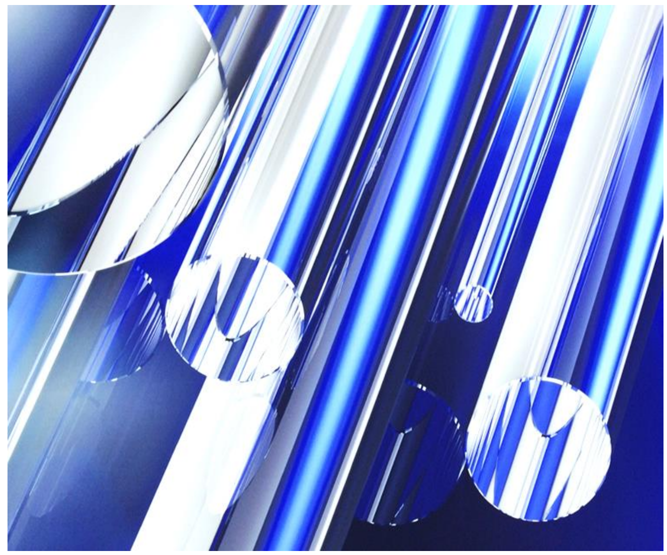
Fiber Bragg Grating Writing Made Easy



Research labs mostly are in need for small quantities of fiber bragg gratings (FBGs) but need to vary their optical properties for e.g. sensing tasks in life sciences and other fields of applications. The result is long lead times and high unit costs when ordering from third party suppliers. Now the scientist can make specifically taylored FBGs himself instead of going through the hassles associated with small batch procurement. Plus, he does not even need to be a laser jock or an expert in FBG writing.

Recent improvements concerning a newly developed 193 nm FBG writing system jointly developed by Hittech Multin BV in the Netherlands and NorthLab Photonics AB in Sweden and based on Coherent's excimer technology from Germany comprising flexible automation of fiber and mask handling design address these aspects. Consequently, FBG manufacturing which mostly addresses optical sensing applications will gain traction toward scientific use. Using short 193 nm wavelength in FBG writing delivers high material coupling and thus facilitates permanent refractive index change as shown in the figure 1 below.

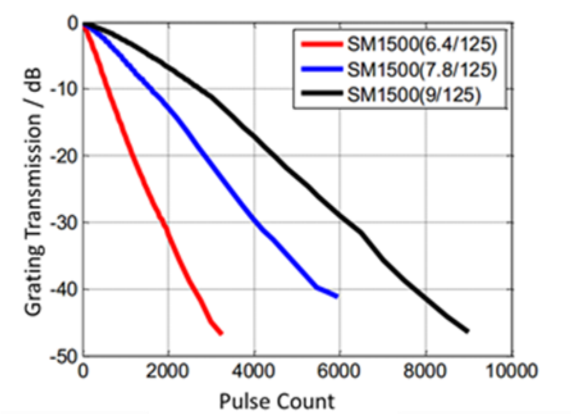


Figure 1. Evolution of grating strength as a function of 193 nm pulse count for three different germanosilicate fibers from Fibercore. (Remco Nieuwland, Hittech Multin BV).

Pulsed excimer lasers are the most powerful 193 nm laser sources on the market and have a history of success in the most demanding industrial applications such as photolithography, refractive eye surgery and high quality laser engraving of transparent materials. Long-term stable pulse energies of up to several 100 mJ are available from excimer lasers for automated FBG writing systems.

FBG fabrication usually occurs via the phase mask method exposing a photosensitive fiber to an interference fringe pattern created by a phase mask. Directing the excimer laser beam through a phase mask the latter diffracts the incident laser light into various orders, which overlap and optically interfere with each other in a region of some 100 µm behind the mask. This results in alternating areas of laser intensity along the fiber core, whose spacing is either equal to the phase mask period, or half of this value, depending upon the exposure geometry.

A recent system approach integrating the Coherent ExciStar excimer laser at 193 nm, beam conditioning optics, up to 16 phase masks (uniform or chirped), automated mechanics and control software for flexible FBG mass manufacture is shown in figure 2.

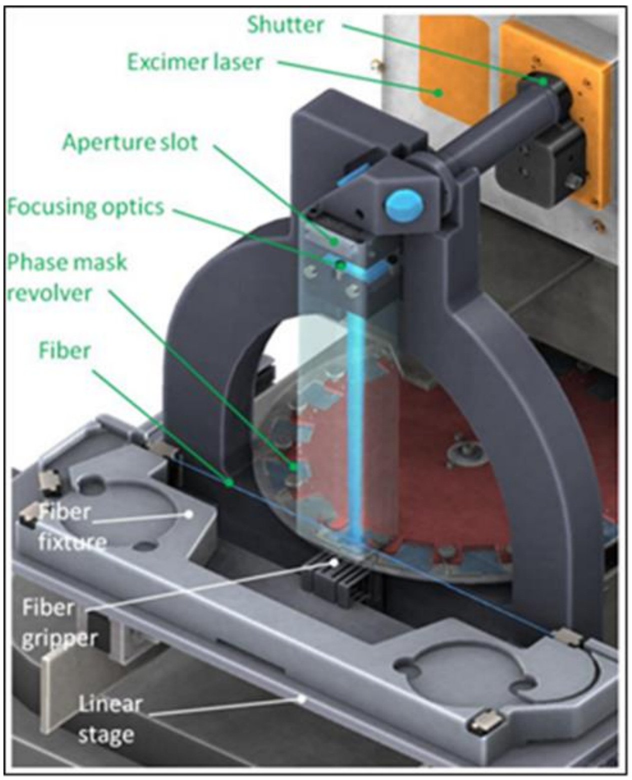


Figure 2. NORIA FBG writing system from NorthLab Photonics in Sweden (Per Karlsson, NorthLab Photonics AB).

Among the most critical parameter for an FBG is the center wavelength. This value is a function of two parameters – the phase mask and the effective refractive index of the fiber. The effective refractive index is dependent of the fiber's numerical aperture (NA), the value of which is stated by the manufacturer for every fiber. As fiber producers do not tightly control the core refractive index, the result is significant variations for different fiber lots.

Reproducible center wavelength value despite lot-to-lot differences in the refractive index of a 125µm fiber is achievable by applying a force in order to stretch the fiber during the writing process via the fiber fixture. The pre-tension force thus accounts for NA variations. As shown in figure 3 below, shifting FBG center wavelength as much as 4 nm for a phase mask nominally centered at 1,550 nm is usually achieved, which is more than twice what is necessary to correct for the typical batch-to-batch variations in fiber numerical aperture. Control of the pre-tension force is precise enough to deliver center wavelength accuracy of 100 pm, and repeatability of ±50 pm in production.

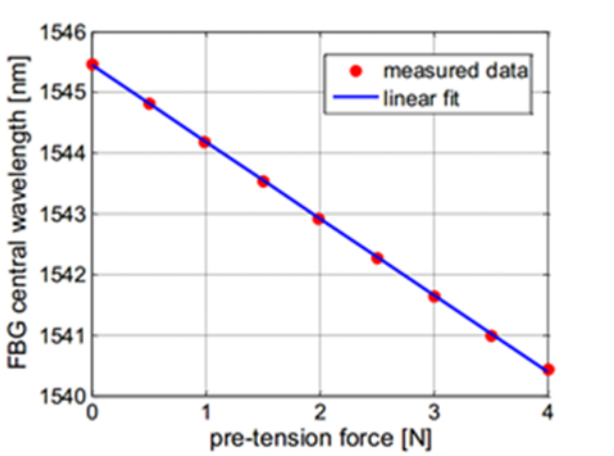


Figure 3. FBG central wavelength tuning by applying pre-tension to a 125 µm fiber during manufacturing (Remco Nieuwland, Hittech Multin BV).

For a grating with a uniform index modulation spectral bandwidth narrows with increasing grating length as shown in figure 4. However, the sharper the reflectance peak, the more energy is shunted into the side lobes. This effect mitigates by varying the depth of index modulation along the FBG, so called apodization. However, this does produce some increase in spectral bandwidth because it decreases the effective grating length.

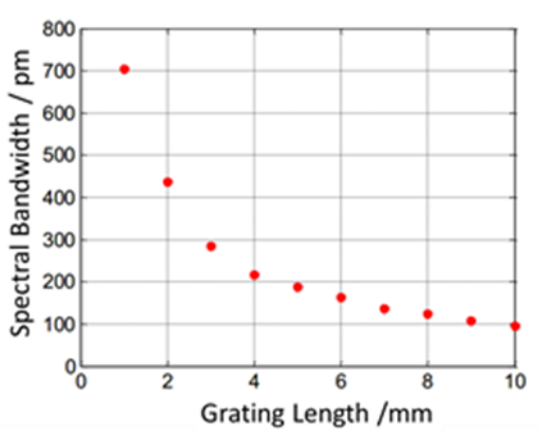
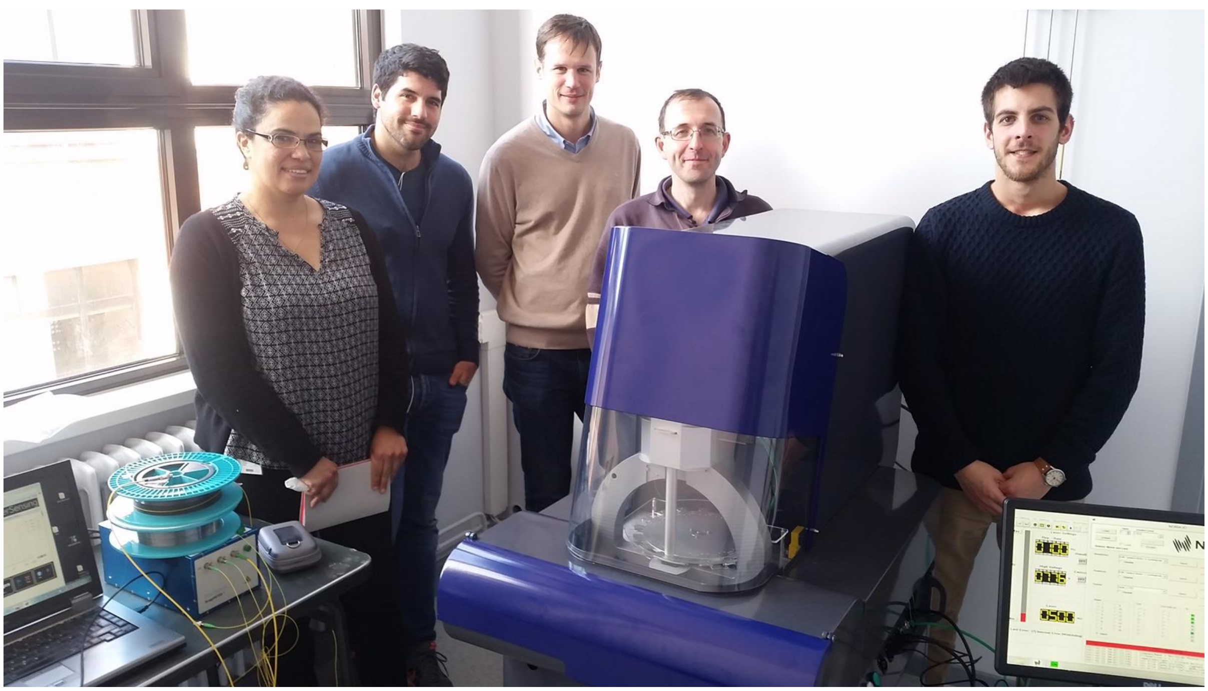


Figure 4. Effect of fiber Bragg grating apodization for side lobe supression (Remco Nieuwland, Hittech Multin BV)

The 193 nm excimer laser has a uniform (top hat) intensity distribution in the long direction, and a near-Gaussian profile in the short dimension. High beam coherence optics for the excimer laser beam will shape the excimer laser beam such that the system can write FBGs from typically 1 to 10 mm in length. From a technical viewpoint, the capability for beam apodization is mandatory and is accomplished by using a shaped aperture in the beam path to convert the uniform distribution of the laser into a Gaussian profile. For example, a Gaussian apodization mask can achieve a side lobe suppression ratio of typically 15 dB for a 10 mm length grating.

Writing a uniform FBG with a center wavelength transmission reduction of 20 – 50 dB requires as many as 1,000 laser pulses at an energy of 5 mJ/pulse from the 193 nm excimer laser. At a repetition rate of 500 Hz, this would imply an exposure time of just two seconds. Chirped FBGs where the grating period changes along the length of the grating require much higher refractive index contrast to reach the same level of reflectance, meaning even longer exposure times. Any relative motion between the phase mask and fiber over this period, even at the nanometer level, is enough to degrade FBG performance. In order to eliminate any relative vibrational motion in a FBG writing system, the fiber must be positioned relative to phase mask with submicron accuracy during exposure. However, the fiber holding and clamping system must meet another important requirement. For sensing applications, in particular, usually multiple FBGs are written into a single fiber. The spacing between these individual FBGs usually have to be controlled very precisely. Fiber positioning technology is thus as important in the case of multiple gratings to be inscribed. Translation stage positional accuracy enabling multiple FBGs to be written over a total fiber length of 250 mm has been achieved recently to be of the order of 0.1 mm using the automated NORIA system based on an ExciStar 193 nm laser.

At the University of MONS in Belgium, the Advanced Photonic Sensors group of Professor Christophe Caucheteur is very happy with the performance of the NORIA and the ExciStar as an addition to their existing FBG manufacturing capabilities (Figure 5). The NORIA will be used jointly by the Electromagnetism & Telecom department of UMONS and by B-SENS a Belgian company specialized in the development of OEM sensors based on the fiber Bragg grating technology.



In conclusion, widespread deployment of FBGs in scientific labs has been limited up to now partly by the expenses and challenges of device fabrication. Coherent excimer laser performance advances in conjunction with the new system approach by companies Hittech Multin and NorthLab Photonics for turnkey, fast and flexible FBG writing with unprecedented accuracy and reproducibility will open up new opportunities in emerging FBG sensor markets. Technological advances of fiber Bragg grating writing systems, i.e. flexible automation of fiber and mask handling design, are expected to result in increased demand for fiber Bragg grating. Next to optical sensing applications and use in fiber lasers, FBG devices serve industrial applications in telecommunications and oil & gas industries. Moreover, FBG based pressure, strain, and temperature sensing becomes ubiquitous in smart manufacturing and non-destructive testing, which includes composite and laminate structures.

ExciStar excimer lasers at 193 and 248 nm are increasingly employed both in research type and industrial FBG production. They are compact, stand-alone lasers designed for easy system integration providing pulse frequencies from 1 to 1000 Hz. The sturdy ALMETA design ensures stable performance and endurance proven in the field while serving a broad range of delicate tasks including ultra-precise cornea ablation, three-shift prescription lens marking, and last but not least FBG manufacturing.

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