical microscope (OM). Fourth, the tensile strength of these carbon-coated optical fibers was measured by standard tensile test equipment. The gage length and displacement rate of the tensile test were set as 100 mm and 5 mm/min, respectively. The tensile strength of the carbon-coated optical fibers was obtained from the average value of ten samples with the same coating structure. Fifth, all of these optical fibers with coatings were immersed in the liquid nitrogen for 1 day. The room temperature and liquid nitrogen temperature were 298 and 77 K, respectively. Finally, the outer surfaces of the optical fibers after one day of immersion in the liquid nitrogen were observed again using OM to examine the thermally induced stress voids on the carbon coating. The resolutions of the above measured results were shown in the next section.

3. Results and discussion

After the examination of SEM, RSS and AFM, the thicknesses, structures and roughnesses of these coating samples were obtained. SEM observation shows that the carbon coating is uniformly deposited on the glass fiber surface, and the thickness of these six kinds of optical fiber samples is approximately 100 nm. The coating thickness was controlled by the deposition time during the PECVD process. The deposition rates are 9.09, 3.33, 2.7, 1.85, 1.59 and 1.33 nm/min for the H_2/CH_4 ratios being 0, 0.67, 1.33, 2, 2.67 and 3.33, respectively. Fig. 1 illustrates an example of SEM picture to demonstrate the fiber cross-section, where the H_2/CH_4 ratio is 3.33. Alternatively, Fig. 2(a)–(f) show the RSS results for these six samples with the H_2/CH_4 ratios being 0, 0.67, 1.33, 2, 2.67 and 3.33, respectively. Fig. 2(a)–(f) reveal that these RSS spectra consist of very broad band range extending from 1000 to 1800 cm^{-1}, and RSS spectra of these six samples vary with the H_2/CH_4 ratios. The feature of these RSS spectra implies that carbon coatings are contributed by the graphitic phase and disordered phase [14–24]. The graphitic phase is called G band and possesses the intensity peak around 1580 cm^{-1}, while the disordered phase is called D band and has the intensity peak around 1350 cm^{-1} [19]. Each spectrum shown in Fig. 2(a)–(f) was normalized by its background spectrum, and then was fitted to evaluate the amount of graphitic phase and disordered phase. The fitting results are listed in Table 1. Table 1 reveals that the graphitic phase with peak located around 1536~1555 cm^{-1} could be

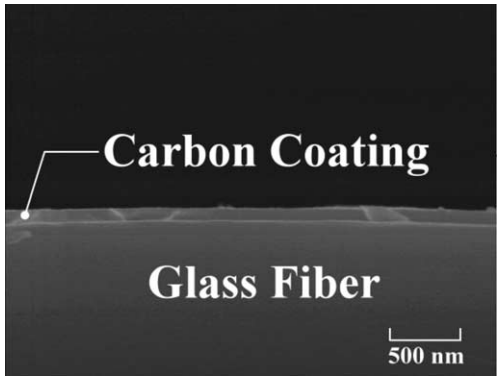

Fig. 1. Cross-section SEM image of carbon-coated optical fiber.