

Study of UV fiber's mechanical properties

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Abstract A number of spectroscopic techniques make use of ultra violet (UV) absorbance and luminescence measurements to characterize materials, for use in medical/pharmaceutical applications, for forensic and sensor applications, and for remote detection or monitoring, especially for hazardous environments. Furthermore, many high-power applications in medicine and industry are looking forward to using UV wavelengths. The UV fiber's mechanical reliability has become one of the most crucial performances with longer length fiber being used. This paper reviews the researched evolvement of the normal single mode fiber's mechanical reliability. Based on the standard measure method of the normal fiber, the mechanical reliability of the UV fiber has been researched. The measurement results show the difference of mechanical reliability between the different doping composition UV fibers.

Keywords ultra violet (UV) fiber, doping content, mechanical performance, tensile strength

1 Introduction

Silica glass has been used as light transmitting mediums, such as optical fibers and various optical elements. In particular, the use of the optical fibers having advantages of light weight and small diameter has recently been widened in various industrial fields including communication, image transmission, and energy transmission [1]. As one of the fields, the use of the optical fiber to transmit ultraviolet rays has been expected in the medical and precise processing fields. However, when glass is irradiated with ultraviolet rays, it deteriorates and its transmission loss increases. That is, there arises a problem

in that deterioration takes place because of ultraviolet ray irradiation [2].

There is a growth in the use of excimer lasers for medical and industrial applications. This has led to the need to address the problems associated with the damage and transmission properties of silica fibers in the ultra violet (UV) region particularly for high-power and for high-repetition pulsed transmission. Although there are a number of commercially available fibers, which can efficiently handle transmission of relatively low intensities of laser radiation, there still exist difficulties for high-power radiation transmission. For example, standard synthetic silica optical fibers with high-OH levels offer low attenuation and high transmission in the 215–254 nm spectral range, but when exposed to an unfiltered deuterium lamp, these fibers drop to less than 50% of the original transmission within 24 h of continuous irradiation.

Also, the standard UV fibers tend to develop significant color center, by 1×10^4 or less pulses of excimer laser radiation at 193 nm at fluences of about 50 MW/cm². Typically, this behavior upon exposure to deep UV light is called “solarizing” behavior [3]. Changing transmission capability of the optical fiber during transmission of UV radiation in a medical treatment creates problems for the practitioner trying to regulate the exposure of a patient to the UV radiation.

In the UV spectral region, below 350 nm wavelengths, synthetic silica optical fibers, having undoped, high-OH cores and fluorine-doped claddings, which have a lower refractive index, are the primary candidates. The basic attenuation of these fibers is generally acceptable. The induced losses, primarily comes from transient or permanent changes in the silica, which are due to nonlinearities arising from two photon absorption [4].

Predicting the strength of optical fibers and fiber components is important for reliable operation of fiber optic links. The mechanical reliability of the silica fiber is the key factor influence the fiber's lifetime. To get the

better UV transmission performance, the fiber's doping composition would be changed greatly to improve its UV transmission efficiency and stability. Then, the fiber's mechanical reliability would very different with the standard single mode fibers. We mainly research the UV fiber's proof-test strength, tensile strength, and dynamic fatigue performance and test the different doping composition UV fiber's mechanical performance to find the optimization methods of this fiber.

2 Mechanical performance

2.1 Fiber's strength and breaking mechanism

The theoretical tensile strength of silica fiber is decided by the SiO₂ tetrahedron's bond combination strength. The standard single mode fiber's tensile strength should be more than 5 GPa, based on intrinsic defects. The intrinsic defects include the inner defects of the glass or quartz scratches. The extrinsic defects include the surface scratches induced impurities during the disposal of the fiber, such as the damage or disrepair of the coating layer, wherein the damage of the glass surface is more serious. Supposing, there is a microflaw on the fiber's surface, this flaw can be simulated as a U type structure [5]; when we bring pressure to bear on this flaw, the pressure on the flaw's peak can be expressed as

$$\sigma = S \left(1 + \frac{2L}{a} \right),$$

where L is the flaw length, a is the half width of the flaw, and S is the pressure.

In the condition of pressure or other conditions, such as the high temperature and humidity, the micro flaw would grow, and the grow speed can be expressed as

$$V = \frac{dL}{dt} = AK^n(t),$$

where A is the parameter associated with the material, K is the stress strength factor of the material, and n is the sensitive parameter of the stress etching.

Based on the above theory, in practice, we can intentionally apply extra stress on the fiber and test the break probability of the fiber to assess its mechanical reliability in application condition.

2.2 Proof-test theory of fiber

The proof test of the fiber is putting a longitudinal stress on the fiber to test its basic strength character. After the proof test, the stress focus points along the fiber length can be eliminated to provide the fiber's mechanical reliability. The ITU-T G.650 and GB/T 15972.3-1998 have stated the proof test's reference test method. When a

longitudinal stress T is put on the fiber, the induced strain on the fiber is

$$\sigma = \frac{(1-F)T}{\pi a^2},$$

where F is the ratio of the stress on the glass part of the fiber, and a is the fiber cladding's radius.

2.3 Fiber's tensile strength theory and measurement

The measurement of the fiber is applying tension on the fiber's longitudinal length, utilizing the Weibull distribution to analyze the fiber's break probability. In some kind of stress, it can be described as

$$F(L, \sigma) = 1 - \exp \left[-\frac{L}{L_0} \left(\frac{\sigma}{\sigma_0} \right)^m \right],$$

where σ_0 is the corresponding measured strength in the standard length L_0 .

In ITU-T G.650, BellCore GR20, and GB/T 15972.3-1998, the test methods have been given. The BellCore GR20 gives the fiber tensile strength's specification in Table 1.

Table 1 BellCore's specification

standard fiber length/m	Weibull break probability	
	15%/GPa	50%/GPa
0.5	3.14	3.80
1.0	3.05	3.72

2.4 Fiber's dynamic fatigue mechanism and measurement

The definition of the fiber's fatigue is, in some condition of stress, the surface crack grows and enlarges, which leads the fiber break. Currently, we use two point bending method to measure the fiber strength for a range of stressing rates and analyze the test result by Weibull method to get the fatigue parameter N_d value [6]. In ITU-T G.650, BellCore GR20, and GB/T 15972.3-1998, the dynamic fatigue test method was given. The fiber's N_d value should bigger than 18 according to BellCore GR20.

2.5 Analysis of UV fiber's mechanical properties

During the fabrication process of the UV fiber, in order to optimize the fiber's UV transmission efficiency and stability, many dopants need to dope into the fiber's core and clad, and also, some treatment should be done on the fiber. For example, the fluorine and OH should be doped into the fiber's core to reduce the defect content of the fiber, and the fluorine should be doped into the fiber's clad to form the appropriate waveguide. All these dopants would induce the influence to the fiber's mechanical reliability. During the fabrication process, the fiber's strength should be ensured with the control of the fabrication process. The

analysis of the fiber's strength would favor the fiber performance's optimization [7].

3 Experiments and discussion

Five kinds of UV fibers had been fabricated. These five types of UV fibers' doping content are listed in Table 2. With the different doping content, these five fibers' numerical aperture (NA) would be different, and the fibers' mechanical reliability would be changed.

The fabricated preforms of these five fibers had been tested by the PK2600 model. The test results are shown in Fig. 1.

The tensile strength and two point bending dynamic fatigue performance (N_d value) of the proof-tested fiber have also been tested. Figure 2 shows the tensile strength

test results and their Weibull distribution (M value). These results show that with the different doping content, the UV fiber's 15% break probability and 50% break probability would be changed obviously. Figure 3 shows the two point bending dynamic fatigue test's Weibull distribution and the 3# fiber sample's test results, and its dynamic fatigue parameter N_d value is about 25.1.

All the five fiber samples' test results are listed in Table 3. From the above test results, it can be concluded that the UV fiber fabricated by the plasma chemical vapour deposition (PCVD) process would not induce additional defects in the glass structure, due to the fabricated process and the special microcosmic structure of these kinds of fibers. The fiber's mechanical test results fulfill the BellCore GR20 standard's requirement. The pure silica core fiber shows the best mechanical performance.

Table 2 Five kinds of UV fibers' doping content and NA test values

fiber sample	doping content		fiber's NA
	Ge/%	F/%	
1#	16	32	0.242
2#	13	8	0.239
3#	0	0	0.219
4#	0	10.8	0.207
5#	0	15	0.181

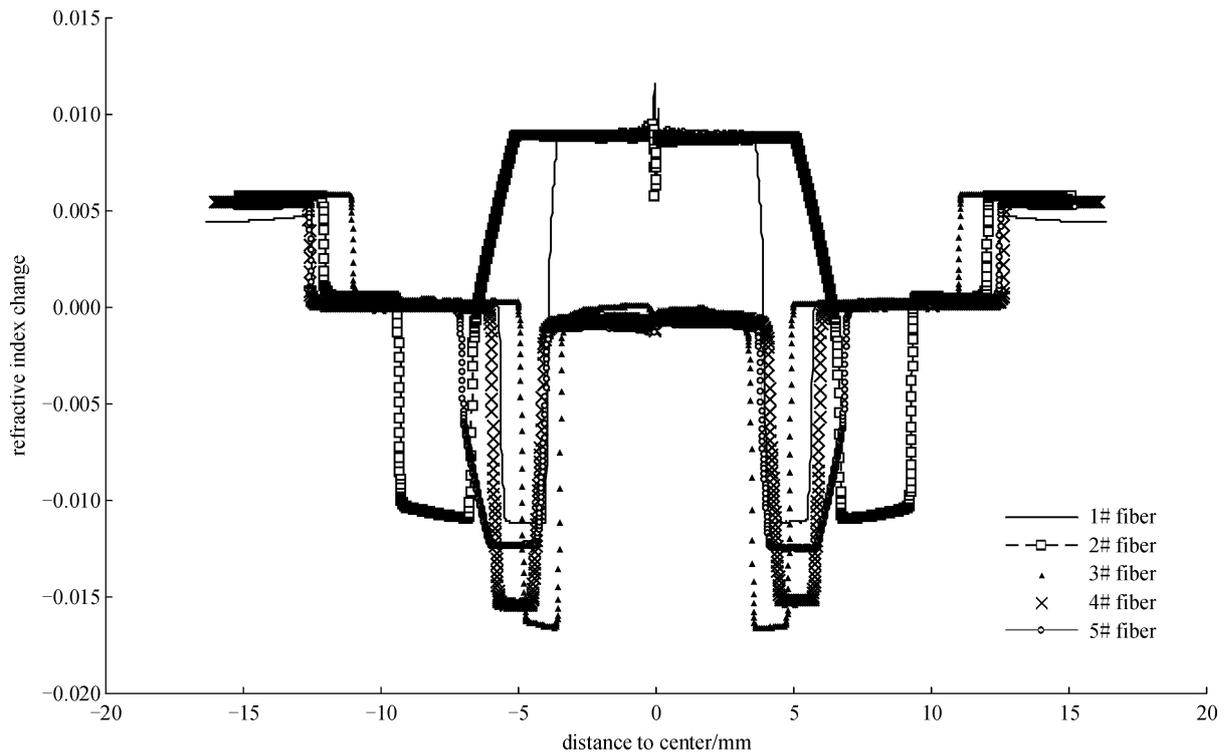
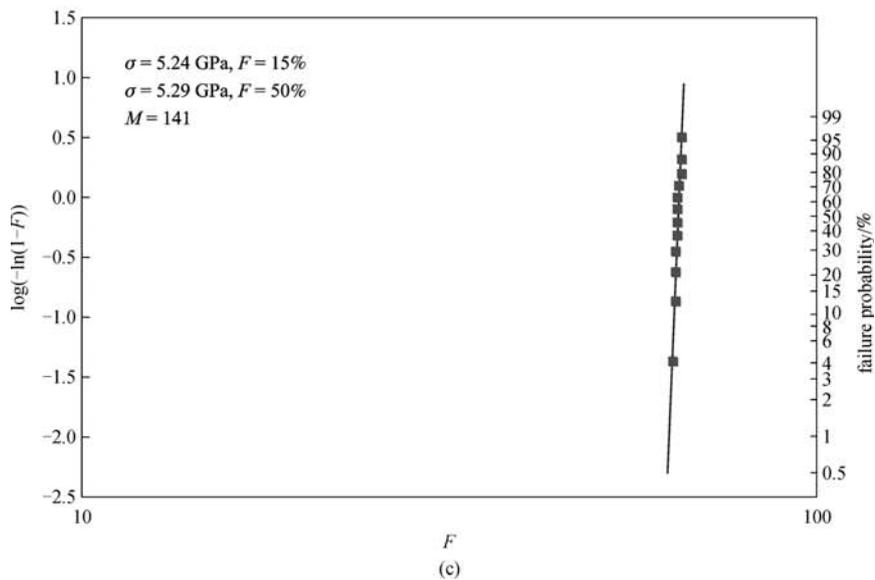
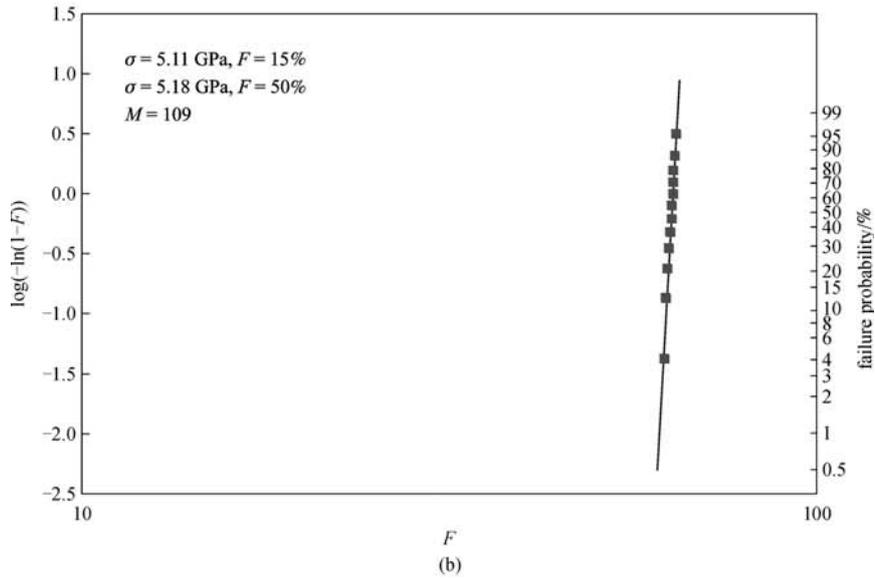
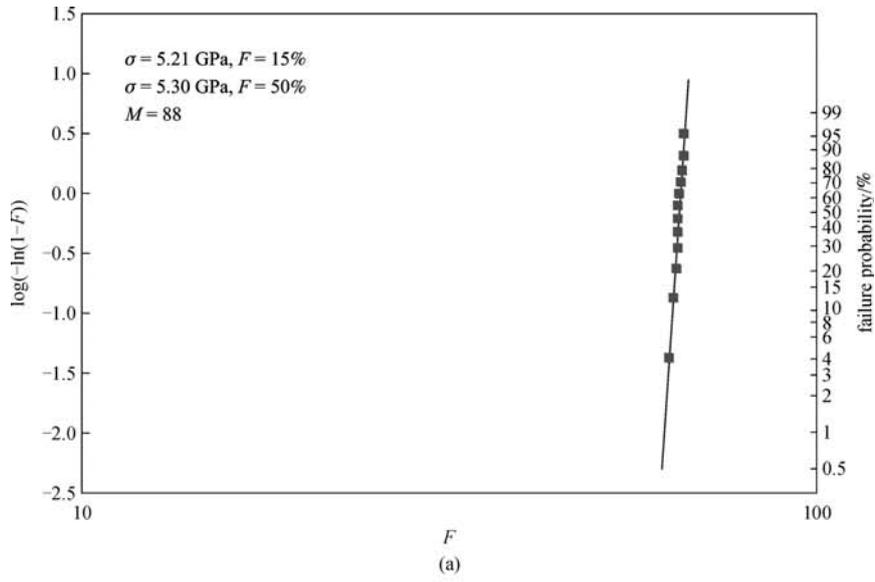


Fig. 1 Test result of preforms of five different doping fibers



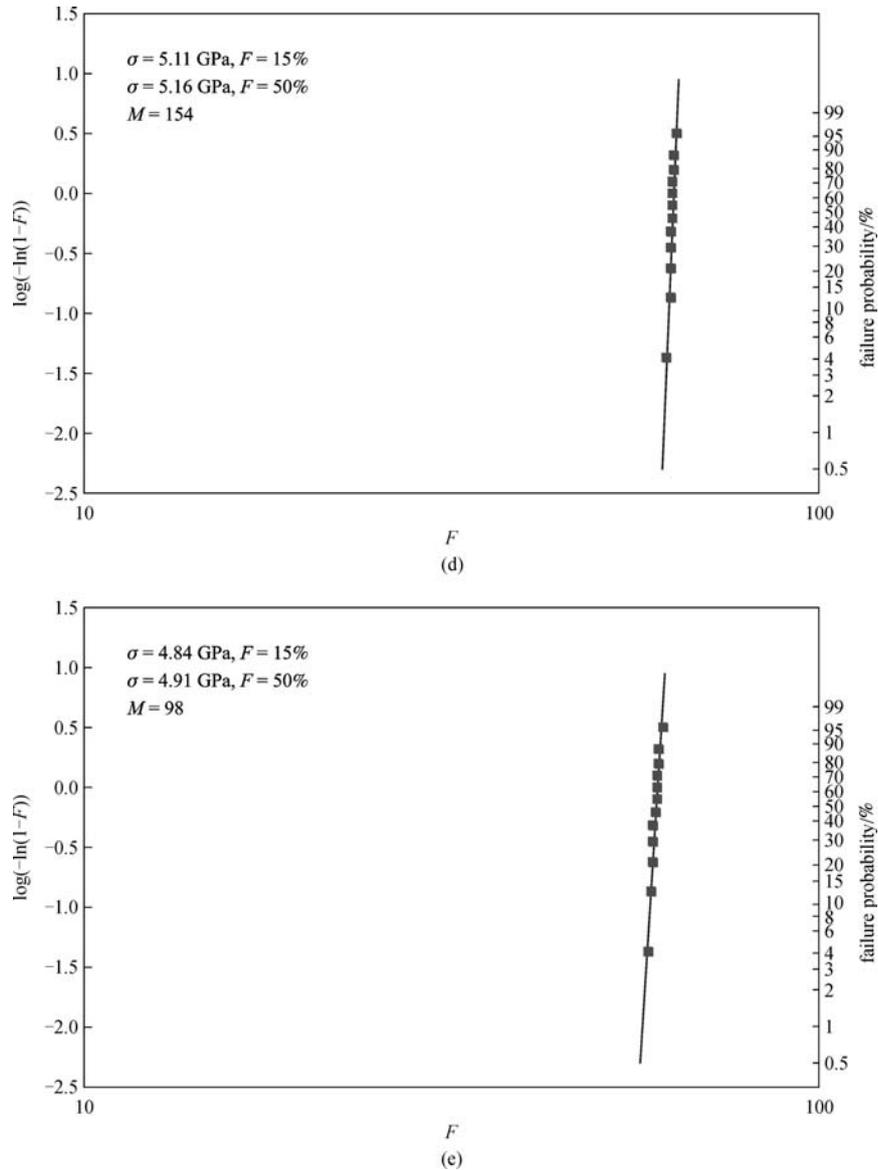


Fig. 2 Five fiber sample M value test results. (a) 1# fiber sample; (b) 2# fiber sample; (c) 3# fiber sample; (d) 4# fiber sample; (e) 5# fiber sample

Table 3 Five fiber sample's M value and N_d value test results

fiber sample	M value	tensile strength 15%/GPa	tensile strength 50%/GPa	N_d value
1#	88	5.21	5.30	20.647
2#	109	5.11	5.18	24.600
3#	141	5.24	5.29	25.060
4#	154	5.11	5.16	22.730
5#	98	4.84	4.91	19.962

4 Conclusion

The UV fiber's mechanical reliability has become one of the most key parameter of this fiber's application since the use of such kind of fiber's volumes has been increased.

Five different types of UV fibers have been fabricated by the PCVD process and combination drawing process. Their mechanical reliabilities had been tested, and the test results were contrasted together. It shows that during the fabrication process, the doping content would influence the

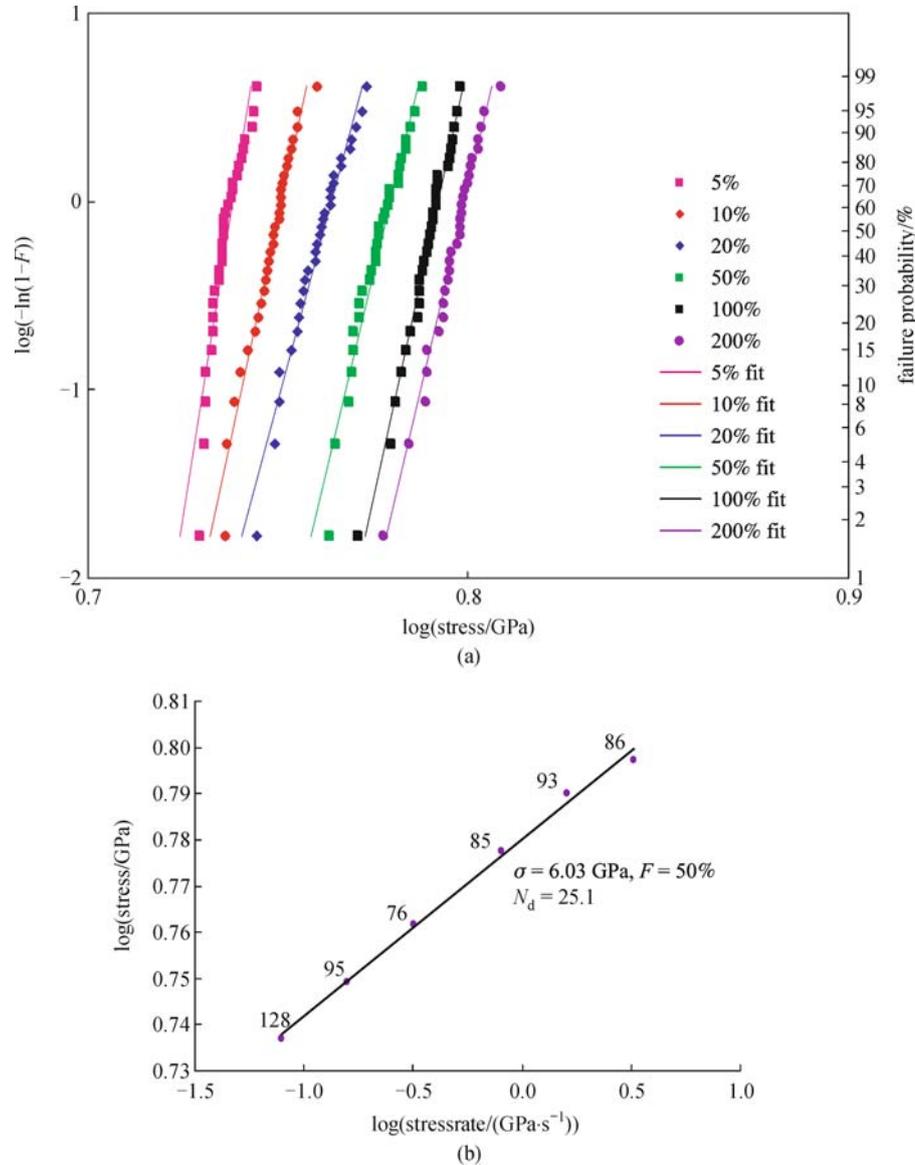


Fig. 3 3# fiber sample's two point bending dynamic fatigue test results. (a) Weibull plots; (b) 50% failure

UV fiber's mechanical performance. Although the UV fiber's mechanical performance would be changed with the different doping content, these UV fibers show almost the same mechanical reliability as the standard single mode fiber.

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