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# Comparison of Photosensitivity in Germanium Doped Silica Fibers using 244nm and 266nm Continuous-Wave Lasers

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**Abstract:** Diode pumped continuous-wave UV lasers offer an interesting alternative to frequency doubled argon-ion lasers. We report the first photosensitivity comparison using these lasers on deuterium loaded standard telecommunication fibers and unloaded experimental fibers.

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**OCIS codes:** (140.3480) Diode-pumped lasers, (140.3610) Ultraviolet lasers, (230.1480) Bragg reflectors.

## 1. Introduction

Photosensitivity in germanium-doped silica glass fibers and planar waveguides has attracted tremendous interest, since it allows the fabrication of components covering many applications within sensors and telecommunication. The photo-induced index change has been obtained using various pulsed and continuous-wave (CW) UV lasers. The most popular lasers are the pulsed ArF and KrF excimer lasers and the CW frequency doubled argon-ion (FDA) laser. Pulsed UV lasers are efficient for fast fabrication of Bragg gratings and provide good stability and high power efficiency. CW UV lasers are, however, preferred for several critical applications, which demand longer coherence length or high beam quality. Problems with the damage threshold in glass can also make CW lasers the preferred choice for applications that require a narrow focused beam, such as direct writing of planar waveguides [1], or phase-trimming of planar optical waveguide components [2].

Recently a 266nm CW diode-pumped all-solid-state (DPSS) laser has been introduced [3]. This laser uses an actively stabilized unidirectional ring cavity to frequency double a diode-pumped Nd:YAG laser with intra-cavity frequency doubling at 532nm. Due to the high efficiency of the laser, it has very low power consumption and does not need external water-cooling. Furthermore, the warm-up time for stable operation is only a few minutes and the operation cost is much lower than for the FDA laser. The beam quality and pointing stability is excellent, and it can provide up to 1W of CW power at 266nm [3]. However, from measurements of the UV absorption spectrum in germanium doped glasses, the photosensitivity is expected to be much higher at 244nm from the FDA laser than at 266nm from the DPSS laser [4].

In this work we present an experimental comparison of the two lasers by measuring the UV photosensitivity in deuterium loaded commercial telecommunication fibers and in non-sensitized, experimental fibers with high germanium concentration.

## 2. Experimental setup

Figure 1 shows schematically the experimental setup. The beam was expanded to a 2mm diameter using a telescope of two spherical lenses with optional spatial filtering. Then it was focused to a 0.1mm wide line on the fiber with a cylindrical lens. Using the phase-mask method to induce 2mm long Bragg gratings in the fibers, the photosensitivity was investigated by monitoring the dynamics of Bragg grating formation. The UV induced effective refractive index change,  $\Delta n_{eff}$ , was deduced from the relation  $\Delta n_{eff} = \lambda_{Bragg} / \Lambda_{mask} n_{eff,0}$ , where  $\lambda_{Bragg}$  is the Bragg wavelength,  $\Lambda_{mask}$  is the phase-mask period and  $n_{eff,0}$  is the effective refractive index before UV exposure.

The 244nm FDA UV laser is a Coherent Innova 300 FRED. Spatial filtering was needed to obtain a good beam profile, which reduced the power to 15mW. The 266nm UV laser is a LAS DELTATRIN DPSS laser providing 125mW with a good beam profile without using spatial filtering. Both lasers are operating in single-frequency. The phase-mask used in the experiments is optimized for 248nm exposure. This has better suppression of the zero-order diffraction at 244nm and consequently gives stronger Bragg gratings. However, this does not disturb the measurement of the UV induced refractive index change, since it only depends on the shift of the Bragg gratings center wavelength.

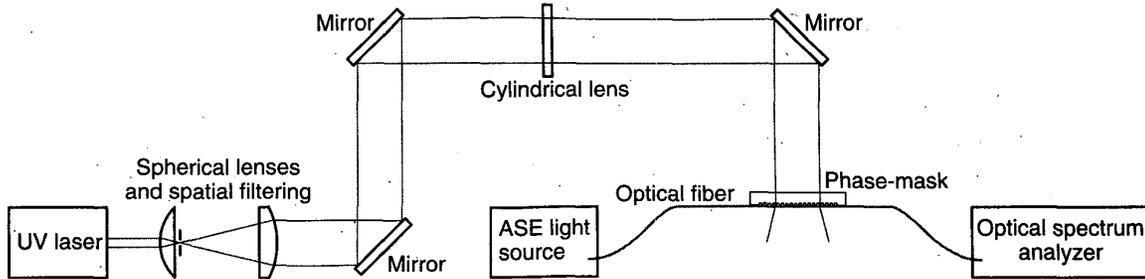


Fig. 1. Experimental setup for measuring the dynamic evolution of the Bragg grating formation. Spatial filtering was only used for the FDA laser. The transmission of an ASE broadband source through the Bragg grating is measured by an optical spectrum analyzer.

In the experiments we used four different optical fibers, which all were provided by Lucent Technology Denmark. The first two fibers are experimental fibers, where one fiber (Fiber A) has a 22-mol.% germanium concentration, and the other fiber (Fiber B) is co-doped with erbium as well as germanium. These fibers are very photosensitive at 244nm and were therefore used without sensitization. The last two fibers are commercial telecommunication fibers: a non-shifted fiber with 3.5-mol.% germanium doping, and a TrueWave® fiber with 6-mol.% germanium doping. These fibers were sensitized for UV light by room-temperature deuterium pressure loading at 135 bar for 10 days.

The dynamic change of the Bragg gratings was monitored by measuring the transmission spectrum of a broadband ASE source. The spectra were recorded using an ANDO optical spectrum analyzer with 0.01nm resolution.

### 3. Experimental results

The photosensitivity of the four fibers is evaluated by monitoring the change in effective refractive index, induced during the UV exposure. This change is shown in figure 2 as a function of the fluence from the two lasers.

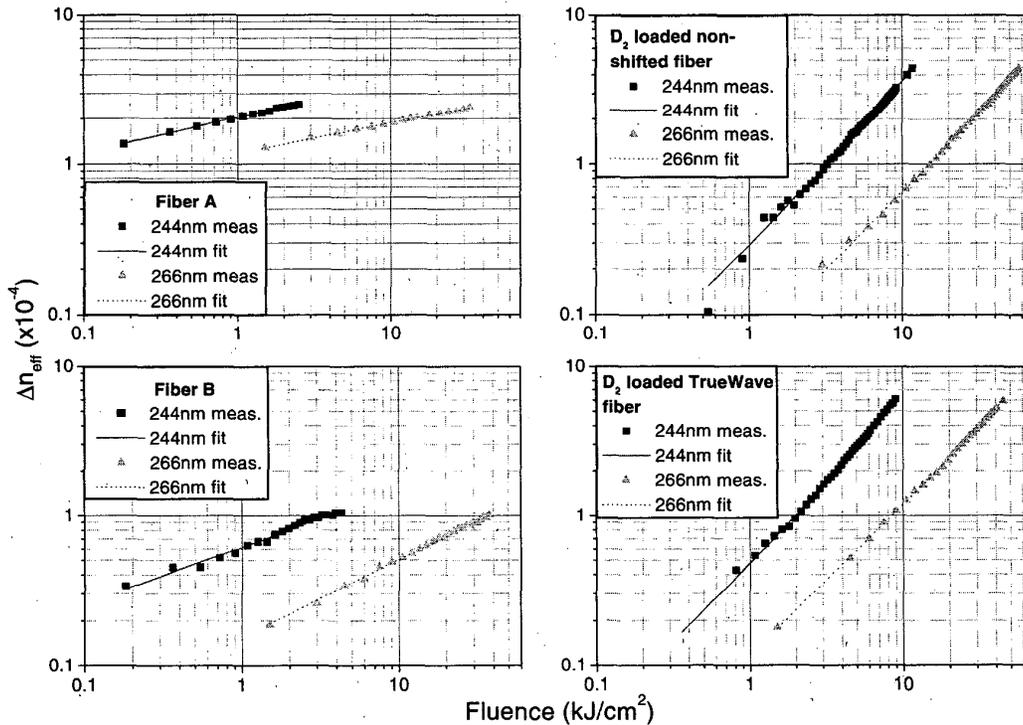


Fig. 2. Comparison of the UV induced refractive index change using 244nm and 266nm CW exposure. Results are shown for two experimental fibers and two deuterium loaded commercial fibers. A power law is used as fit for the index change of the experimental fibers, whereas a parabolic fit is used for the deuterium loaded commercial fibers.

The UV induced refractive index change of the unloaded fibers is fitted well by a power law of the form  $\Delta n_{eff} = CF^b$ , where  $F$  is the UV fluence [5]. However, the deuterium loaded fibers are described better by a parabolic fit of the form  $\Delta n_{eff} = AF + BF^2$ .

The observed refractive index changes show high photosensitivity in all the fibers with potential for writing strong Bragg gratings. As expected from the UV absorption spectrum, higher fluence is needed at 266nm than at 244nm to induce a given index change. The ratio between the required fluences is nearly constant, but is different for the four fibers as shown in table 1.

Table 1. UV fluence ratio,  $F_{266nm}/F_{244nm}$ , required to induce a given index change

	Non-sensitized fiber		D pressure loaded fiber	
	Fiber A	Fiber B	Non-shifted fiber	TrueWave®
$F_{266nm}/F_{244nm}$	14±4	13±3	4.8±0.2	4.7±0.4

The table suggests that deuterium pressure loading of the fibers provide higher enhancement of the photosensitivity at 266nm than at 244nm.

An important factor to be considered when the efficiency of the two lasers is compared, is the exposure time required to induce a given index change. In the experiments presented in this paper, the DPSS emits eight times more power than the FDA laser. Although both lasers are available with higher power, this power ratio is reasonable for comparison of lasers with similar initial cost. In this comparison we find that the DPSS 266nm laser is the fastest laser for writing Bragg gratings in the deuterium loaded fibers, whereas the FDA laser is fastest for writing in the unloaded fibers.

#### 4. Conclusion

We have compared the photosensitivity in germanium doped fibers for continuous-wave exposure at 244nm and 266nm. As expected from UV absorption measurements we find that the photosensitivity is highest at 244nm. For non-sensitized experimental fibers we find that we need more than ten times as much 266nm fluence as used at 244nm to induce a given refractive index change. However, the ratio of the necessary fluence is less than five times when using deuterium pressure loaded standard telecommunication fibers.

The recently introduced all-solid-state diode pumped laser at 266nm provides several attractive features. Among these are high power efficiency, short warm-up time and low running costs. The laser is capable of emitting 1W of 266nm power with a good beam quality which makes it an attractive source for applications utilizing the UV photosensitivity in germanium doped silica glass.

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