OPTICAL SENSING TECHNOLOGIES

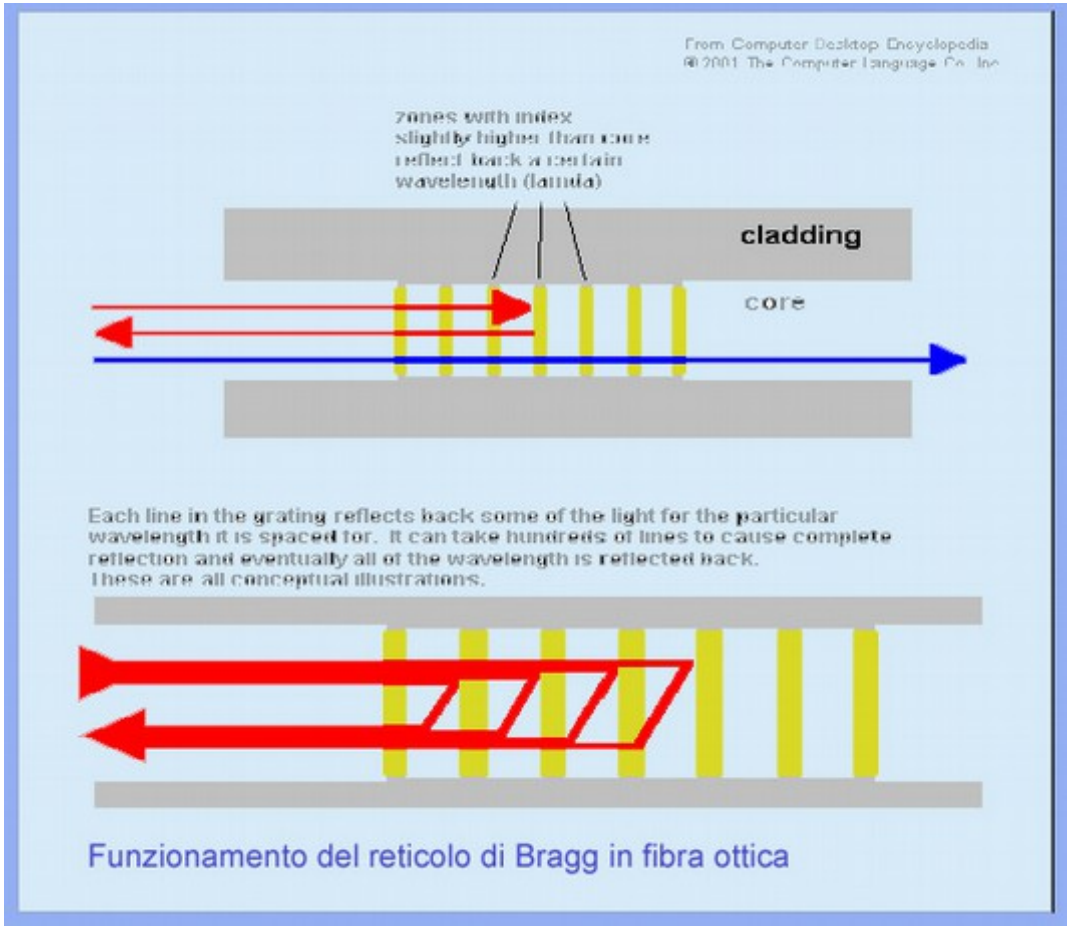
Fiber Bragg Grating Sensors

Summary

Introduction to Fiber Bragg Grating (FBG)

- principle of operation (3 slides)
- characteristics and detectable parameters (3 slides)
- application examples (3 slides)
- production process (3 slides)
- measurement equipment (2 slide)

FBG: optical principle



Periodic variations of the refraction index in the fiber optic *core* determine the reflection of the guided light at a specific wavelength λ_{Bragg}, said the Bragg wavelength.

The relationship between this wavelength and the period Λ of the grating is the following:

$$\lambda_{Bragg} = 2\, n_{eff}\, \Lambda$$

Where n_{eff} is the refraction index of the fiber optic.

The FBG formula

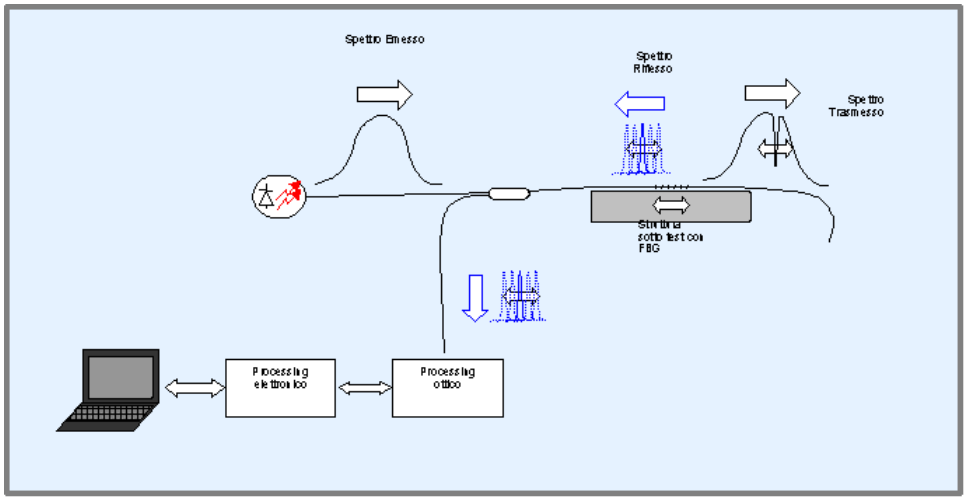
A variation of the period of the grating inscripted in a fiber optic – induced by mechanical or thermal perturbation – causes a shift of the reflected peak wavelength, due to the related optical path length variation.

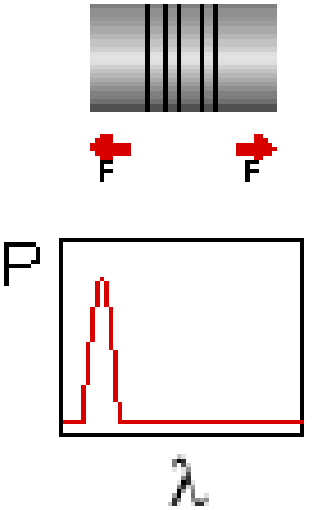
This is expressed by the formula:

$$\Delta\lambda_{Bragg} = 2\, n_{eff}\, \Lambda \left(\left\{ 1 - \left(\frac{n_{eff}}{2} \right) \left[P_{12} - \nu \left(P_{11} + P_{12} \right) \right] \right\} \epsilon + \left[\alpha + \frac{\left(\frac{dn_{eff}}{dT} \right)}{n_{eff}} \right] \Delta T \right)$$

where Pij are the Pockel coefficients of the elasto-optic tensor, ν is the Poisson coefficient, ε is the applied deformation, α is the thermal expansion coefficient of the fiber and ΔT is the temperature variation.

How a FBG sensor works





By replacing the typical coefficient values for a fiber optic in the FBG formula, the calculated Bragg wavelength shifts due to strain or temperature are of the order of:

- 1 pm/με
- 10 pm/°C

It is also evident from the formula that it is impossible to separate the two effects mechanical and thermal from one another

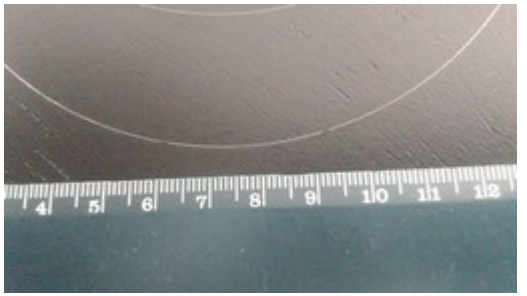
Typical FBG characteristics

- Typical FBG length: 1 - 15 mm
- Reflectivity: 1 – 95 %
- Operating wavelength: compatible with the fiber optic transmission band
- Thermo-Mechanical Characteristics:
  - **Long term resistance at high temperature exposure**: 4% reflectivity reduction after 100 days @ T=200°C [*], 6% after 1000 days
  - **Strain resistance**: 1,5-2 kg typical breaking load for recoated fibers, corresponding to a max elongation of around 2%; > 5 kg or 6% elongation for DTG (draw tower gratings)
  - **Duration in long term loading conditions**: 20 years for a strain induced elongation of 0.2%

  [*] for fiber with high temperature coating only

FBG sensors: advantages

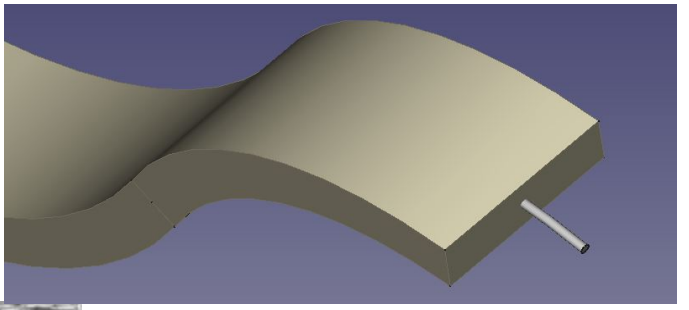
- Small size, low invasivity
- Long lifetime → Reduced maintenance cost
- Insensitivity to electromagnetic noise
- Industrial production process
- High insensitivity of the sensor to the perturbations on the connection fiber (variations of intensity, polarization, etc.)
- Easy integration and multiplexing of more sensors on the same fiber
- Different coatings, packaging and connectors for various application exigencies



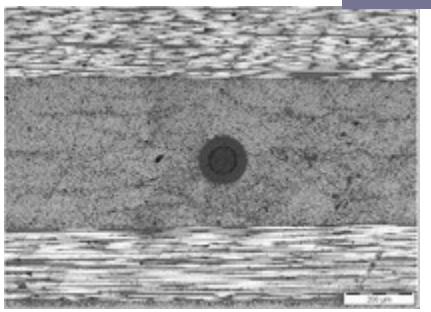
Detectable parameters

With proper *packaging and installation*, including embedding, glueing, soldering of metal coated fibers, FBG sensors can detect several physical parameters:

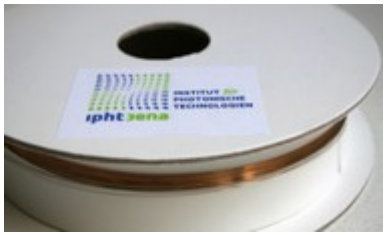
- Strain
- Temperature
- Pressure
- Acceleration
- Chemical concentration



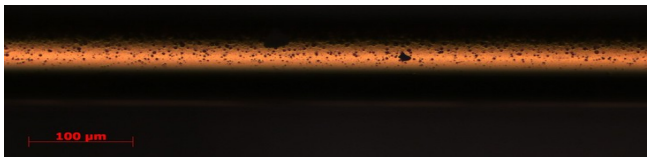
composite tape



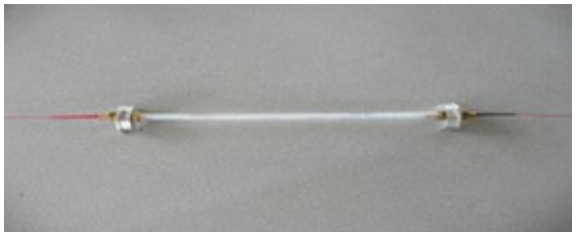
reduced cladding size embedde fiber



gold coated fiber



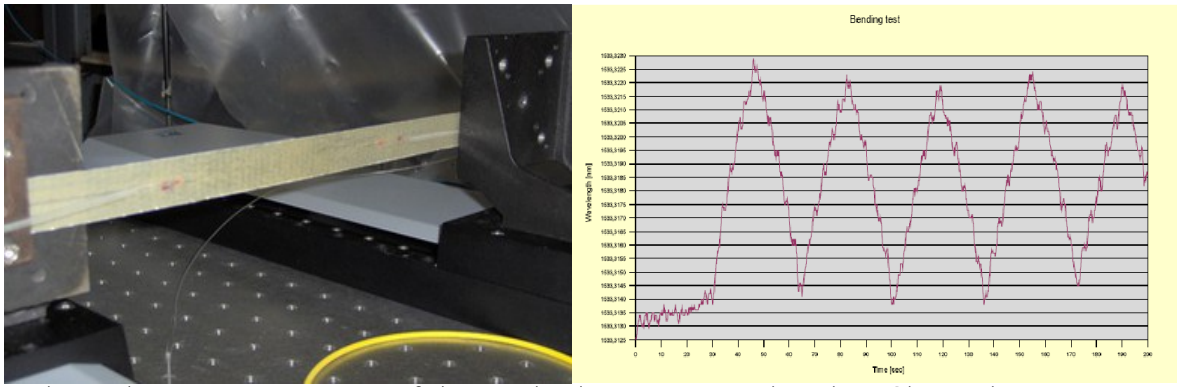
wall mount sensor



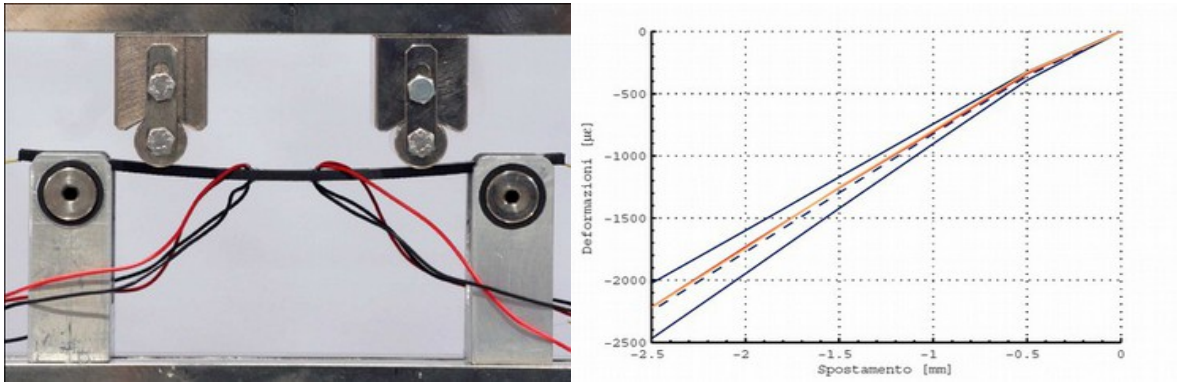
Application examples - 1

Strain measurement for structural health monitoring

Coupling of composite materials with fiber optic sensors and actuators allows the development of **Smart Materials** and of Structural **Health and Usage Monitoring Systems** (HUMS)



High resolution measurement of the tip displacement on a bending Glass-Fiber specimen

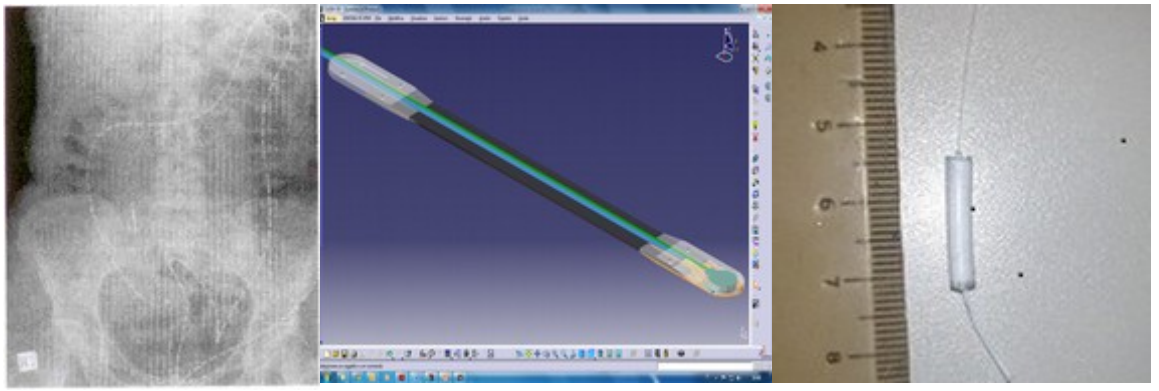


4 points bending of a Carbon-Fiber specimen for structural aircraft components: FBG sensors on neutral axis, compared to strain gauges on the surface

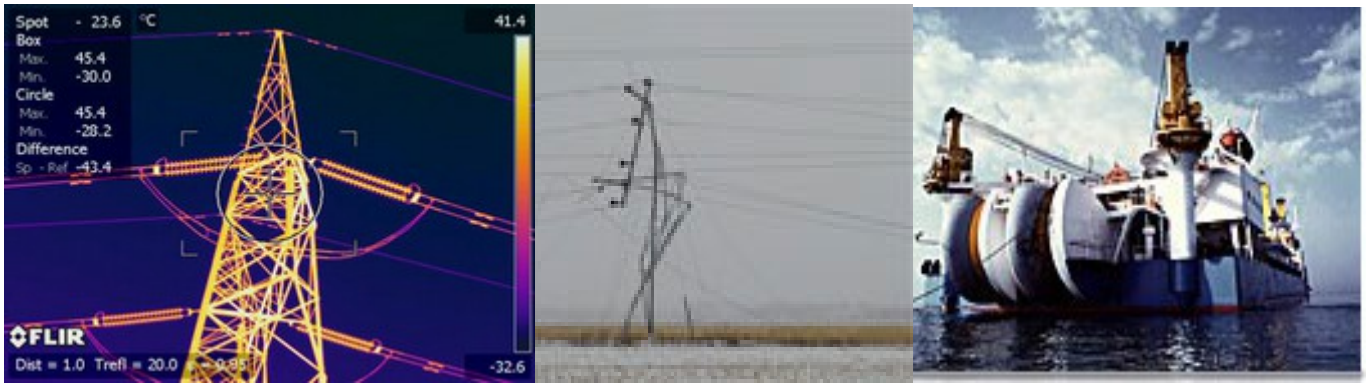
Application examples - 2

Medical field applications

- DTG array for in-human-body measurements
  [adapted from Arkwright JW, et al. Design of a high-sensor count fibre optic manometry catheter for in-vivo colonic diagnostics. Opt Express 2009; 17: 22423–31]
- High sensitive device for surgery
  [courtesy of Politecnico di Milano, Dipartimento di Ingegneria Aerospaziale]
- Miniature FBG sensor pressure probe



FBG sensors on power cables



- Hot spots detection
- Ice load on power lines and tower deformation
- Submarine Cable Monitoring during installation and operation

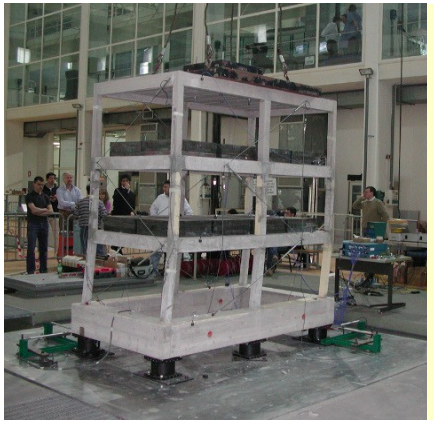
Application examples - 3

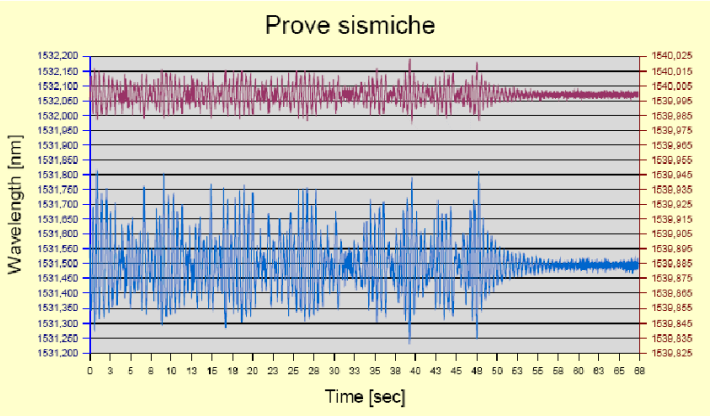
Artistic goods conservation

Non invasive FBG sensors installed on the Colleoni statue by A. Verrocchio in Venice, during the restoration of what is considered one of the most important equestrian monument of the Italian Renaissance

Civil structural monitoring for seismic applications

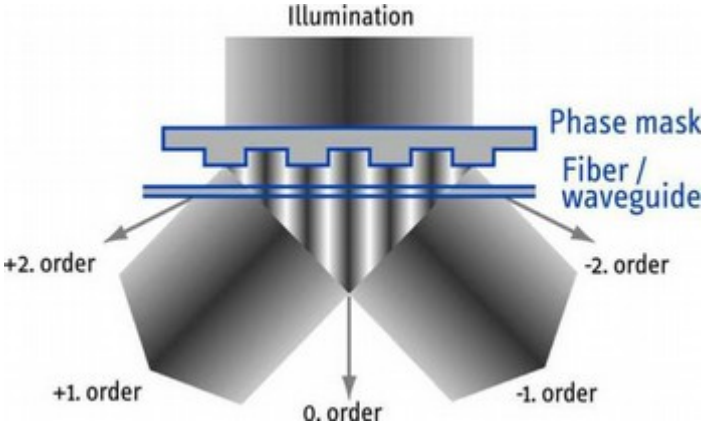
FBG sensors can be successfully employed in structural monitoring for seismic applications and damaging diagnostics. Proper sensor packaging allows embedding in concrete for durable installation





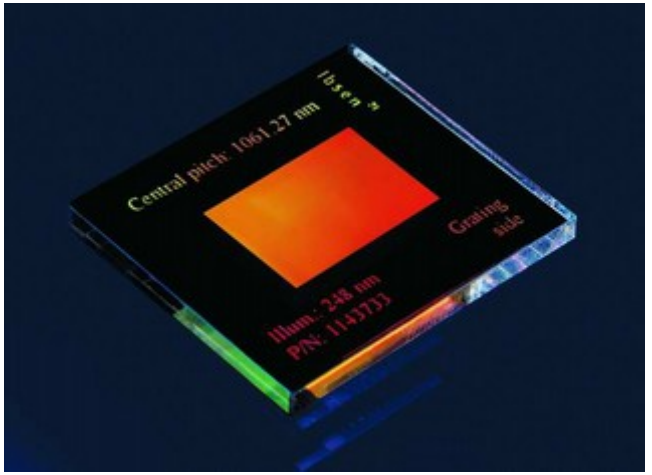
Bragg grating production

Phase mask



Operating principle

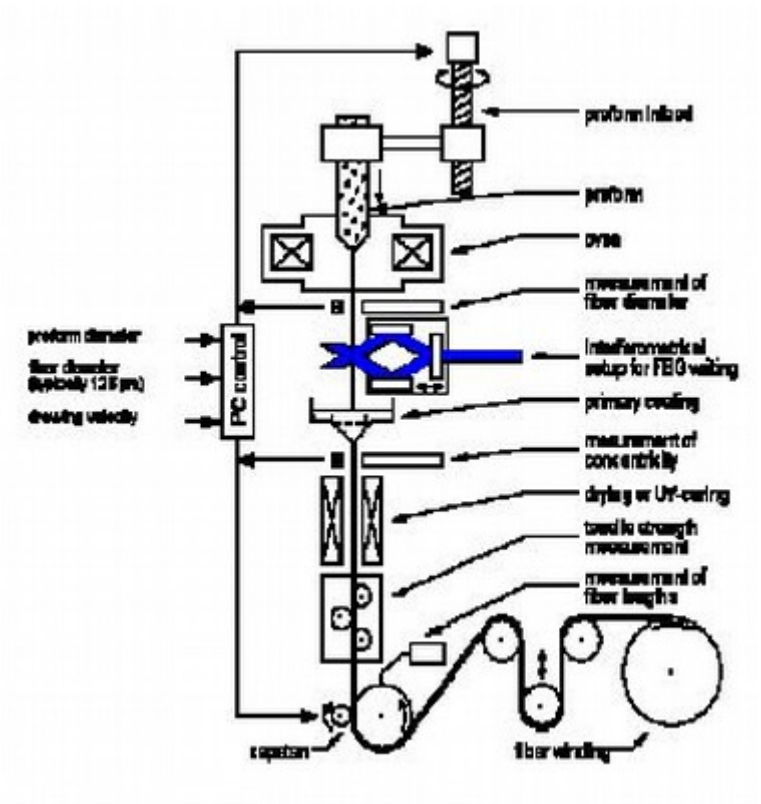
The fiber to be “written” is placed in the intensity modulated field of light, produced by the mutual interference of the orders +1 and -1 diffracted by the mask, illuminated by a UV laser beam. The resulting FBG has the same period of the interference field.



Commercial phase mask [Ibsen]
with central pitch of 1061.27 nm and operating laser wavelength of 248 nm

Bragg grating production

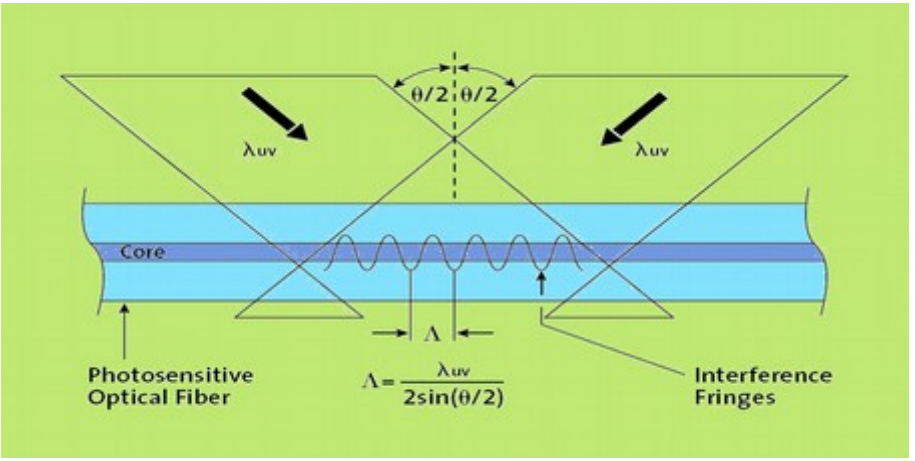
Direct writing of Draw Tower Gratings



Bragg grating inscription directly after the drawing process with single UV pulse exposure (DTG gratings)

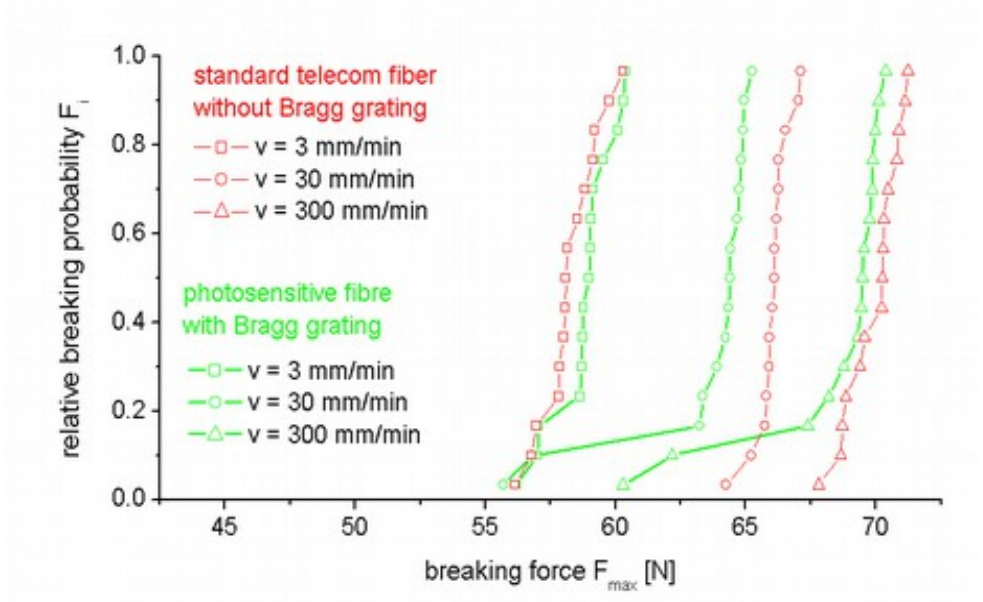
Coating is applied to the fiber after grating writing

Industrial process for production of highly reliable Gratings



FBGS
DRAW TOWER GRATINGS

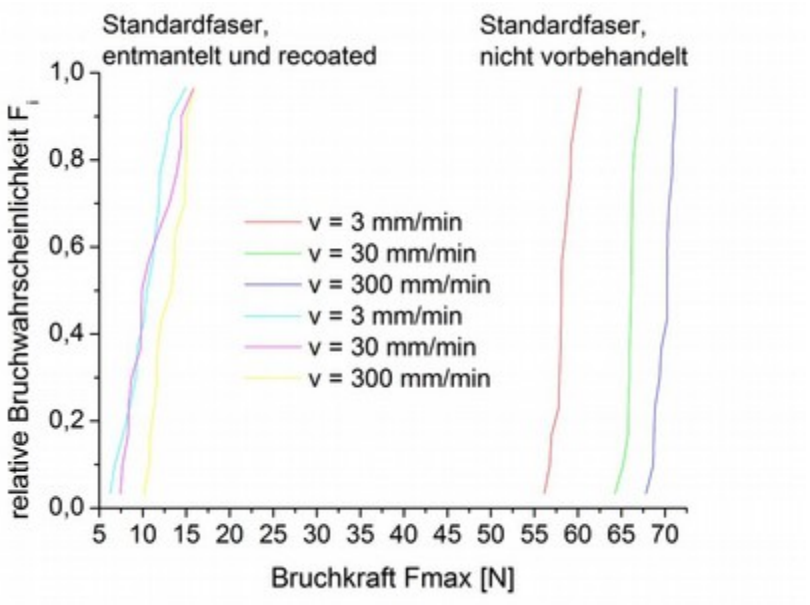
High Strength FBG sensors



high strength of photosensitive fiber with DTG compared to standard telecom fiber (without grating)

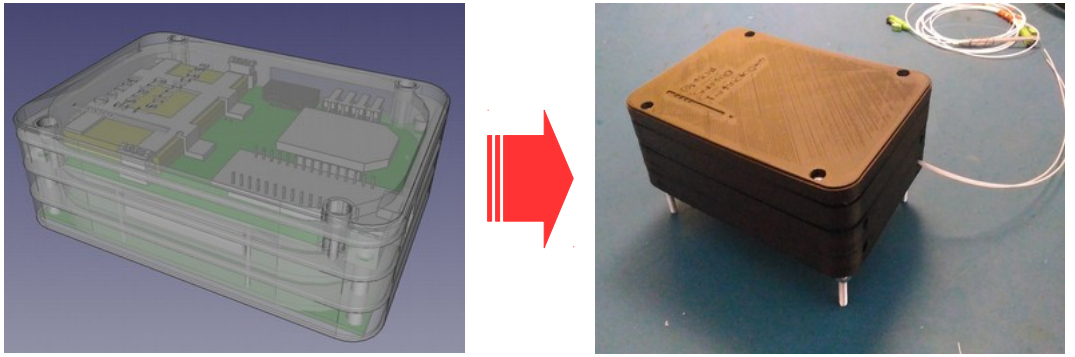
Very good resemblance!!
> 55 N (=5kg)!!

Always poor strength when coating is stripped
(stripped standard telecom fiber compared to standard telecom fiber with original acrylate coating)



Measurement instruments

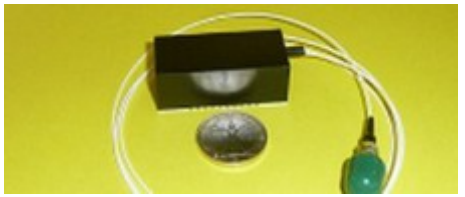
Several measurement techniques are available for different applications, the most common being based on spectral peak analysis of the Bragg wavelengths.



Anyway, when off-the-shelf solutions cannot satisfy specific exigencies of the most demanding applications, we can support the development of custom measurement equipment.

Custom equipment

Industrial applications have the most demanding exigencies and require a special attention to cost/performance ratio



Custom devices development capability allows to find high performance original solutions even for harsh environment operation