

Deuterium treatment of low water peak fiber

Xinwei QIAN (✉), Deming LIU, Feng TU

College of Optoelectronic Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

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Abstract The deuterium (D_2) treatment of low water peak single-mode fiber (LWP-SMF) after drawing has been investigated. The D_2 treatment time and concentration have important effect on fiber's properties after D_2 treatment. The insufficient treatment of D_2 cannot ensure fiber resistant to hydrogen aging, whereas excessive treatment of D_2 will result in excess loss on fiber at 1383 nm. The optimization on viscosity match between the core and the cladding is helpful on problem solving of excess loss after the D_2 treatment. However, by designing proper time and D_2 concentration in the D_2 treatment process, it can produce fiber with good hydrogen aging resistance and low excess loss and lower the cost of the D_2 treatment process.

Keywords deuterium (D_2) treatment, time, concentration, excess loss, low water peak (LWP) fiber

1 Introduction

Low water peak single-mode fiber (LWP-SMF) develops very fast in recent years. Compared with the conventional SMF (G652A/B), the LWP fiber has significantly reduced optical attenuation at water absorption wavelength around 1383 nm. It provides expanded transmission window from 1310 to 1550 nm continuously and makes fiber useful for communication at O, E, and S bands. This optical fiber is designed and manufactured to meet the requirement in applications in optical fiber communication networks, cable TV, utilities, and special optical networks. It has been predicted that the LWP-SMF will be the main type of SMF products in the market in the future.

Deuterium (D_2) was popularly used in fiber production to produce fiber with low water peak at 1.38 μm . The reduction of hydroxyl (OH) absorption in optical fiber can be achieved by isotope exchange from OH to deuterioxyl

(OD) [1]. There is almost no added loss by OD absorption in the entire window between 1.3 and 1.6 μm . It has been reported that the treatment of D_2 on optical fiber at high temperature (800°C) can effectively reduce the OH level in the glass fiber [2]. However, this method is not suitable for application in the production of optical fiber.

The fabrication of LWP fiber in the production includes two main steps. The first is to produce glass preform with low OH level inside. To achieve this target, many methods to reduce OH level in glass had been researched. The details of the OH-reducing process vary with the type of preform fabrication. In outside vapor deposition (OVD) and vapor-phase axial deposition (VAD) process, the important way to reduce water content is by drying the silica soot before it is consolidated. The porous preform consisting of silica soot particles is heated in an atmosphere of SOCl_2 or Cl_2 . In modified chemical vapor deposition (MCVD) process, Cl_2 is used in deposition process and reacted with water to reduce OH level. The OH reduction in plasma activated chemical vapor deposition (PCVD) process is more complex. Because the transformation from silica soot to glass is so quick, it is not possible to dry the soot with Cl_2 in deposition process. Thus, in PCVD process, the reduction of OH focuses on humidity control of raw material, environment, and equipment [3].

Although OH can be incorporated into the glass fiber in many stages from the starting material to the fiber-drawing operation, the control of OH level in the drawing process is relatively simple. However, after drawing, the second important step for LWP fiber production is the D_2 treatment. For GeO_2 -doped silica glass fiber, some structural defects always result in the fiber core during the fiber fabrication process. The defects include several different types of atomic defects and impurities present in the silica fiber. For this type of fiber, there is a significant risk that the optical loss could increase due to the chemical reaction between defects and molecular hydrogen present in or around optical cables [4]. The increase of optical loss for this reason is called hydrogen-induced loss (HIL).

The HIL generally includes two main parts: one part is the loss caused by diffusion of molecular H_2 in the glass fiber. It is reversible and can be eliminated by heat treatment. The other part is the loss resulting from chemical reaction between defects and H_2 . It is irreversible and difficult to be eliminated [5]. However, by D_2 treatment (exposing fiber in D_2 environment) after drawing, the defects in the glass fiber can react with D_2 prior to H_2 . The formation of OD and SiD is harmless to the normal operating wavelength windows. After that, the reactive silica defects in the glass fiber being passivated by deuterium reaction will no longer be able to cause additional HIL in the field.

For the D_2 treatment process, the determination of treatment time and concentration of D_2 in the environment is important. The improper design on these parameters will result in two opposite results: one is the insufficiency of reaction between D_2 and defects in the fiber. The fiber will have problem of HIL in later use. The other is the excessive diffusion of D_2 in the glass fiber. The attenuation of fiber will increase obviously after D_2 treatment.

This paper will try to investigate the reaction between D_2 and defects in glass fiber to get proper set point for the D_2 treatment process.

2 Experiment

2.1 Fabrication of preform

Preforms for fiber drawing were pure silica glass doped with GeO_2 and F. The preform is fabricated by PCVD process. The deposition speed of glass in the PCVD process is about 0.5–2.0 g/min in the core. Most of the cladding of the fiber is pure silica glass. The amount of dopants in the core is about 1.5 mol% GeO_2 and 0.7 mol% F.

2.2 Drawing process of fiber

Optical fiber was drawn on drawing tower with the height of 25 m in total. In experiment, the drawing speed was 1300–1500 m/min, and the drawing tension was kept at 100–150 g. Inert gases, Ar and He, were used in the electricity-powered drawing furnace.

2.3 Process of D_2 treatment

After measurement on geometry and optical parameters, the fiber was packed with plastic film and put into box filled with N_2/D_2 gases. The device is schematically described in Fig. 1. The temperature in the box was kept constant at 21°C. The concentration of D_2 in the box can be monitored and controlled by a computer. During the experiment, the concentration of D_2 changed in the range of 1.0%–2.0%.

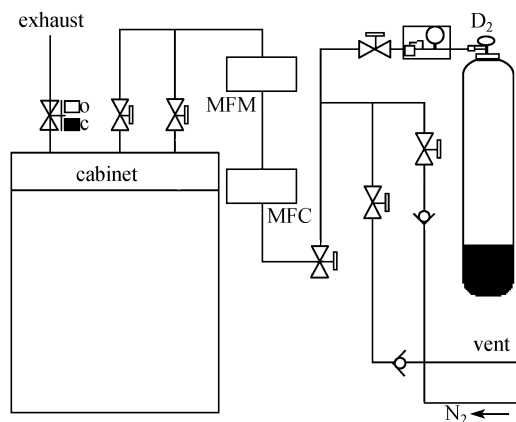


Fig. 1 Schematic structure of D_2 treatment system

2.4 Measuring of fiber after D_2 treatment

After D_2 treatment, the fiber was kept in natural environment for about 2 h. After that, the fiber was measured on attenuation and tested on hydrogen aging. The difference on attenuation of fiber before and after D_2 treatment is defined as the excess loss resulting from the D_2 treatment.

3 Results and discussion

3.1 Effect of D_2 treatment time on HIL

The fiber was treated with 1.2% D_2 for 12, 16, 24, and 40 h. The same experiment also has been done on 1.5% D_2 for 12, 24, and 40 h. The fiber which has not been D_2 treated was selected as the reference fiber. The HILs at 1383 and 1530 nm of these fibers were shown in Figs. 2(a) and 2(b), respectively.

Figure 2 shows that the time of D_2 treatment has obvious effect on hydrogen aging resistance of fiber. If the treatment time is less than 24 h, the HIL at 1383 nm will be higher than 0.035 dB/km. It means that the fiber cannot be qualified on the property of the hydrogen aging resistance as LWP fiber. Thus, the time of D_2 treatment should be more than 24 h; 40 h will be better for safety. Long-time D_2 treatment will consume too much of D_2 , which is very expensive. However, the time of D_2 treatment seems to have no important effect on HIL at 1530 nm. It proves that the formation of SiH during hydrogen aging test is very little.

3.2 Effect of D_2 concentration on excess loss

Based on experiment results discussed above, the effect of D_2 concentration on excess loss of fiber after D_2 treatment has been investigated. The fiber was treated with different D_2 concentration of 0.8%, 1.0%, 1.2%, 1.5%, and 2.0%.

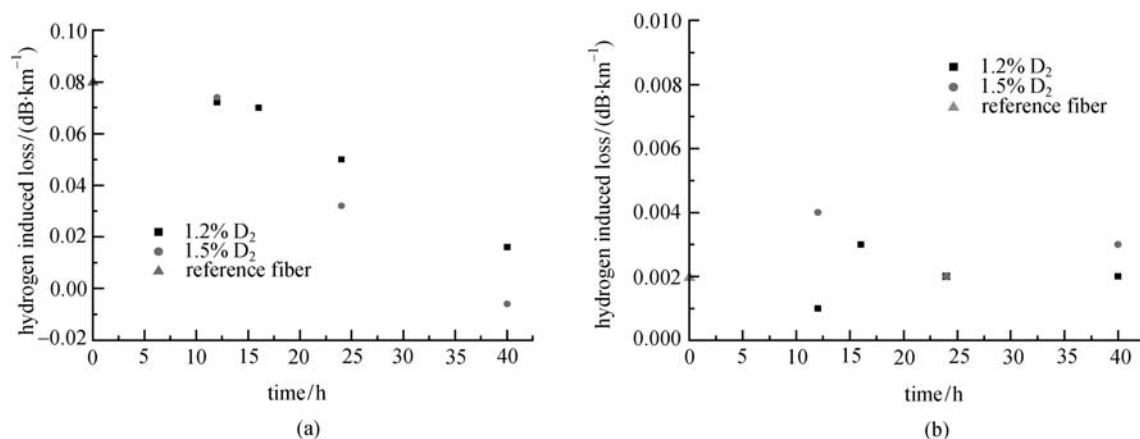


Fig. 2 HIL of fibers samples. (a) HIL at 1383 nm; (b) HIL at 1530 nm

The time of D₂ treatment was kept for 40 h. After the D₂ treatment, the fiber samples treated with 0.8% and 1.0% D₂ cannot be qualified for the hydrogen aging test. The HIL at 1383 nm is high even with long treatment time of 40 h.

The excess loss of fiber samples at 1383 nm after D₂ treatment is shown in Fig. 3.

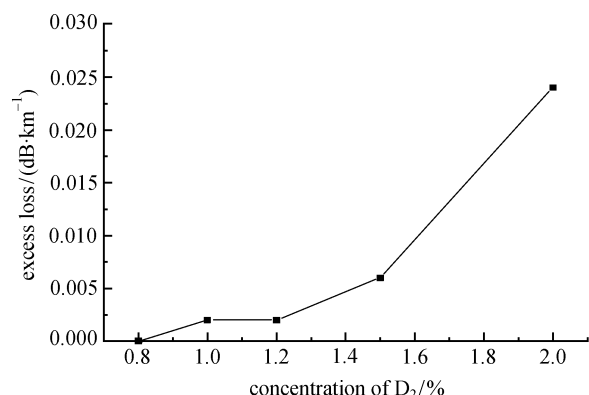


Fig. 3 Excess loss at 1383 nm of fiber after D₂ treatment

In Fig. 3, when the concentration of D₂ is more than 1.5%, the excess loss at 1383 nm after D₂ treatment will become obvious. For fiber production, the excess loss should be controlled at a low level to ensure that the fiber will be kept as LWP fiber after D₂ treatment. So the concentration of 1.2% is the ideal choice for production.

3.3 Mechanism of excess loss resulting from D₂ treatment

The excess loss of fiber after the D₂ treatment was thought to result from D₂ molecules in the core of the fiber. When fiber was heated to about 50°C for 24–48 h in the air, most of the excess losses can be reduced because the D₂ molecules can be released from the fiber by diffusion. This

means that there is no strong chemical bond between D₂ molecules and silica structure. However, only some weak bond formed between the D₂ molecules and the defects in the silica. The combinations between D₂ molecules and defects may form through a special “bridge”.

Because the excess loss is related to defects in the glass fiber, some ways to reduce defects in the glass fiber would be helpful on reduction of excess loss.

3.4 Effect of fiber RI profile design

To reduce the drawing-induced defects in the glass fiber, the viscosity match between the core and the cladding was optimized. For conventional SMF, the viscosity of the cladding is much higher than that of the core. So, in the drawing process, there will be defects formed at the boundary between the core and the cladding. By adding a buffer layer between the core and the cladding, the viscosity match between the core and the cladding can be effectively optimized. The refractive index (RI) profile and viscosity profile of the glass fiber are shown in Fig. 4, where Δ in Fig. 4(a) represents the percentage of change on RI compared with that of pure silica.

With this optimized viscosity match between the core and the cladding, the excess loss at 1383 nm of fiber after the D₂ treatment with 2.0% D₂ for 40 h can be reduced to less than 0.005 dB/km.

3.5 Optimization on D₂ treatment process

Based on experiment results discussed above, the proper D₂ treatment process for production can be decided. To ensure that the fiber has resistance to hydrogen aging while not resulting in high excess loss after D₂ treatment, and also to save the cost of D₂ treatment process, the concentration and time of the D₂ treatment should be set as 1.2% and 40 h, respectively.

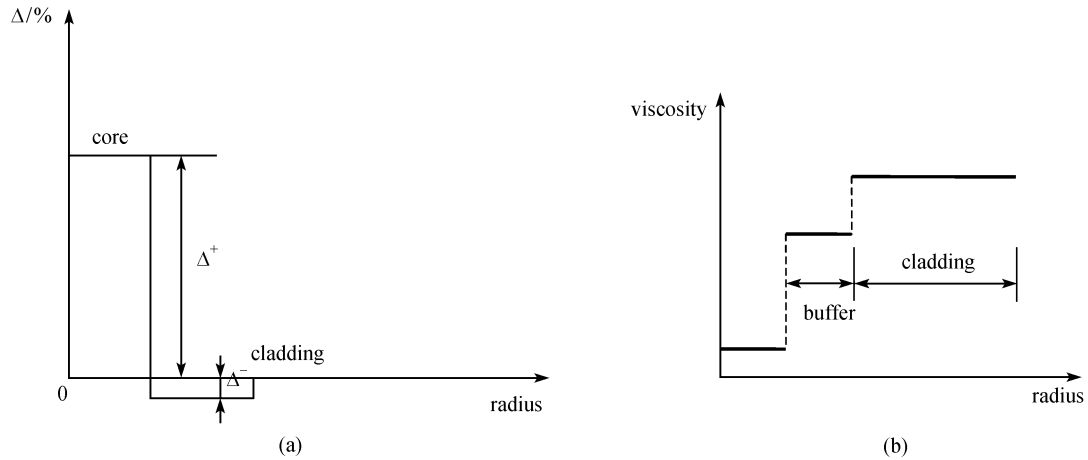


Fig. 4 RI and viscosity profile of optimized SMF. (a) RI profile; (b) viscosity profile

4 Conclusion

The results of the experiment prove that both the D_2 treatment time and concentration have an important effect on the fiber's properties after D_2 treatment. For the D_2 treatment time, 40 h is suitable for fiber production to ensure that the fiber has resistance to hydrogen aging, because longer D_2 treatment time will cause too much consumption of D_2 . The concentration of D_2 with 1.2% is enough for common LWP-SMF and will not result in obvious excess loss after D_2 treatment. The excess loss is thought to be related to combinations between the D_2 molecules and defects in the glass fiber, and the excess loss can be reduced by optimization on viscosity between the core and the cladding of the glass fiber.

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