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The road to: Knowledge Design Manufacturing Application

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NORIA - the Fiber Bragg grating manufacturing solution

Introduction to fiber optic sensing

Measurements in difficult conditions often require the use of photonics rather than electronics. For example, imagine measuring the temperature and (blood-) pressure of a patient while he or she is positioned inside an MRI scanner. The large magnetic field prohibits the use of any metals inside or close to the scanner and renders any electronic device useless. Light, guided through a fiber optic cable, on the contrary, can be used without any problems. There is no interaction between the light and the magnetic field. Other applications in the field of fiber optic sensing can be found in the oil and gas industry in which various parameters down hole (pressure, temperature, flow) influence the production yield. Better insight down the well is required. However this poses a lot of technical difficulty for conventional sensors. The high temperature, high pressure and corrosive environment renders most electrical sensors useless while fiber optics provides clear advantages.

The Fiber Bragg Grating (FBG) is the most popular fiber optic sensing technique, in which a Bragg grating positioned in the core of an optical fiber, is used as the sensor basic building block. The FBG is a periodic modulation of the refractive index along the propagation direction of the optical fiber and is often visualized as a 'barcode' like pattern with approximately 20,000 'stripes' inscribed over 10 millimeter fiber length.
The periodic pattern, i.e. the Bragg grating acts as a filter which reflects an incident optical field. Reflection of the incident field is maximized if the wavelength of the incident field matches the periodic pattern by, $\lambda_B = 2n_{eff}\Lambda$. In which, λ_B is the Bragg wavelength, n_{eff} the effective refractive index of the fiber and Λ the grating period. Any change in the grating period or effective index, either by temperature or strain will shift the central reflectance wavelength, λ_B. See Figure 1.

Note that multiple FBG's can be written along the same fiber (multiplexed) each with a different grating periodicity and can be read-out simultaneously (more commonly referred to as interrogated). The multiplexing capability is one of the unique features of FBG's.

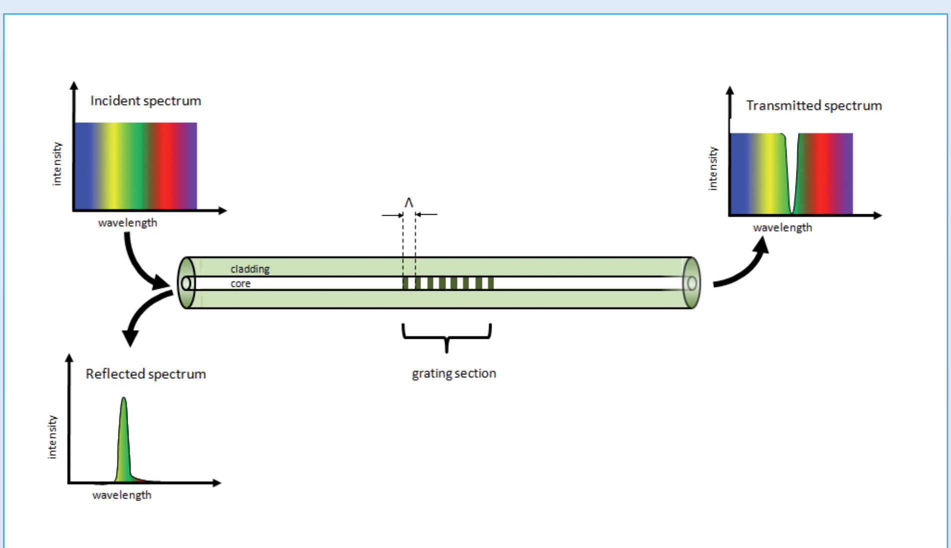
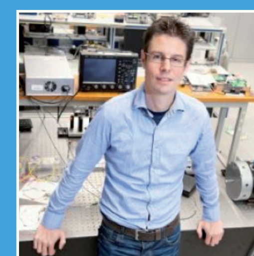


Figure 1: Fiber Bragg grating operating principle



Remco Nieuwland studied applied physics at the University of Twente in the Netherlands and obtained his MSc in 2005. He started his industrial career in 2005 at ASML in Veldhoven within the Sources and Dose control development group as a senior developer. In 2009 he moved to TNO Industrial Innovation as an optical research scientist within the field of photonic sensing (fiber optic and integrated optic). Most of his work focussed on fiber optics for sensing applications and he started leading the technology line Fiber Optic Sensing Systems within the Optics of TNO department in 2012. At the end of 2014, due to the development of a commercial Fiber Bragg manufacturing tool which he initiated a few years earlier, he decided to move to Hittech Multin, also located in Delft to pursuit further development and commercialization of the NORIA Fiber Bragg Grating manufacturing tool. As of November 2014 he is leading the Optics group at Hittech Multin which focuses on fiber optics and free space optics to complement the opto-mechanical expertise.

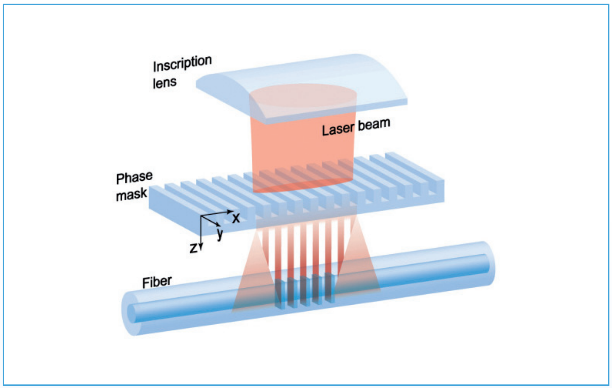


Figure 2:
FBG inscription setup using a phase mask in close proximity to the fiber.
A cylindrical lens is used to create a line focus along the length of the fiber.

Fiber Bragg manufacturing

An FBG can be manufactured by lithographic transfer of the periodic pattern into the core of a photosensitive optical fiber. Most commonly a phase mask combined with an UV laser is used to generate and transfer the periodic pattern. See Figure 2.

The phase mask diffracts the light into the +1 and -1 order while suppressing the zeroth order transmission.
Self interference between the two orders generates an interference pattern with a period equal to half the phase mask period which is transferred into the optical fiber. The fiber is in close proximity to the phase mask.

The optical fiber exhibits a change in refractive index induced by exposure to UV light. Multiple different (complex) mechanisms are widely accepted to be responsible for the change in refractive index, however defects in the silica matrix of the fiber plays an important role. More specifically, defects associated with incorporation of germanium have significant effects on photosensitivity.
Germanium is commonly used in the core of an optical fiber as a dopant to increase the core's refractive index forming a step-index fiber. The increase in germanium gives rise to an increase in defects, corresponding to an increase in photosensitivity. The high dopant level, however, gives rise to some undesired effects, such as an increase in optical losses and Numerical Aperture and a decrease in mechanical strength.
An alternative method to increase the photosensitivity without increasing the dopant levels is to load the fiber with hydrogen. Under high pressure, hydrogen diffuses into the glass matrix and gives rise to permanent refractive index changes under UV exposure. Afterwards the hydrogen will simply diffuse out under normal pressure, returning the fiber to the original state prior to loading.

NORIA

Nowadays FBG's can be bought commercially at a number of suppliers worldwide. Each supplier has developed a dedicated setup for manufacturing FBG's and creates revenue by retailing the manufactured FBG. Note that retail prices are steep and can easily exceed €€100,- per grating.
The photolithographic process required to transfer the periodic pattern from a mask into the core of an optical fiber is discovered and patented by K.O. Hill. Recently the patent expired, but still a significant barrier for sensor manufacturers remains in terms of material cost, time and know-how to initiate the development of an in-house setup.

The NORIA provides a solution for sensor manufacturers to fabricate the FBG's in-house instead of procuring the FBG's from a third party source. The FBG quality control, steady supply of FBG's and more importantly reduction in unit cost price are key drivers for NORIA customers. See Figure 3.

The NORIA is equipped with a Deep Ultra Violet excimer laser (Coherent Excistar XS), emitting nanosecond pulses at

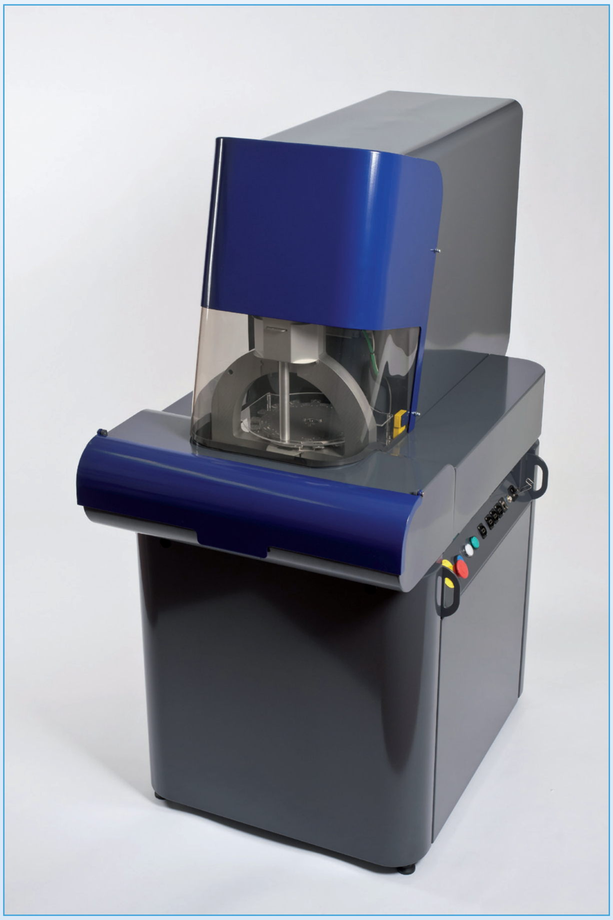


Figure 3: The NORIA FBG manufacturing solution

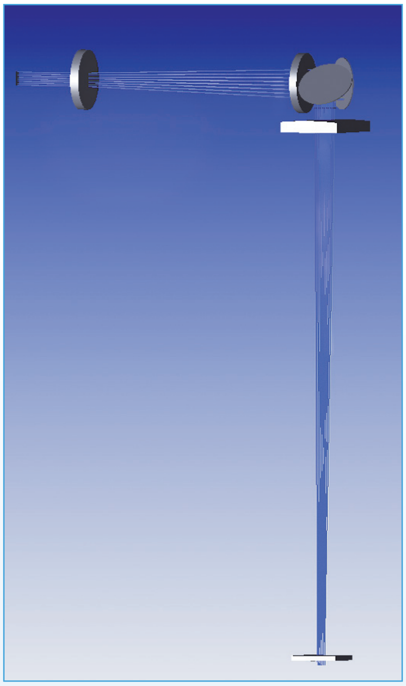


Figure 4: Shaded model of the NORIA from ZEMAX raytrace software

a wavelength of 193 nanometer. At the heart of the NORIA is the optical assembly (Figure 4 presents the ZEMAX optical design). The beam from the excimer laser is conditioned such that a set of high grade fused silica lenses efficiently illuminate the fiber through the phase mask. Multiple different phase masks can be selected using a rotating disc, capable of supporting up to 16 phase masks. The optical fiber is mounted in a modular fiber fixture and is positioned on a linear stage such that FBG's can be written along the fiber in an automated fashion. In addition, a novel fiber gripper is developed to position the fiber with micrometer accuracy and reproducibility with respect to the phase mask. See Figure 5.

Business arrangement

The development of a high tech product such as the NORIA only makes sense if a viable business case with the right market outreach can be forged. Therefore, prior to the technical

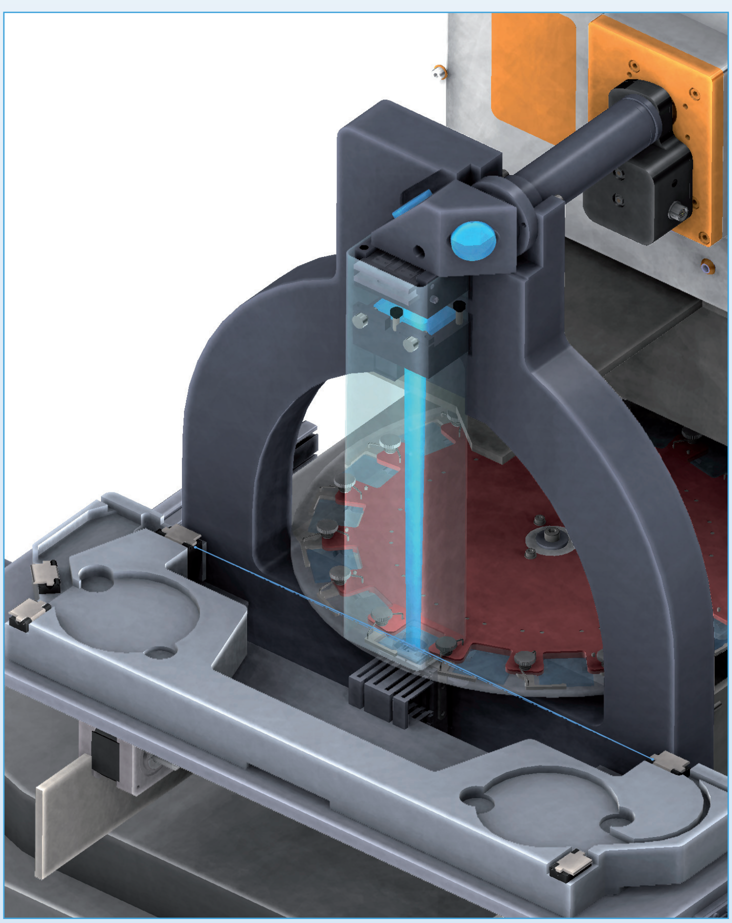


Figure 5: NORIA close-up view

Fred Couweleers holds a Master's degree in Applied Physics from the Technical University Eindhoven (1990). He started his career in various positions within Philips, focusing on opto-mechanical design of equipment necessary for production of the triangulation sensor of the TriScan solderpaste inspection machine.
In 2001 he moved to Norway where he worked at SINTEF Materials Technology, predominantly on the development and use of structured light methods for non-contacting 3D shape measurements (combining photogrammetry and fringe projection).
Back in the Netherlands he worked at Mapper Lithography (2007-2015), being responsible for design and production of a capacitive stage position measurement system and an optical alignment sensor before moving to Hittech Multin where he is part of the Optics group, where he works on various free space optics projects such as laser beam shaping, tolerance analysis using Zemax and concept designs for a lithography tool calibration sensor.

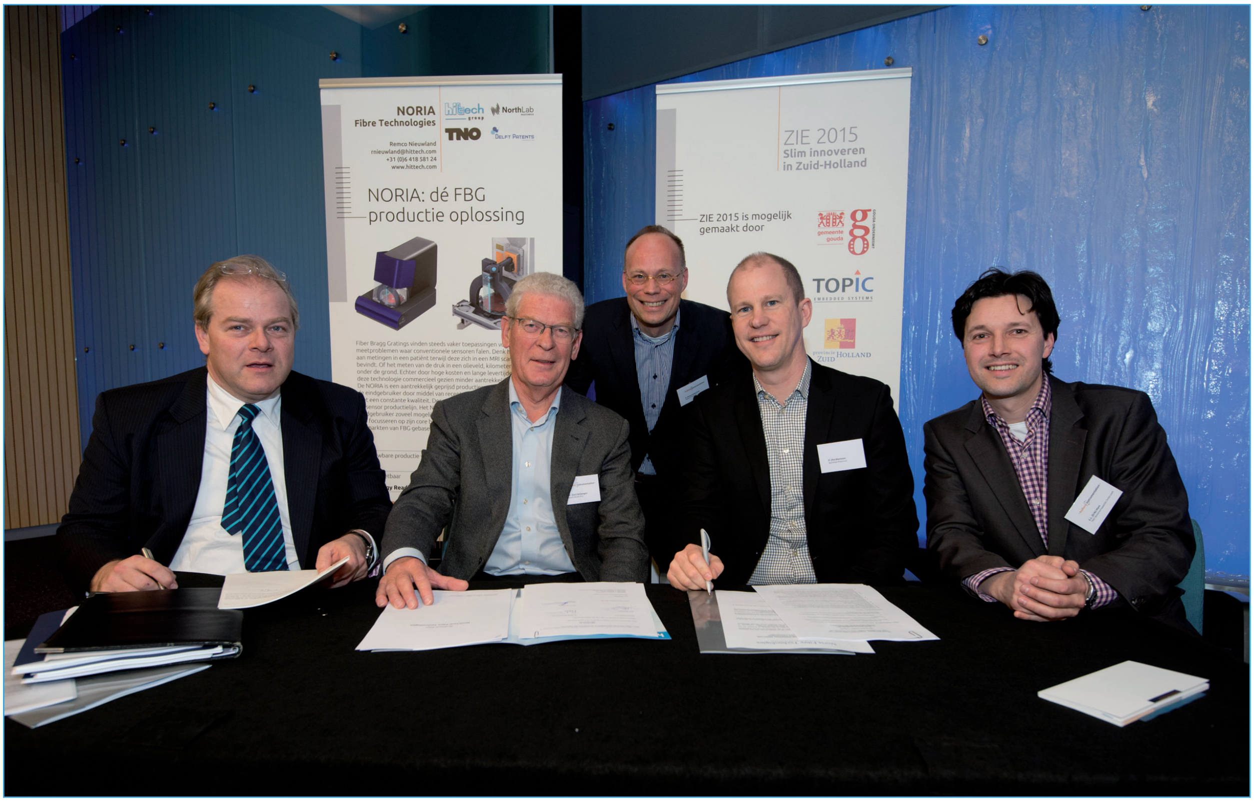


Figure 6: NORIA Fibre Technologies formal signing event. From left to right:
Mr. G.E.A. Kienhuis (solicitor), Cor Heijwegen (Hittech group), Peter Reijneker (Hittech Multin), Per Karlsson (Northlab) and Erik Ham (TNO / Delft patents)

engineering, quite a bit of effort was spent in setting up the right business arrangement. TNO was responsible for initiating the NORIA concept and had produced a laboratory demonstrator. At this stage Hittech Multin was approached by TNO to participate and jointly investigate the business case. With Hittech Multin as the development and manufacturing partner and TNO providing the intellectual property, an obvious partner with the right market outreach, willing to market the NORIA, was missing. This partner was found in Northlab Photonics based in Sweden. Northlab Photonics is active in the field of fiber optic processing equipment for some years and has a global sales network through distributors. TNO, Hittech Multin and Northlab Photonics have joined forces in a joint venture called NORIA Fibre Technologies (NFT). Founded on the 31st of March, NFT is directed by Peter Reijneker, managing director of Hittech Multin.

Market introduction

The NORIA is launched on the 22nd of June at the Laser World of Photonics trade fair in Munich. With 31.000 visitors from all over the world the Laser World of Photonics was the trade fair to launch the NORIA and see first interest from potential customers.

See also: http://www.northlabphotonics.com/product-category/fbg-manufacturing/

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