Sensing - lab02   **Teammates:**
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1   Introduction

In this experiment we analyzed the behavior of an FBG (Fiber Bragg Grating). The FBG uses the Bragg Mirror, which is a specific type of photonic crystal that acts as a mirror for a given range of frequencies. This photonic crystall can be modeled as a multilayer film where two materials with different refractive index are alternated. Imagining an ideal Bragg mirror the reflected wavelength is defined as $\lambda_{BRAGG} = \frac{2\pi}{k_{BRAGG}}$ where k_{BRAGG} it is the propagation constant of the phase and respects this rule $k_{BRAGG} \cdot (L_1 + L_2) = m \cdot \pi$ with $m \in \mathbb{N}$ and L_1, L_2 are the two lengths of the films. By inserting a Bragg mirror into the fiber we obtain a mechanical coupling between the two in particular in compression and elongation, in fact pulling the fiber is also pulled the mirror and then modified the period $(L_1 + L_2)$ which that turns into a changes of λ_{BRAGG}. From this physical effect we can then relate elongation with the reflected frequency. This mirror, however, is also sensitive to temperature variations, in fact, in addition to creating an expansion or compression of the period, it introduces a variation of the silica refraction index induced by the thermo-optic effect.

The setup we use is composed of an optical amplifier that produces broadband light that is inserted into a fiber containing an FBG, the light that is reflected then passes through an optical circulator that sends it to a spectrum analyzer (Fig.1).
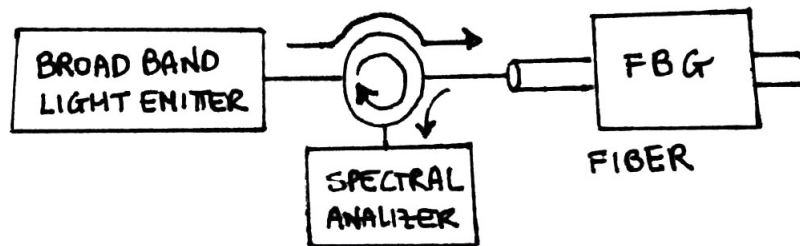

Figura 1: Setup.

What is done in this experiment is to measure the reflected wave frequency according to the applied elongation. In this case the elongation is performed by turning a circular manual tensor (ring): each rotation corresponds to an elongation of $0.5[mm]$ and on the ring there are 50 notches and

therefore we have an elongation of 0.01[mm] for notch. Our fiber started from a length of 14[mm] and we elongated it by 1.5[mm]. The measurements we have performed are shown in (Tab.1), where for each rotation the value of the reflected frequency calculated by eye was reported. The table has three measuring columns because more consecutive measurements have been made starting from 14[mm] and reaching 14.75[mm] then going back to 14[mm] and then returning to 14.7[mm]. The table also specifies with x the measurements where the spectrum was stored for computer analysis. From a first analysis we obtain the curve shown in (Fig.2).

| Position [mm]	λ_B [nm]	λ_B [nm]	λ_B [nm]
14	1534,691	1534,682(x)	1534,682
14.05	1534.861	1534.87	1534.861
14.1	1535.032	1535.032	1535.041(x)
14.15	1535.229	1535.186	1535.212
14.2	1535.391	1535.357	1535.391(x)
14.25	1535.604(x)	1535.562(x)	1535.587
14.3	1535.784	1535.749	1535.767(x)
14.35	1535.937	1535.92	1535.946
14.4	1536.125	1536.108	1536.108(x)
14.45	1536.305	1536.262	1536.305
14.5	1536.509(x)	1536.45 (x)	1536.467(x)
14.55	1536.663	1536.646	1536.646
14.6	1536.851	1536.851	1536.842(x)
14.65	1537.03	1537.005	1537.005
14.7	1537.184	1537.184	1537.184(x)
14.75	1537.389(x)	1537.389	1537.38

Tabella 1: Measures.
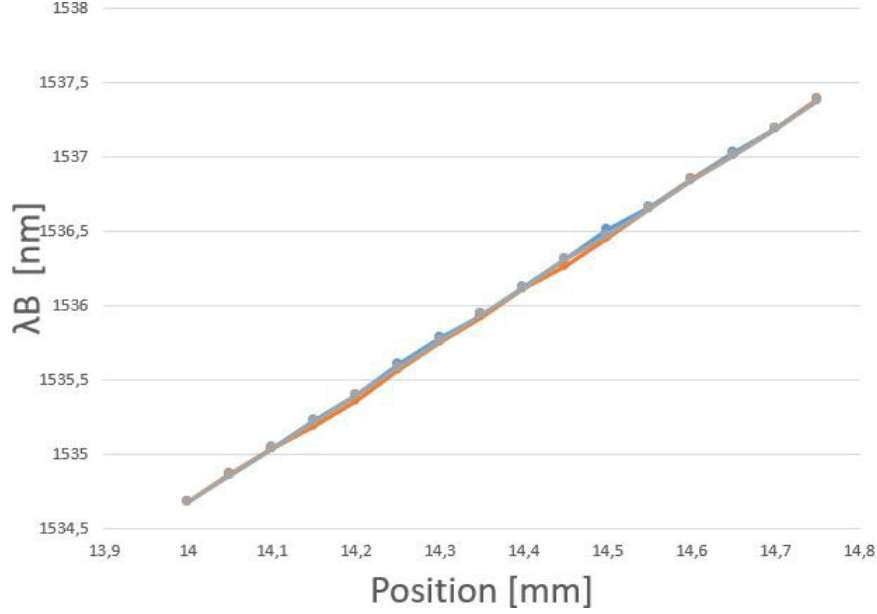
Figura 2: First analisy.

2 Analysis

First of all, the 13 files were imported. They contain the data related to
the spectra measured by the spectrometer and contain: the two values of
starting frequency and frequency step in THz; and then the list of reflected
power values read in dB. The importation was made by converting the fre-
quency values into wavelength values through the physical relation $\lambda = \frac{c_0}{f}$,
to each of these values the corresponding power value has been assigned as
shown in (Fig.3). From this figure it is also possible to clearly identify the
peak to be analyzed, since while the signal has values lower than $-50[dB]$
and it has a value of approximately $-30[dB]$. At this point, for each file, the
value of the wavelength corresponding to the maximum point is searched;
to improve the analysis an interpolation of the points is performed through
a quadratic function. A key point was to choose which points to consider
in the approximation. The first attempt was through a classic approach, we
chose to consider all the points that are above 90% of the peak that resulted
in a solution like in (Fig.4), as we can see in this image there are a few points
around the peak that add noise, the next choice would then be to opt for
a greater percentage but doing so would have to calculate by hand for each
spectrum the optimal value of percentage; instead another approach was
chosen. The alternative solution was based on the peak symmetry characte-
ristic and follows the following approach: starting from the maximum point
we move sideways until we find points with decreasing values, the example
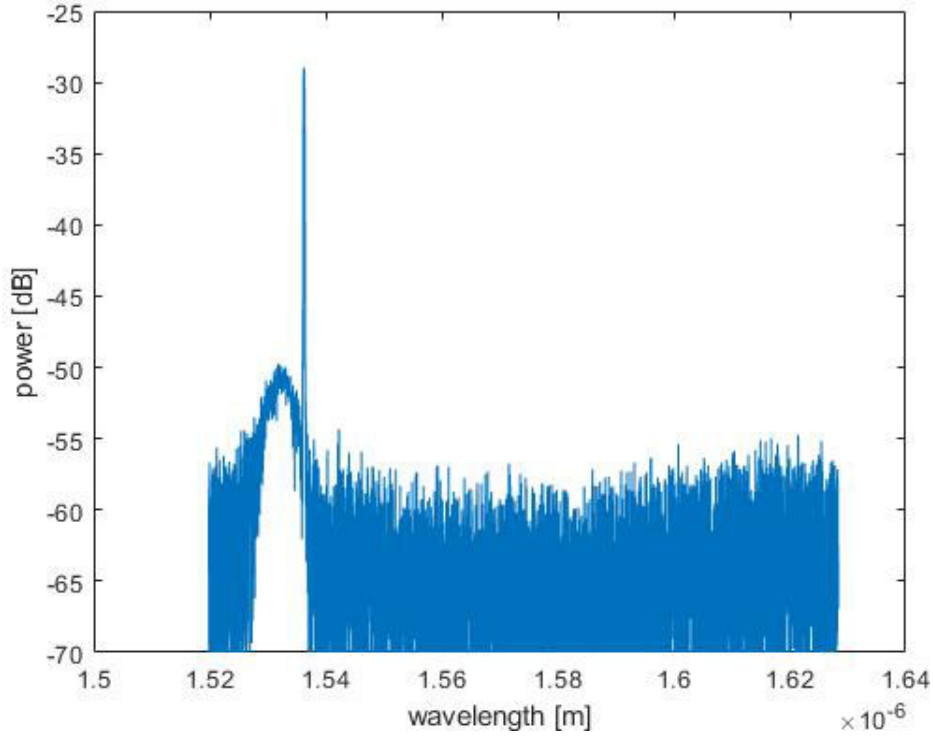
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Figura 3: Spectral power for 14[mm] of elongation.

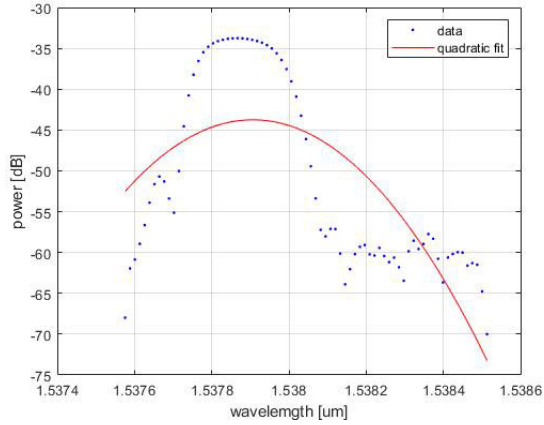of filtering the points is shown in (Fig.5).
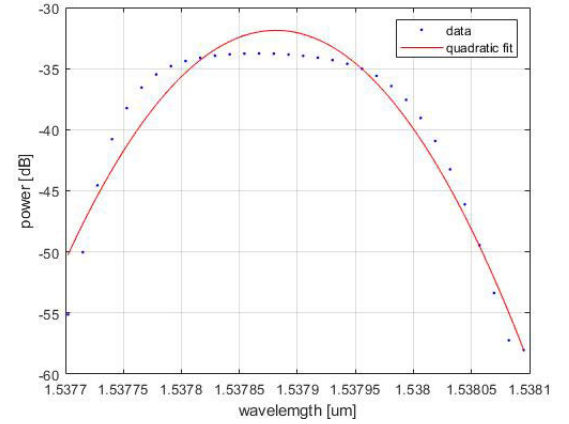

Figura 4: Quadratic fit scale 90%.

Figura 5: Quadratic fit descending cutting mode.

Abbiamo successivamente calcolato i valori di elongazione impostando come 0 il nostro valore di 14[mm] ottenendo quindi un valore massimo di elongazione di 0.75[mm]. A questo punto abbiamo calcolato gli strain dividendo questi valori per la lunghezza a riposo della fibra $L = 310.5$ che successivamente abbiamo messo in relazione con i picchi precedentemen-

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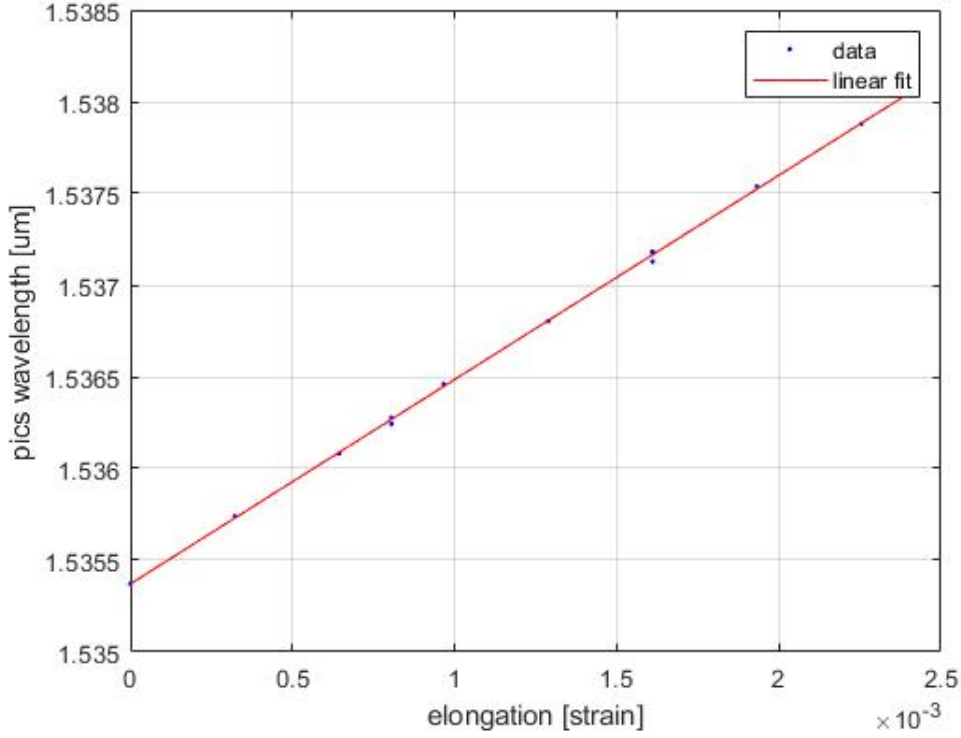te misurati come si vede nel grafico (Fig.6). Da qui possiamo ricavarci il

Figura 6: Elongation.

coefficiente angolare che prende l'unità di misura di:

$$\frac{\lambda}{strain}\left[\frac{\mu m}{\epsilon}\right] = \frac{\lambda}{strain}\left[\frac{pm}{\mu\epsilon}\right]$$

e vale

$$a = \frac{\Delta\lambda}{\Delta strain} = 1.114\left[\frac{pm}{\mu\epsilon}\right]$$

dalla quale ci ricaviamo la sensibility:

$$s = \frac{1[pm]}{a} = 0.898[\mu\epsilon]$$

Per calcolarci l'errore possiamo sfruttare il discostamento che i punti hanno nell'asse delle y dalla funzione con cui noi abbiamo fatto il fit ovvero $rmse = 1.68\cdot10^{-5}[um]$. Applicando la correzione dove $M = 2$ sono i punti di libertà e $N = 13$ sono i punti presi $q = \frac{rmse}{\sqrt{N-M}}$ ed invertendo la relazione con il coefficiente angolare otteniamo:

$$e = \frac{q\cdot10^{-6}}{a} = 4.54[\mu\epsilon]$$

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3 Conclusion

The value obtained is very similar to the typical values for sensors of this type:

$$s = \frac{1[pm]}{1.2\left[\frac{pm}{\mu\epsilon}\right]} \approx 0.8[\mu\epsilon]$$

The performance of the data collected was excellent because they produced a linear trend as we expected with a deviation of $rmse = 1.6 \cdot 10^{-5}$. Having performed both contraction and elongation measurements, we have had the possibility to check the existence or absence of a hysteresis behavior. Data collected although very few suggest lack of hysteresis given the low value of RMSE.