Innovative Insights

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Improved Deep UV Fiber For Medical And Spectroscopy Applications ›

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Fiber used in biomedical applications must not only be safe, sterile and robust enough for autoclaving, but also highly stable and reliable to ensure accurate diagnostics and, most importantly, safe for patients. The unique characteristics of deep UV fiber help enable advanced biomedical diagnostic equipment, including patient diagnostics, minimally invasive surgical procedures and sensors attached directly to the body for monitoring purposes.

A majority of fiber used in spectroscopy is used for material and optical sensing in the mid-ultraviolet (UV) range down to 190 nm. Many biomedical sensing applications require optical fibers which transmit light in the UV region. Within the industry, demand is rising for laser and other biomedical equipment using deep UV fiber. Deep UV fiber is suitable for laser delivery in eye surgery, plastic surgery, urology and other procedures requiring a combination of UV light and smaller core diameter fiber.

Risk of Solarization in Deep UV Fibers

The pure silica core material used in step index optical fibers is susceptible to UV-induced attenuation. This increase in attenuation is caused by the increase in localized defect centers in the glass structure induced by exposure to UV radiation. It is commonly known as solarization. Most of the attenuation occurs in wavelengths less than 275 nm, in the absorption bands at 214 and 265 nm. The degree of damage varies greatly with the type of fiber. For example, synthetic fused silica used as the core material in common step index optical fibers is an extremely pure material. However, several intrinsic and impurity defects are present in varying concentrations. In addition, certain defects in the silica structure can be caused by incident UV radiation. The concentration of each defect is dependent on several factors, including contaminants from the preform fabrication process, preform fabrication technique and fiber draw process. Refer to Table I for a summary of defect types.

Defect Description	Chemical Structure	Comment
E1' center	Ξ Si•	Radiation induced absorption band at 214 nm
Non Bridging Oxygen Hole Center (NBOHC)	Ξ Si-0°	Radiation induced absorption bands at 265 nm and 620 nm
¯OH in Silica structure	Ξ Si ¯OH HO- Si Ξ	Stable configuration
Strained Silica bond	Ξ Si-0 ¯Si Ξ	Weakened regular bonds
Chlorine impurity	Cl_2	Absorption band at 320 nm
HC1 impurity	HC1	Absorption band near 165 nm
Silicon without unpaired electron	Ξ Si+	Absorption band at 163 nm
Peroxide radical	Ξ Si-0-0	No absorption in measurement region

Table 1. Defects in High-OH fibers in UV region

For the spectral region of 190 to 300 nm, the primary defects of greatest concern are the E1' and NBOHC. These two defects are responsible for the induced attenuation at 214 and 265 nm, respectively. Improved performance in the optimized fiber was achieved primarily by reducing the distribution of these two defects.

Tracking Developments UV Fiber

The stability of deep UV transmission is an important parameter in optical system design, especially in high performance spectroscopy applications. Historically, fibers with high ¯OH content have been used for wavelengths shorter than 400 nm. However, the transmission can be degraded by exposure to high levels of UV illumination. This degradation, known as solarization, is caused by UV radiation induced defect concentrations in the pure silica core of the fiber, leading to optical absorption in the UV.

Over the years, many fibers have been developed to minimize the effects of solarization. Solarization resistance has been improved by optimizing various aspects of the fiber, including preform design and post processing of the drawn fiber. Several fibers have been developed for use in UV applications. The following are representative fibers, as produced by Polymicro:

FVP – Standard UV/visible fiber. This fiber uses a high ¯OH pure silica core preform which has not been optimized for solarization resistance. The fiber is very sensitive to solarization.

- UVM – This fiber is made with a preform with High ¯OH silica core material which has been optimized to reduce the defect content.
- UVMI – This fiber is drawn using the same preform used in UVM above. Following the draw process, the fiber is loaded with dissolved hydrogen at elevated temperature and pressure. This yields a fiber almost completely insensitive to solarization. The problem is that the hydrogen will diffuse out of the fiber over time, even at room temperature. Once the hydrogen is out-diffused, the fiber returns to the solarization resistance performance of UVM. Depending on the size of the fiber, the effective life before out-diffusion can be on the order of weeks for small diameter fibers (100 µm core) to around a year for larger diameters (600 µm core). Environmental temperatures above ambient will increase the rate of diffusion and reduce the effective lifetime of this fiber.
- FDP – FDP fiber has been around for almost a decade. An improvement on UVM fiber, FDP fiber has in part replaced UVM as the industry standard. Developed at Polymicro to reduce the solarization sensitivity below that of UVM fiber, FDP improvements were achieved by material and process changes in the design. Since the fiber does not contain dissolved hydrogen, there is not an

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issue of the performance degrading over time as seen with the out-diffusion effect of UVMI. In FDP fiber, the UV-defect concentrations have been substantially reduced, such that the solarization degradation resistance properties are optimized.

Technological Breakthrough Enhances FDP Fiber Solarization Resistance

In the past year, technological breakthroughs have led to a significant improvement in the solarization resistance performance of Polymicro deep UV-optimized fiber, known as FDP fiber. Raising the bar on performance, the improved FDP fiber reflects a series of successful efforts to reduce UV-induced defect centers and improve solarization resistance as compared to the existing FDP and UVM fibers.

Although there are no official industry standards for evaluating deep UV fibers, extensive testing of the improved FDP fiber has yielded the best data available in terms of fiber performance. Results demonstrate that this fiber shows significant reduction in the 214 and 265 nm absorption bands typically associated with solarization effects in fused silica. The improvements were applied to fiber core diameters from 68 to 600 µm. Characterization of the solarization resistance was performed with added attenuation from UV exposure demonstrated to be less than 1dB per two meters tested for all fibers in the core size range.

Solarization Measurement

Solarization resistance is evaluated using a test known as a "Four Hour UV Exposure Test" as shown in Figure 1. The test uses a 2 m segment of fiber. Light from a high intensity Deuterium lamp is launched into the fiber using a focusing lens to maximize the intensity. The focus is aligned to maximize the intensity at 214 nm (generally the most sensitive wavelength for UV solarization). The output of the test sample is monitored using an Ocean Optics UV spectrometer, and data is collected for four hours.

Six important wavelengths are traced throughout the test process (214, 229, 245, 255, 266 and 330 nm). Also, the entire spectrum is measured and compared at the beginning and end of the test. The rate of degradation of each wavelength decreases as the test progresses, ideally reaching a saturation point before the four hour end of the test. Quick saturation is a desirable quality in a UV fiber, along with minimum degradation. The level of degradation at saturation is mostly independent of light intensity. Increasing the intensity tends to only change the speed with which the saturation is reached.

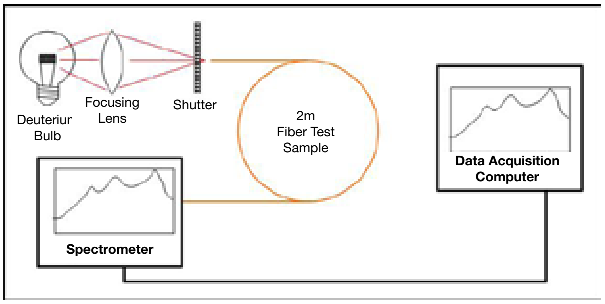
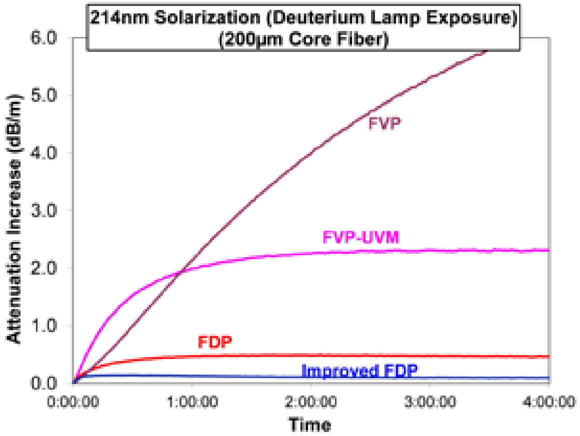


Figure 1. Four Hour UV Exposure Test Set-up

Side-by-Side Comparison of Solarization Results

As discussed, silica optical fibers are susceptible to UV-induced attenuation caused by damage induced by exposure to UV radiation. Most attenuation occurs in wavelengths less than 275 nm, with the peak damage occurring at 214 nm and 265 nm. The degree of damage varies greatly with the type of fiber. In the chart below, the change in the transmission at 214 nm during the 4 hour UV exposure test is compared for the four UV fibers discussed previously.



In order to get a clear picture of the performance improvement between the existing FDP and the new optimized FDP fiber, four hour tests were performed for comparison with fibers with a range of core diameter sizes from 600 µm to 100 µm. The relative spectral attenuation increase induced by the radiation during the test was measured for each of the fibers. The two charts below illustrate the difference in spectral solarization performance for the two fibers,

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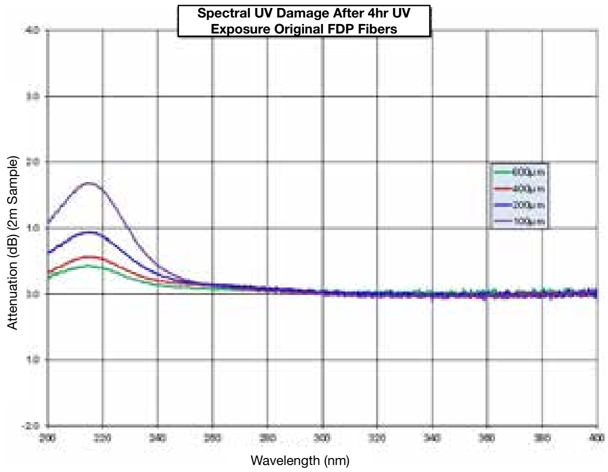

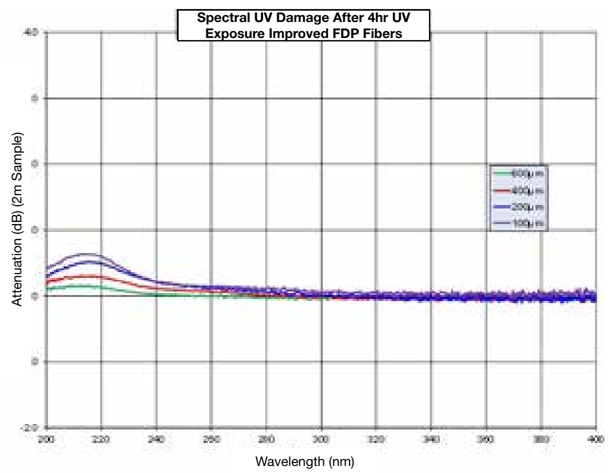

specifically showing the spectral solarization improvement from FDP to enhanced FDP in a range of fiber sizes. Complete data results are available on request from Polymicro.

Optimized Fiber Expands Uses for Biomedical Applications

The optimized FDP fiber showed significantly greater resistance to the formation of defect centers under radiation. The improvement is particularly noticeable in smaller core diameter fibers commonly used in minimally invasive biomedical applications requiring UV transmission. The optimized FDP fiber transmission remains stable under UV radiation over a wider range of input powers than all other fibers tested. Numerous applications could potentially benefit from this improved performance, ranging from industrial spectroscopy to biomedical applications requiring UV transmission.

Optimized FDP fiber is particularly beneficial to smaller fiber diameters less than or equal to 100 µm diameter, which makes it most useful for in-vivo medical application where small size and high flexibility enable improved and less traumatic access to remote areas of the body. Highly sensitive Polymicro FDP fiber can be used for photodynamic medical therapies requiring light activation, in addition to a range of dermatological treatments, catheters and other medical laser applications and diagnostic testing. Polymicro is a registered manufacturer of medical devices which meet the FDA 21 CFR 820 QSR standard. FDA registration ensures the biocompatibility of the fiber materials and sterilization protocols used in the manufacture and delivery of safe medical equipment, including fiber, connectors and subassemblies for biomedical sensing, endoscopic imaging, real-time diagnostic imaging and thermal ablative treatments using RF radiation.

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