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# Fabrication and stability of fiber Bragg gratings for WDM applications using a 266nm CW-laser

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**Abstract:** Diode pumped continuous wave all solid state UV-lasers operating at 266nm offer an interesting alternative to frequency doubled Argon ion lasers. We compare photosensitivity, UV-writing of Bragg gratings and thermal decay at 244, 257 and 266nm.

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## 1. Introduction

UV-writing in germanium-doped optical waveguides is a well established industrially applied technique for the fabrication of components within sensors and telecommunication. The most popular technique for inscribing fiber Bragg gratings (FBGs) is the phase-mask technique using a continuous-wave (CW) frequency doubled argon ion laser (244 or 257nm) or a pulsed ArF (193nm) or KrF (248nm) excimer laser as the UV-source [1]. By scanning the UV-beam over the phase-mask fiber assembly, a uniform grating may be written. Uniform gratings show significant side-lobes and will effectively increase the pass-band and limit the channel spacing. Apodization of the index modulation is commonly applied to reduce the side-lobes and flatten the pass-band. A simple and robust technique for apodization is the double-scan technique, where the index change is controlled by the exposure time defined by the velocity profile using a computer controlled translation stage. Using a chirped phase-mask offers the opportunity to inscribe chirped gratings used for dispersion compensation applications.

In this paper we present the implementation of the double-scan technique using a diode pumped CW all solid-state laser at 266nm (UV-Millennia / Spectra Physics) as the UV-source. The photosensitivity at 266nm in deuterium loaded standard telecom fibers has been studied previously [2,3]. In this study we compare the growth dynamics of deuterium loaded highly Germanium-doped fiber at 244, 257 and 266nm using CW lasers. In addition we also compare the thermal stability of the written FBGs at the different wavelengths.

## 2. Experimental setup

Three different types of experiments have been applied to study the basic performance of the CW laser system operating at 266nm:

- a) Photosensitivity.
- b) Continuous thermal annealing [4].
- c) Implementation of the double-scan method.

Figure 1(a) shows the implementation of the double-scan technique used for the fabrication of the presented FBGs. The setup consists of the UV-source, guiding optics and lenses to collimate and focus the UV-beam through a phase mask (PM) onto an optical fiber placed on a  $x$ - $y$  optical table consisting of two translation stages. The optical spectra of the Bragg gratings during UV-exposure (a) or thermal annealing (b) in a programmable high temperature oven, are monitored by measuring the transmission spectrum using an external cavity laser (ECL) and an optical spectrum analyzer (OSA). Two different types of fibers supplied from OFS Fitel Denmark have been studied, a standard telecommunication fiber (TW fiber; 6% Ge content) and an experimental highly photosensitive fiber (HNLf fiber; 22% Ge content).

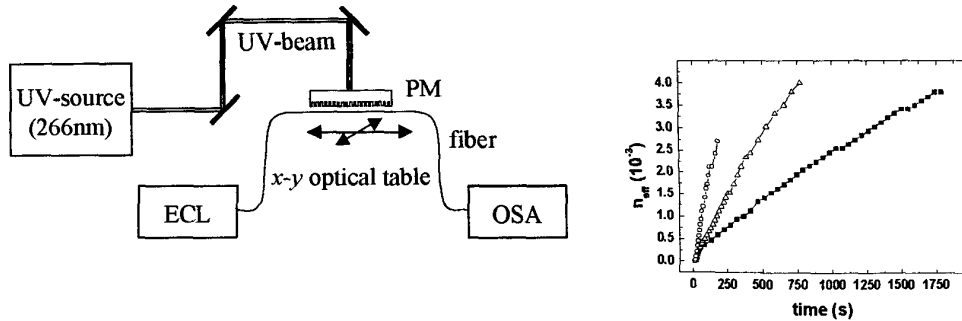


Fig. 1. (a) Experimental setup for UV-writing of FBGs. (b) Comparison of the UV induced refractive index change using 244nm (o), 257nm ( $\Delta$ ) and 266nm ( $\bullet$ ) CW exposure.

### 3. Results and Discussion

(a) Figure 1(b) shows the results of the photosensitivity study using a deuterium loaded HNLf fiber. The photosensitivity at the three different wavelengths is evaluated by monitoring the effective refractive index during the UV-exposure. The UV-beam (100mW in all three cases) was focused using a cylindrical lens along the fixed fiber phase-mask assembly.

The observed refractive index changes show high photosensitivity at all the three wavelengths with potential for writing very strong Bragg gratings. As expected from the UV absorption spectrum, a ca. 8 times longer exposure time is required at 266nm when compared to 244nm to induce a given index change when using the same UV-power. This disadvantage can be compensated, by using a higher beam power at 266nm up to 1.0 W or very high-pressure deuterium loading of the optical fiber [5]. The lower absorption coefficient at 266nm on the other hand leads to a higher penetration depth and a more isotropic UV-exposure in the fiber core, which could lead to lower induced birefringence [6].

(b) Using a lower photon energy for the inscription of FBGs rises the question of the lifetime of the FBGs. From very simple theoretical models for the UV-induced index change it might be expected that the lifetime, which is related to the thermal stability of the UV-induced oxygen deficiency centers, depends on the energy of the UV-excitation (e.g. the depth of the trap state) [7].

Figure 2 shows the thermal decay of pre-annealed (100° Celsius for 12 h; 10 dB initial strength) FBGs written at different wavelengths in deuterium loaded HNLf fiber at a constant ramping rate of 0.025 K/s.

The thermal decay curves are almost identical in the temperature range between 300K and 700K and similar at higher temperatures with the 244nm grating the least stable. This indicates, that more detailed models have to be applied to understand the thermal decay of FBGs as a function of writing wavelength.

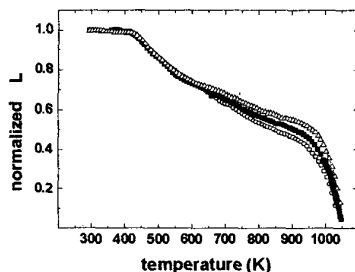


Fig. 2. Comparison of the thermal decay of FBGs written at 244nm (o), 257nm ( $\Delta$ ) and 266nm ( $\bullet$ ).

(c) In figure 3(a) and 3(b), two representative FBGs written with the scanning method at 266nm are presented. In figure 3(a) a uniform grating ( $L=5.6$ mm) written in a single scan using a constant velocity in TW-fiber is shown. The reflection spectrum shows a bandwidth of 25 GHz at -3dB and a side lobe suppression of 7dB with a

transmission dip of -12 dB. Both the reflection and the transmission spectra are in very good agreement with simulations using coupled mode theory (IFO-gratings\_4, by Optiwave Inc.) [8].

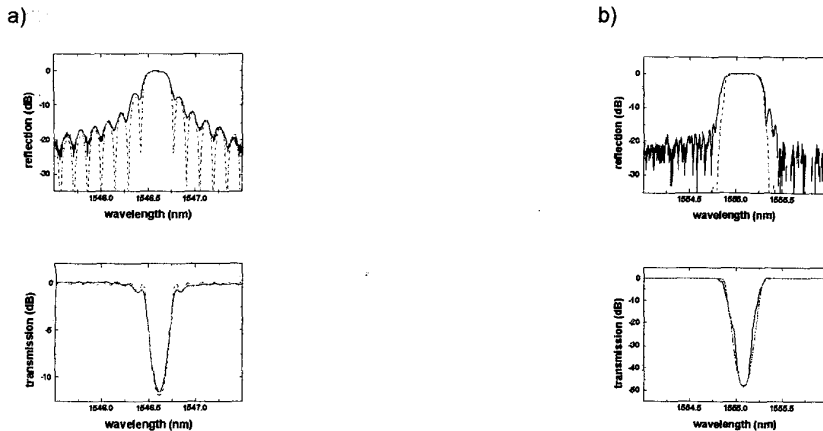


Fig. 3. Reflection and transmission spectra of (a) uniform grating in TW-fiber by a single scan and (b) raised Gaussian grating in HNLf fiber obtained by the double-scan technique. Experiment (—); Simulations (- - -)

For reduction of the side lobes of the filter function, apodization of the index modulation is needed. In a first scan a Gaussian apodization is achieved by using a Gaussian velocity profile along the fiber phase-mask assembly. This induces a chirp in the spectral response. A second scan without the phase-mask using an inverted velocity profile compensates for this effect and a so called raised Gaussian profile is achieved. Figure 3(b) shows a typical raised Gaussian FBG with a side lobe suppression of 20 dB with a transmission dip of -50dB. These Gratings can be applied as optical filters in WDM systems.

#### 4. Conclusions

We have implemented the double-scan technique for the UV-writing of FBGs using the UV-Millennia operating at 266nm as the UV-source and have demonstrated that very strong gratings can be achieved. As expected from UV absorption measurements, the photosensitivity at 266nm is lower than at 244 or 257nm increasing the writing time at a given laser power. The UV-Millennia can deliver an UV-output power up to 1.0 Watt compensating for this disadvantage. The thermal decay of the written FBG at 266nm shows a similar behavior when compared to 244 or 257nm implying a similar lifetime of the UV-written FBGs.

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