Federal Institute for
Materials Research
and Testing

BAM Information Summary

Seaside Exposure of Sensor Samples in the North Sea

within the research project “Development of standards for fibre optic sensors under offshore-typical conditions” (BAM-VH 8138)

Company: Smart Fibres Limited

Brants Bridge, Bracknell RG12 9 BG, United Kingdom

Report period: June 2012 to November 2013

Report writer: Dr.-Ing. Vivien Schukar

The minutes consist of 17 pages and exclusively serve as confidential information for the company Smart Fibres Limited. This information is not available internally at BAM. Only anonymous technical information is being processed in the sense of the research project.

Preliminary remark:

The seaside exposure of applied sensors on sheet metal test plates in the North Sea, the visual inspection of the measuring points and the gained measurement results of reference and calibration measurements in the laboratory and during the seaside exposure, as described in the following, are exclusively related to the sensor installations provided by the company Smart Fibres Limited.

The reported results do not refer to sensor installations of other companies.

The reported results do not involve generally valid statements about sensor installations under harsh environmental conditions.

Within a research project supported by the German Federal Ministry of Economics and Technology with the objective to push forward standards and guidelines for fibre optic strain sensors, especially for their use in the offshore environment, BAM cooperates with the German Fraunhofer Institute for Wind Energy & Energy System Technology (IWES) in Bremerhaven and the GESO Company in Jena. Within this project, application-related issues of a representative number of commercially available FBG strain sensors after application and exposure to the offshore environment are investigated. The objective of this seaside exposure is to get information about application-related issues eligible for generalization which allow then deriving statements for standards, guidelines and/or recommendations for users who want to apply fibre optic sensors.

The company Smart Fibres Limited agreed to participate in these field tests by providing sensor test specimen. For the field test, the sensor installations were exposed to the North Sea in a test field and periodically checked by BAM. Four sheet metal plates have been applied with two sensor installations each by Smart Fibres Limited. The application of the sensors, the protection against climatic influences and the cabling were carried out on choice of Smart Fibres Limited. Three of the plates with installed sensors have been exposed to the North Sea while one plate (with measuring point 39 and 40) has been kept in the laboratory of BAM for comparison reasons.

The following configuration of the sensor installation has been performed by Smart Fibres Limited:

Measuring point	Sensor type	Adhesive	Protection	Wavelength	Picture
33	SmartPatch, surface mounted FBG	No data	No data	1534.973 nm	
34				1537.892 nm	
35				1546.903 nm	
36				1544.086 nm	
37				1540.986 nm	
38				1562.054 nm	
39				1559.206 nm	
40				1550.126 nm	

In the following, the sensor installations will be named by the measuring point number.

All fibre optic cables connected to the sensor installations have been fixed with a protective coating to the plates by BAM. On June 21st 2012, the plates have been exposed to the North Sea tidal water zone in test rigs at the German island Sylt. The tidal water zone consists of a lower zone where one rig with plates is most of the time exposed to sea water, a second (middle) zone with a rig of plates that is in the mean exposed to sea water and surrounding air and a third (upper) zone with a rig of plates that is only exposed to sea water during flood, as can be observed in Fig. 1. Plate 33/34 was located in the middle zone, plate 35/36 was located in the upper zone and plate 37/38 was located in the lower zone. Fig. 2 shows exemplarily one of the three test rigs.

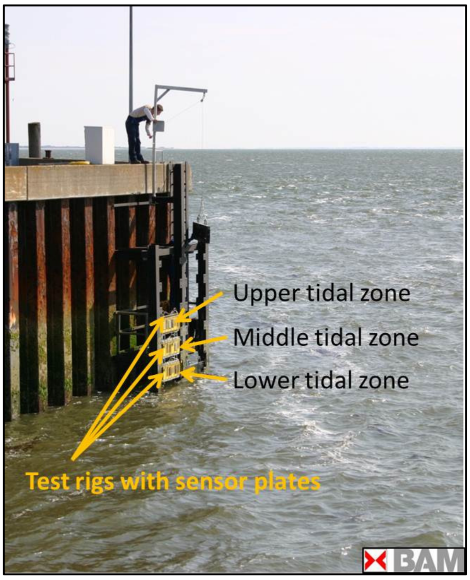


Fig. 1: Set-up of the test rigs with sensor plates in the three tidal zones

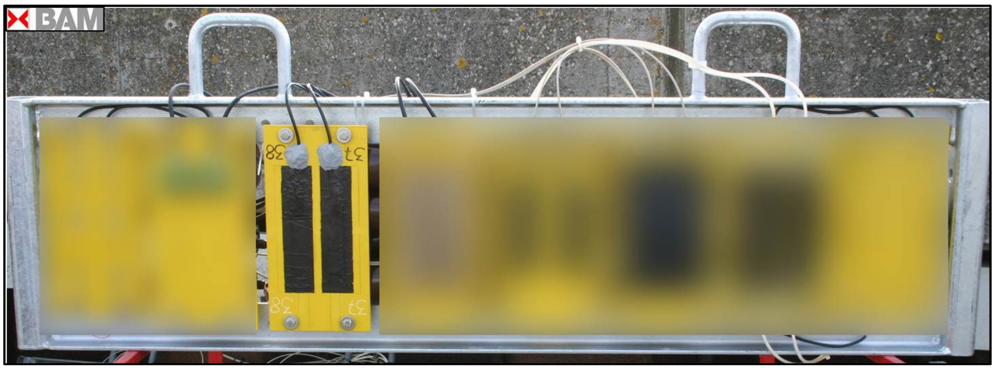


Fig. 2: One of the test rigs with sensor plate installations

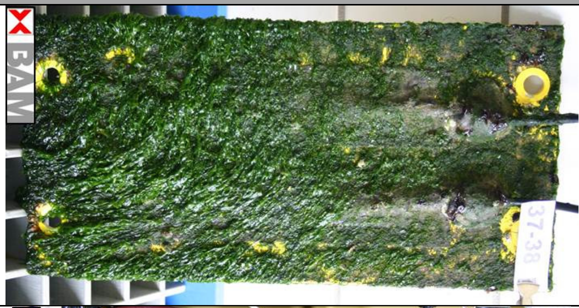
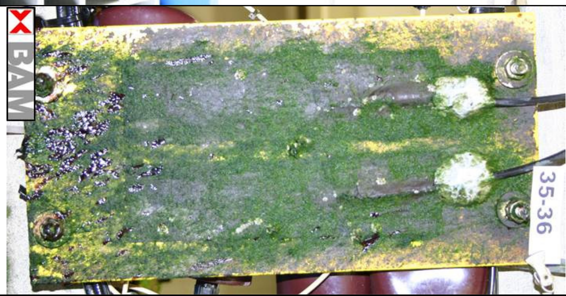
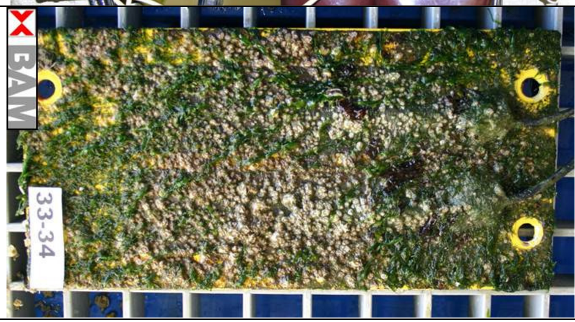
A visual inspection was done on September 5th 2012. The rigs were taken out of the water and visually examined as shown in the following table.

Tidal zone	Plate	Picture
Lower	37/38	
Middle	33/34	
Upper	35/36	

It was observed that plate 37/38, which were exposed most of the time to sea water, showed already a strong marine biological fouling, mainly consisting of algae, on the plate surface.

After that, the order of the plates has been changed and the rigs were located back again in the tidal water zone. Plate 33/34 was located in the lower zone, plate 35/36 was located in the middle zone and plate 37/38 was located in the upper zone. The change in the ordering of the plates was done to expose all plates periodically to the same environmental conditions.

At the beginning of December 2012, all plates were taken out of the North Sea and a measurement campaign was carried out. The following table shows the plates after five months exposure to the North Sea environment.

Tidal zone	Plate	Picture
Upper	37/38	
Middle	35/36	
Lower	33/34	

It was observed that the biological fouling continued in a strong way. The plates and the sensor installations were affected by growth of algae and barnacles. Especially plate 33/34 was significantly overgrown by barnacles.

After measuring the applied sensors on the test plates, the order of the test rigs was changed again and the rigs were located back again in the tidal water zone. Plate 33/34 was located in upper tidal zone, plate 35/36 was located in the lower tidal zone and plate 37/38 was located in the middle tidal zone.

In the middle of April 2013, all plates were taken out of the North Sea and a second measurement campaign including visual inspection has been performed. The following table shows the plates after ten month of exposure to the North Sea environment.

Tidal zone	Plate	Picture
Upper	33/34	
Middle	37/38	
Lower	35/36	No picture available

The ice growth and the low temperatures in the North Sea during the winter period 2012/2013 lead to the death of algae and barnacles and “washed” the sensor plates from biological fouling. At the locations were the barnacles were fixed, the first layer of painting was damaged. However, corrosion attack was not observed. Plate 35/36 could not be investigated. The rack with sensor plates that was installed in the lower tidal zone in December 2012 was not found in its place in April 2013. It is assumed that it was ripped or pressed out of the rack suspension probably due to severe ice growth and ice floes pressing against the racks in the winter. This rack, mounted with plate 35/36 finally was found by divers on the ocean ground nearby in summer 2013. The damaged rack was then placed again on top of the rack suspension until the end of November 2013. The two remaining plates of the measurement campaign in April 2013 were changed in place and mounted back again in the racks and exposed to the North Sea. Plate 33/34 was placed in the middle tidal zone and plate 37/38 was placed in the lower tidal zone.

At the end of November 2013, the plates were taken out of the North Sea. They were visually inspected as shown in the following table and a third, final measurement campaign was carried out. Again, a strong biological growth of algae and barnacles was observed during summer 2013. The black protection layer of the plates 33/34 and 37/38 was attacked by barnacles. The edges of this protection layer already ripped and started to peel off. Barnacles were creeping under the protection layer. No significant corrosion was observed.

Tidal zone	Plate	Picture	
Upper	No plate mounted		
Middle	33/34		
Lower	37/38		

Plate 35/36 was also recovered from the damaged rack in November 2013. Fig. 3 shows the damages from ice floes of the complete rack. Plate 35/36 was plastically deformed, as shown in Fig. 4. The protective layer of the sensors was significantly damaged. Corrosion was observed in the area of the sensors. A measurement in a four-point bending machine was no longer possible for plate 35/36. The back-reflected spectrum was analysed at room temperature.

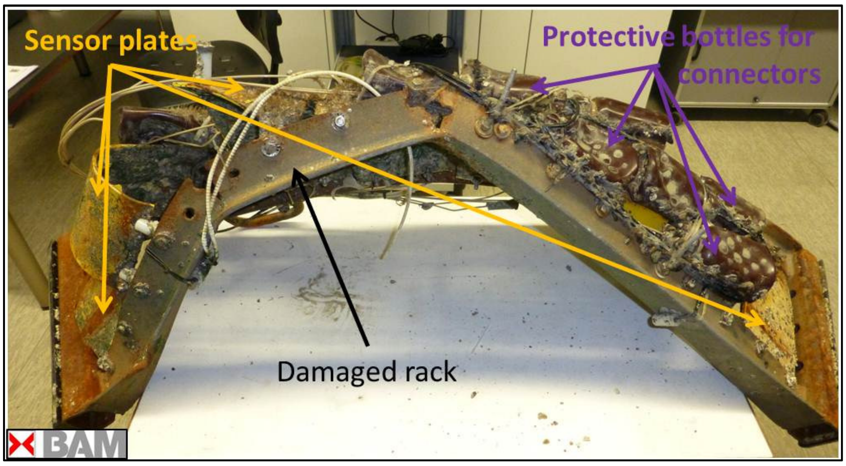


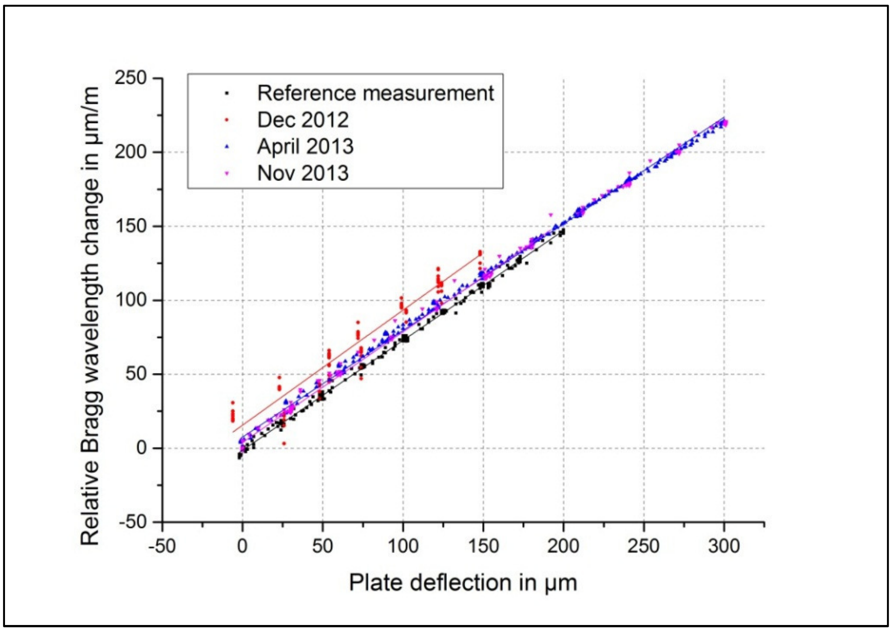
Fig. 3: Side view of the damaged rack with sensor plates.

Fig. 4: Plate 35/36 after removal from the damaged rack.

In order to characterize the applied sensors on the plates, a calibration of the measurement signal in a four-point-bending machine was performed before the plates were exposed to the North Sea (reference measurement). At each following measurement campaign (in December 2012, April 2013 and November 2013), the plates were again loaded mechanically in the four-point-bending machine and the Bragg wavelength and the back-reflected spectrum were measured. A comparison of the sensor signals from the reference measurement and the signals obtained from the measurement campaigns reveals the evolution of the measurement results during the exposure to the North Sea environment.

In the following, the results obtained from the measurements are shown for each measurement point.

Measurement point 33:



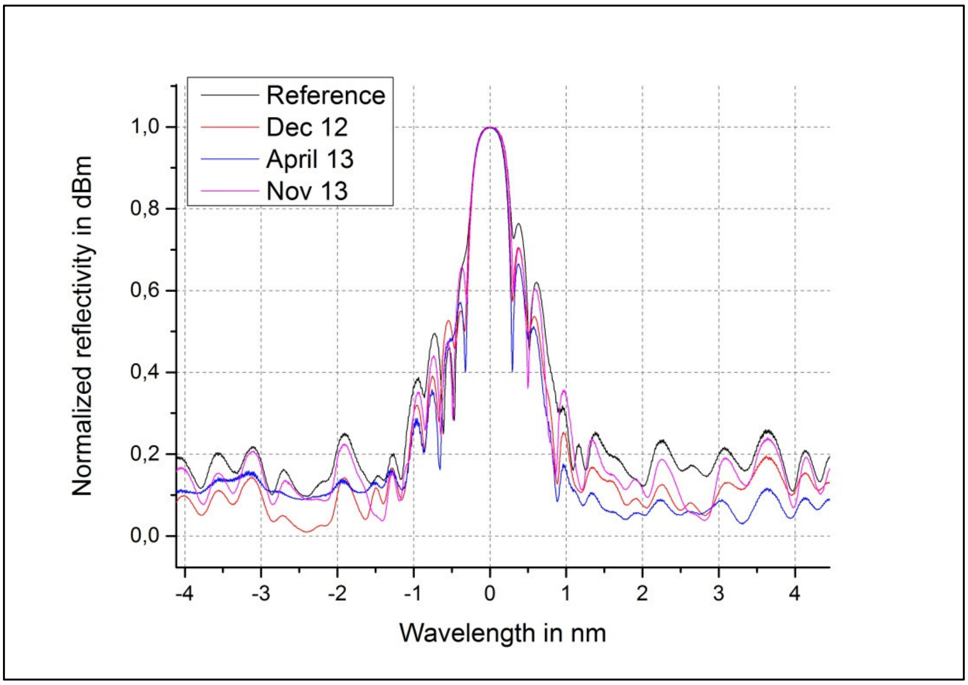
It can be seen, that measurement point 33 shows a linear relation between the change in relative Bragg wavelength and the deflection of the plate during four-point-bending over the total duration of the test. The relation (slope) between plate deflection and relative Bragg wavelength change is defined as the sensitivity coefficient γ, as shown in Table 1.

Table 1:

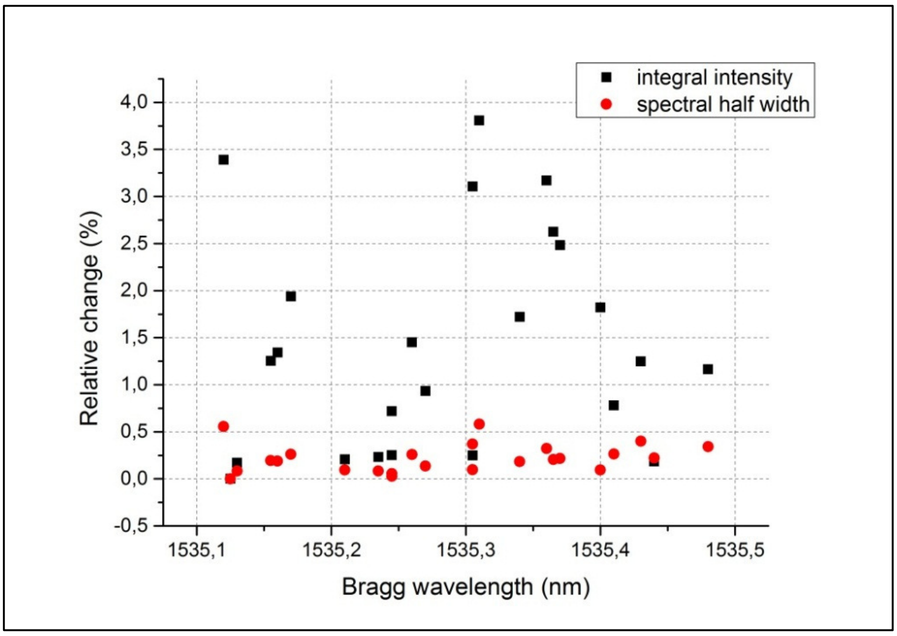
Measurement	Sensitivity coefficient γ	Deviation from reference
Reference	0.7430	-
December 2012	0.7782	4.74 %
April 2013	0.7206	3.02 %
November 2013	0.7478	0.65 %

The deviation of the sensitivity coefficient from the reference measurement is within a margin of 5 %. This deviation includes uncertainties from the measurement object like slight deformation of the sample plates due to ice floes and from the four-point-bending test itself (no strain reference, no way to define a certain deflection).

Taking a look at the spectral response signal, it can be seen that the spectrum preserves its original form in the unloaded case of the sample plate.



Characteristic parameters that describe the spectrum deformation are the spectral half width δ and the integral intensity S. A significant change in these parameters during loading may indicate a non-homogeneous strain field acting on the sensor and/or partial debonding or interface failure. During loading, the change in spectral half width was below 1 % and the change in integral intensity was below 4 %. These deviations are considered to be acceptable. Therefore, measurement point 33 was not affected by delamination.



Measurement point 34:

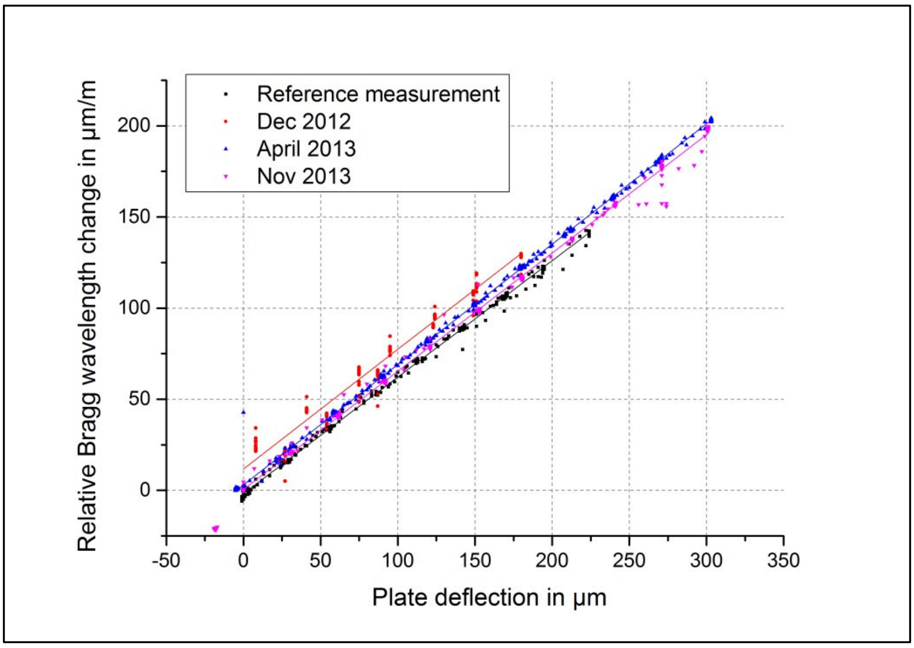
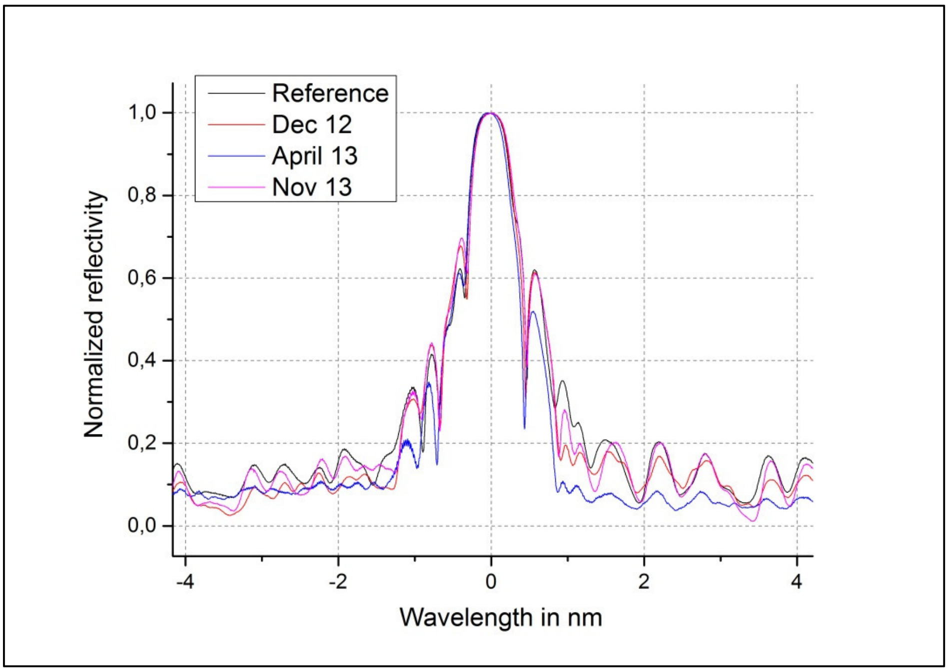


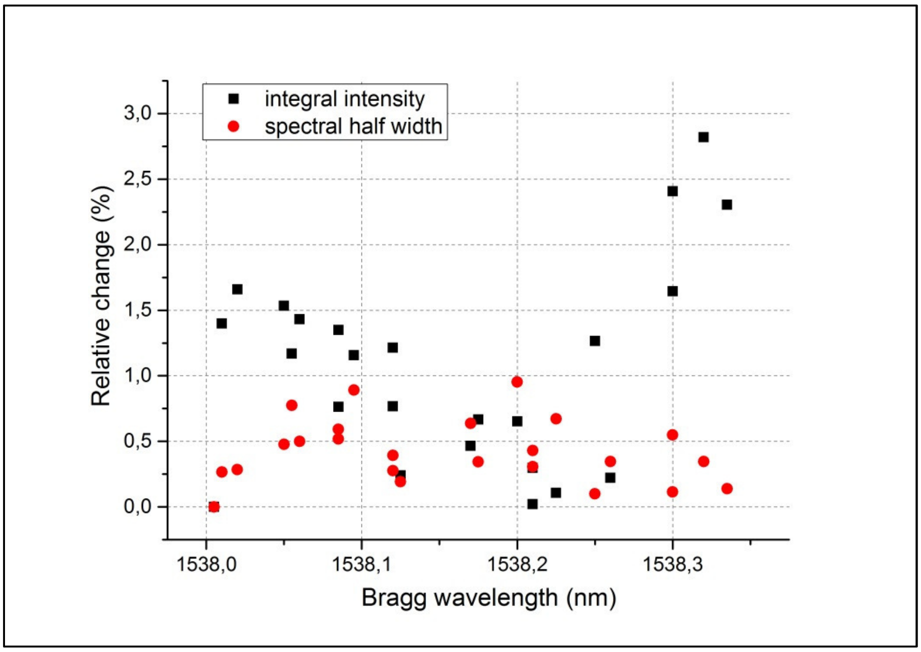
Table 3:

Measurement	Sensitivity coefficient γ	Deviation from reference
Reference	0.6574	-
December 2012	0.6602	0.43 %
April 2013	0.6490	1.30 %
November 2013	0.6389	2.81 %

The deviation of the sensitivity is within a margin of 5 %. The measurement point shows linear behaviour due to the plate deflection.



During loading, the change in spectral half width was below 1 % and the change in integral intensity was below 3 %. These deviations are considered to be acceptable. Therefore, measurement point 34 was not affected by delamination.



Measurement point 37:

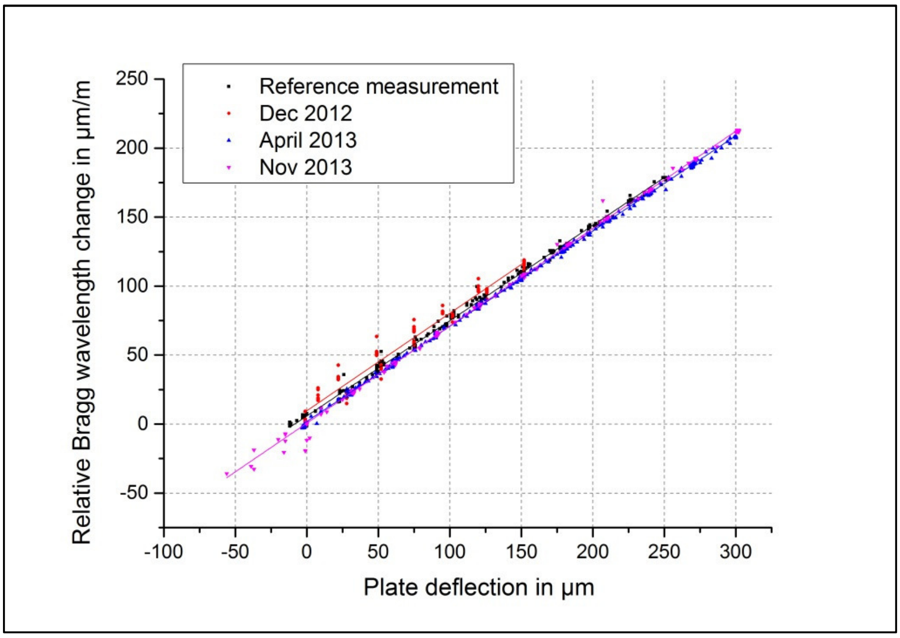
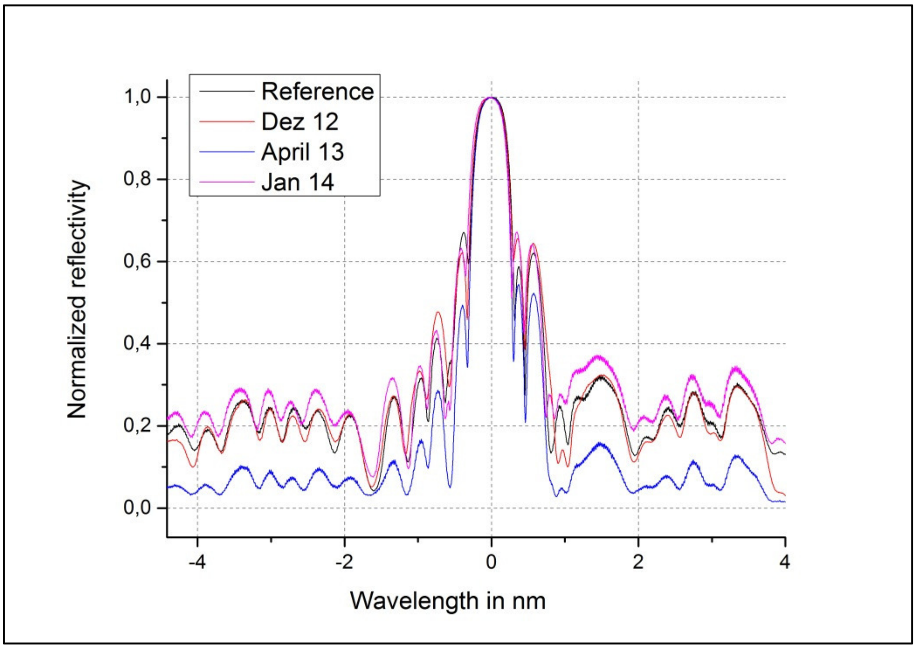
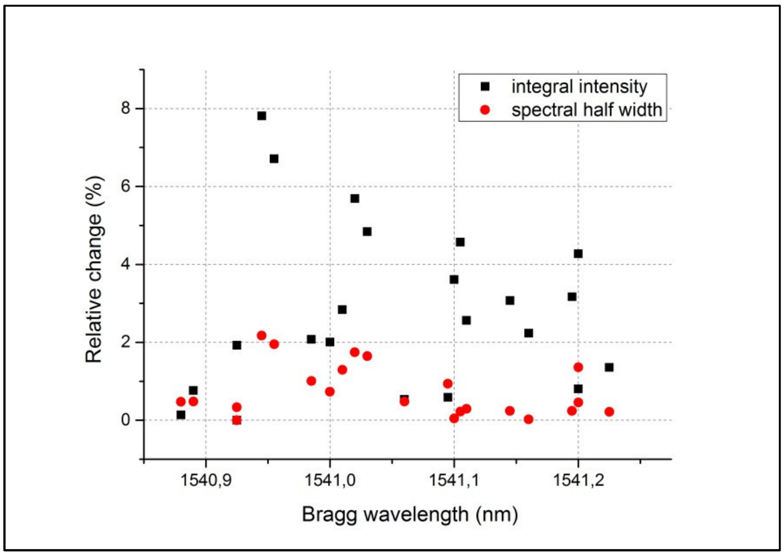


Table 4:

Measurement	Sensitivity coefficient γ	Deviation from reference
Reference	0.6911	-
December 2012	0.7074	2.36 %
April 2013	0.6900	0.16 %
November 2013	0.7052	2.04 %

The deviation of the sensitivity is within a margin of 5 %. The measurement point shows linear behaviour due to the plate deflection.





During loading, the change in spectral half width was around 2 % and the change in integral intensity was below 8 %.

Measurement point 38:

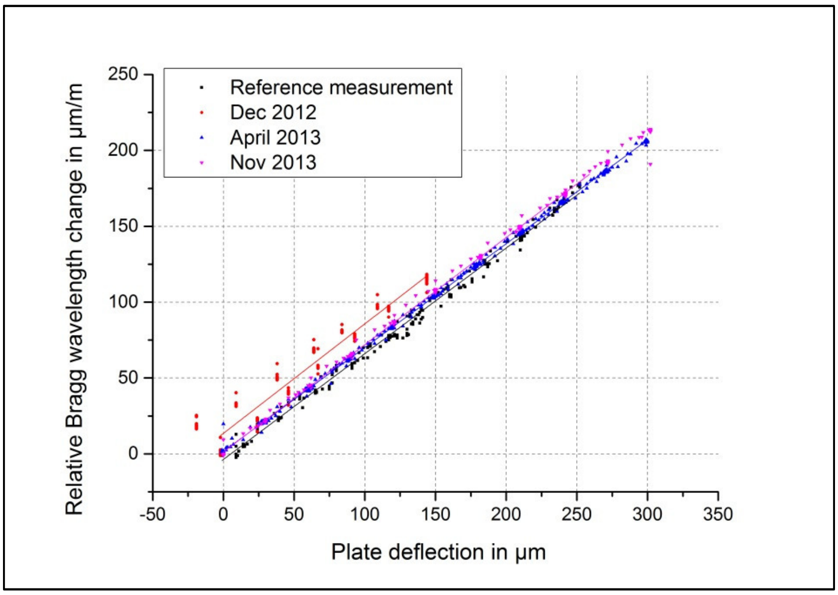
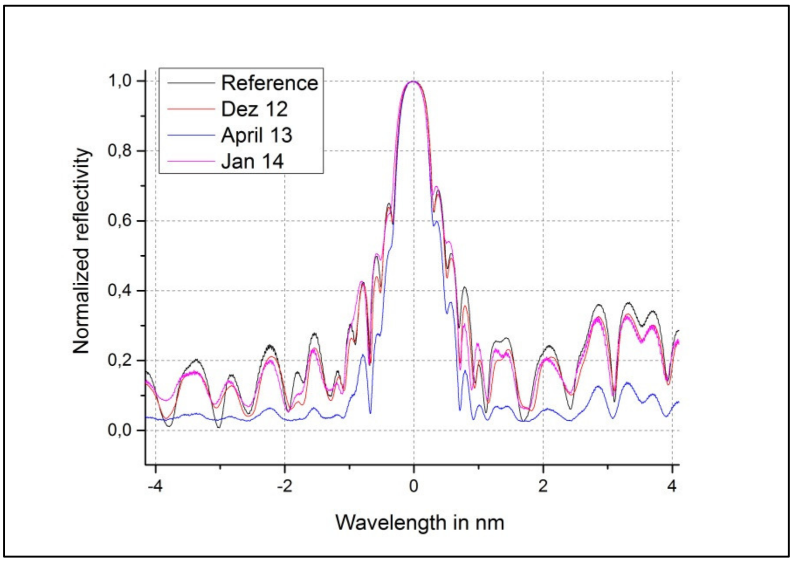


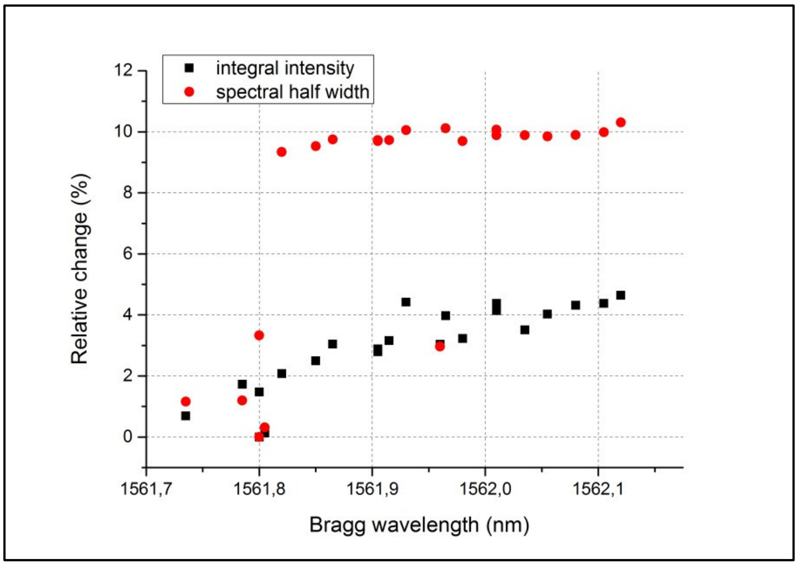
Table 5:

Measurement	Sensitivity coefficient γ	Deviation from reference
Reference	0.6966	-
December 2012	0.7213	3.55 %
April 2013	0.6840	1.81 %
November 2013	0.7067	1.45 %

The deviation of the sensitivity is within a margin of 5 %. The measurement point shows linear behaviour due to the plate deflection.



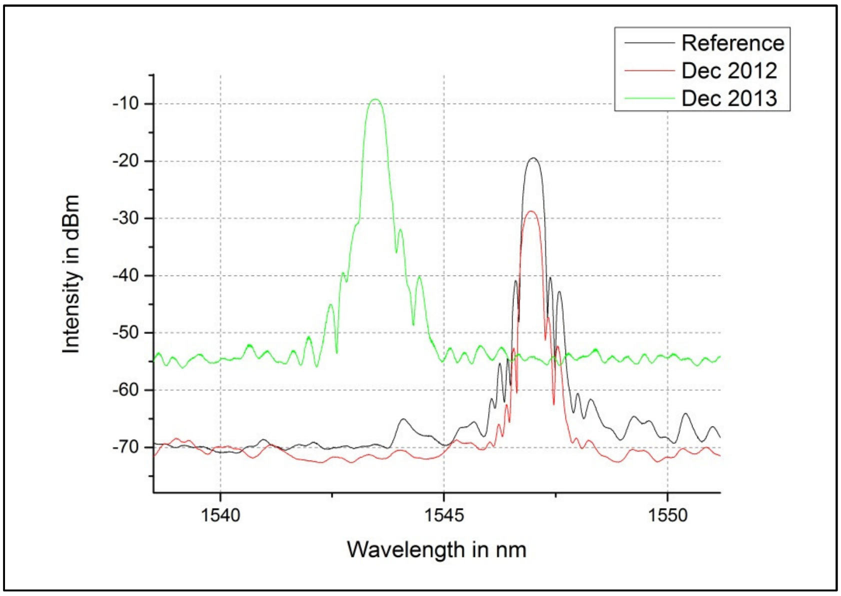
In the following figure, the change in spectral half width and integral intensity of the spectra are shown during loading. The integral intensity increases constantly while the spectral half width changes rapidly after the first three load steps and then keeps on almost constant. It is assumed, that the sample plate itself is not straight but slightly plastically deformed. When loading in the 4-point-bending machine at a certain load, the plate has been straightened and the change in spectral width keeps constant around 10 %.



It was observed that plate 37/38 was severe attacked by barnacles. The black protection layer was wrecked and the barnacles were crawling beneath it, like shown in the picture beneath (Fig. 5).

Fig. 5: Barnacles creeping under the protection layer of plate 37/38.

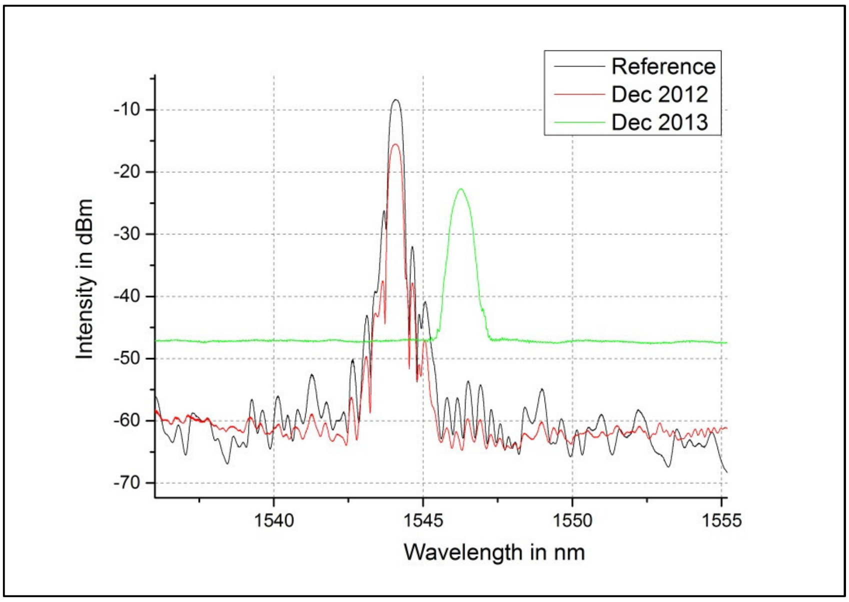
Measurement point 35:



Sample plate 35/36 was lost due to the severe winter and ice floe in 2012/2013. The sample plate could not be tested in the four-point-bending machine because it was plastically deformed. A comparison of the spectra in the unloaded case shows that the sensor of measurement point 35 is still operating. It has suffered a negative wavelength shift due to the compression of the sensor on the plastically deformed plate.

Measurement point 36:

A sensor signal can also be found at measurement point 36 and a spectral response signal was obtained from this sensor. The sensor signal shows a positive wavelength shift which indicates strain acting on the sensor. However, the intensity of the signal is very low at room temperature.



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Berlin, April 14th, 2014

Division 8.6 Optical and Fibre Optic Methods

On behalf

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