UV-Induced Absorption, Scattering and Transition Losses in UV Side-Written Fibers

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Bragg gratings in single-mode fibers made by UV illumination are now widely used as wavelength selective devices, in particular in WDM networks. Depending on the particular application, more or less attention has to be paid to apodization of the index variation [1], to chirp of grating constants [2], mode conversion properties [3] etc. Also to be listed but often ignored is the fact that UV-written components add loss to an optical network and - what may be even worse - light can be scattered there and might deteriorate the overall performance of a device.

In this paper we investigate the contributions of UV-induced absorption, UV-induced scattering and of transition losses caused by asymmetries of the UV-induced index increase. Our experimental results for hydrogen loaded photosensitive fibers indicate that all these effects are of practical importance and must be taken into account.

![Figure 1: Loss evolution during scan of a focussed UV-laser beam along the fiber. The transmitted infrared power is monitored.](image)

A schematic of our loss measurement is given in the inset of Fig. 1: Infrared light emitted by a LED (mean wavelength 1550nm, bandwidth Δλ = 50nm) and transmitted through the fiber under test [4] (hydrogen loaded, 3 mol% H₂) is monitored while the fiber is illuminated by a focussed UV beam from a frequency-doubled Ar-Ion laser operated at λ_{UV} = 244nm. The UV-beam having a power of 80 mW and a
spot diameter of about $200 \mu m$ is scanned along the fiber at a speed of $2.5 \text{mm/min}$ by means of a translation stage proceeding in steps of $0.5 \mu m$. Note that light guided in cladding modes is not detected because of a mode-stripping coating at either end.

![Graph](image)

**Figure 2:** Transmission drops caused by the stripping of cladding modes. The height of the step corresponds to the initial step in Fig. 1.

The graph in Fig. 1 shows the measured relative transmission data in a logarithmic scale versus the position of the UV spot. Its most remarkable features are the initial stepwise drop which is followed by a linear decrease. The height of the step is evaluated to be $0.07 \text{dB}$. It is due to a displacement of the fundamental mode in the UV-illuminated section with respect to the unilluminated sections, caused by the side-writing which yields an inhomogeneous index profile [5]. This explanation is supported by Fig. 2. In the first part of that measurement the power of the LED transmitted through the UV-finished fiber is monitored with the rear coating removed so that cladding modes are guided. At some instant $t = 0$ the cladding modes are stripped by using an immersion liquid. This causes the detected power to drop by $0.06 \text{dB}$, i.e. the amount coupled to cladding modes by the mismatch of the local fundamental modes. A coupling to cladding modes like this will not be welcome in most cases but desirable when making long period gratings [6].

The linear part of the graph in Fig. 1 corresponds to a loss of $0.2 \text{dB/cm}$. To decide whether this loss is due to absorption or scattering we made a fiber - treated with UV in a similar way - being inspected by coherence domain reflectometry (low coherence reflectometry). The result is shown in Fig. 3(a) [7] where the distributed reflection in the illuminated fiber section of $4.5 \text{mm}$ length is displayed. The mean value deduced from Fig. 3(a) is $-86 \text{dB}$ which is the mean reflection out of the instrument’s spatial resolution element of about $50 \mu m$. Thus, the mean power reflection density $\rho = S \alpha_S$ is equal to about $5 \cdot 10^{-5} \text{/m}$ where $S$ denotes the capture fraction [8] and $\alpha_S$ the scattering loss coefficient. In a second experiment (see Fig. 3(b)) we focussed a He-Ne laser beam perpendicularly onto the UV-written section and measured the light launched into guided core modes by a supposed scattering structure. The rugged appearance of both graphs Fig. 3 can be explained by the effect of coherent superposition of contributions of a large number of individual scatterers (random walk problem). According to a very simple model for the experiment of Fig. 3(b) we expect the ratio of the detected power $P_D$ and the incident He-Ne laser power $P_L$ to be

$$\frac{P_D}{P_L} = \sqrt{2\pi \rho} \frac{a^2}{w_L} \left[ 1 - \frac{1}{2} \frac{a^2}{w_L^2} \right]$$

(1)
where \( \rho' = \frac{S\alpha_S}{(1.55/0.633)^4} \). \( \alpha_S \), \( a \) is the core radius, \( w_L \) the spot radius of the He-Ne laser beam. The value we get from this formula and the mean value taken from Fig. 3(b) are of the same order of magnitude: \( 9 \cdot 10^{-9} \) and \( 1 \cdot 10^{-8} \), respectively. Assuming a capture fraction \( S = 5 \cdot 10^{-3} \) we obtain a scattering loss coefficient \( \alpha_S \) of the UV-illuminated section of about 0.01 \( /m \) corresponding to 0.04 dB/m. Since the length dependent loss determined from Fig. 1 is 20 dB/m, only a very small part of that loss can be explained by scattering. The major part of it must be due to UV-induced absorption of the infrared light. Though in this respect the UV-induced scattering is negligible it is on the other hand of appreciable magnitude as compared to ordinary Rayleigh scattering of about \( 2 \cdot 10^{-4} \) dB/m observed in non-UV treated silica fibers. It might therefore cause undesired effects in grating devices, e.g., a modulation of the dispersion curve of chirped grating compensators.

In conclusion, UV-written fiber optical devices may suffer from different loss contributions: transition losses, UV-induced absorption and UV-induced scattering. The values we found in our experiments (0.07 dB per double-transition, 0.2 dB/cm absorption, and a scattering level of 0.04 dB/m - more than 20 dB above ordinary Rayleigh-scattering in silica) may affect the properties of grating devices.

References

[4] Ge-doped silica fiber, OFTC, Sydney, Australia
[7] measurement performed by G. LeBoudec, Photometrics, Marly-Le-Roi, France