Thermal Current Sensor based on Metal Coated Hi-Bi Fiber Loop Mirror

B. V. Marques, O. Frazão, S. Mendonça, J. Perez, M. B. Marques, S. F. Santos, J. M. Baptista

***Abstract*—In this work we report a thermal current sensor based on a metal coated Hi-Bi fiber loop mirror. This sensor quantifies the current through the measurement of the temperature which varies accordingly with the magnitude of the electric current. The temperature change is analyzed through the variation of the phase shift of a Hi-Bi fiber loop mirror.**

***Index Terms*—Fiber Optic Sensors, Optical Current Sensor, Hi-Bi Fiber Loop Mirror, *Sagnac* Interferometer**

I. Introduction

In very particular industrial environments, where electric current based systems are considered potentially dangerous for human physical integrity or where there is highly contaminated electromagnetic interference, optical device sensors are preferred instead of the traditional electric ones, normally based on the Faraday or other magnetic effects [1-3]. Traditionally, the optical current sensors based on the Faraday effect are built under a silica fiber coil around the current conductor, but this approach has some disadvantages.

The sensor presented in this article is based on a phase shift of the optical signal caused by thermal effects of the metal current conductor. It is demonstrated, experimentally, one way to measure electric current due to the respective variation of the conductor's temperature. The apparatus that supports the sensor head is a fiber loop mirror (FLM) incorporating a segment of high-birefringence (Hi-Bi) fiber, coated with a thin metallic layer in order to allow an homogeneous thermal coupling between the fiber and the electric current conductor.

II. Principles

It can be seen in the literature that a certain variation in the temperature ΔT, implies a well defined variation in the spectral width of the interference pattern fringes of a FLM that incorporates the Hi-Bi fiber [4]. On the other hand, it is possible to relate these parameters, knowing the fiber thermal expansion and thermal-optic coefficients, C_{T1} and C_{T2}, respectively. With well determined fiber parameters like length (l), birefringence index (n_e-n_o) and operation wavelength (λp), it is possible to establish the following relation given by Equation 1:

$$\Delta\lambda = \frac{1}{k_p}[l \times C_{T2} \times \Delta T + (n_e - n_o) \times C_{T1} \times \Delta T] \qquad (1)$$

where, constant k_p is defined by Equation 2:

$$k_p = \frac{l \times (n_e - n_o)}{\lambda_p} \qquad (2)$$

Other expression needed is the one relating ΔT with the direct variation of the electric current (I). This last one, involves variables like de conductor's electric resistance (R_0), the environment temperature (T_a), the conductor self physical characteristics (length, thermal expansion coefficient, electric resistivity, conductor's cross section) and some adjustment constants (k and α). Therefore, it is shown in Equation 3, the relation between the temperature and the current crossing the material.

$$\Delta T = T - T_a = \frac{-R_0 \times I^2}{R_0 \times \alpha \times I^2 - k} \qquad (3)$$

III. Fiber Metal Coating Process

In order to improve the stability of the measurement, an homogeneous thermal coupling between the fiber and the electric current conductor was achieved by applying a metal coating to the fiber. The Hi-Bi fiber segment was covered with a 300 nm Nikel-Cromium (80/20) layer. This layer was deposited at room temperature, using an Edwards 306 evaporator with a vacuum condition of 6×10^{-6} mbar and a constant current of ≈20 A in order to achieve a deposition rate of 0.5 nm/s.

IV. Experimental Description

Figure 1 presents the experimental setup which consists of an optical broadband source, a 3 dB coupler, an optical fiber loop mirror including the Hi-Bi metallic coated fiber segment attached to the current conductor, a thermal clamp in order to control de conductor's temperature and the optical spectrum analyzer (OSA). The fiber was fixed to the current conductor with epoxy glue. The Hi-Bi fiber loop mirror [4-5] acts as a band pass filter for the input signal from the source. The difference between the optical path, introduced by the Hi-Bi

B. V. Marques and S. F. Santos are with ISEP, Rua Dr. António Bernardino de Almeida 431, 4200-072 Porto, Portugal, bvieiramarques@gmail.com
O. Frazão, S. Mendonça, J. Perez, M. B. Marques and J. M. Baptista are with INESC Porto, Rua do Campo Alegre 687, 4169-007 Porto, Portugal.
S. Mendonça, M. B. Marques are also with Dep. de Física, Fac. de Ciências, Univ. do Porto Rua do Campo Alegre 687, 4169-007 Porto, Portugal.
J. M. Baptista is also with Dep. de Matemática e Engenharias, Universidade da Madeira, Campus da Penteada, 9000-390 Funchal.

fiber segment, for the two counter propagating waves coming from the coupler as they transverse the loop results in constructive and destructive interference pattern which can be seen in the filter response (Figure 2).

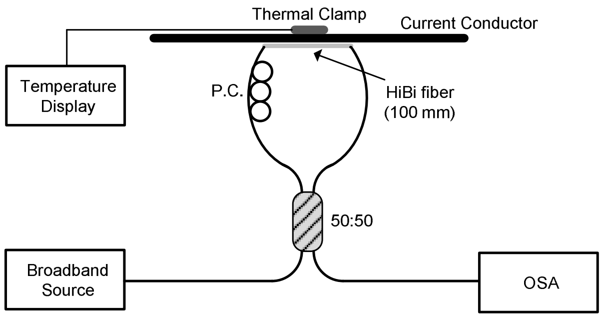

Figure 1 – Experimental setup of the FLM

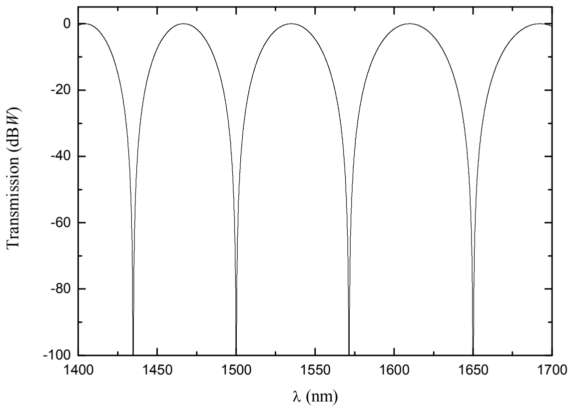

Figure 2 - Band pass filter spectral behavior of Panda fiber segment.

The experience was made with a 100 mm (l) PANDA Hi-Bi fiber segment with a birefringence index of 3.3×10^{-4} and a fringe spectral width ($\Delta\lambda$) of approximately 78 nm was achieved. This result can be confirmed through $\Delta\lambda = \lambda^2/\beta l$, where λ represents the central wavelength of the source and β the index of birefringence (n_e - n_o) of PANDA's fiber segment.

The copper current conductor used had the intrinsic values of 5×10^{-7}/ºC and -3.47×10^{-7}/ºC for C_{T1} and C_{T2}, respectively, and it was crossed by an electric current in the range of 100-700 A. For each step of input current from the electrical source, the conductor's temperature was measured with a conventional thermocouple and the wavelength variation through the OSA.

The two measurements can be seen in Figure 3. As expected, and in accordance to equation 3, a non linear relationship between temperature and applied current was obtained. On the other hand the wavelength response has a similar behavior but with opposite sign. This is due to the thermal response of the optical fiber.

The sensitivity of the wavelength versus the current is aprox. -0.046 nm/A for the low current (0-300 A). For high current (300-700 A) the sensitivity is aprox. -0.146 nm/A.

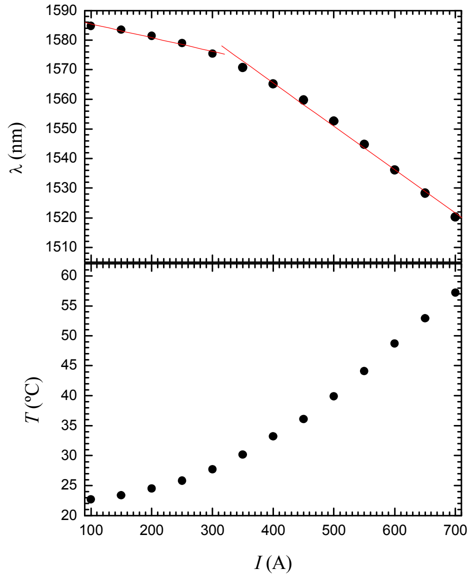

Figure 3 – Conductor's temperature and wavelength responses with variation of current

V. Conclusion

A current sensor based in the Hi-Bi fiber loop mirror was demonstrated with a sensitivity of -1.73 nm/ºC. Due to nonlinear response between current versus wavelength, the current sensitivity can be divided in two regions. For low current the sensitivity is -0.046 nm/A and for high current the sensitivity is three orders of magnitude higher (-0.146 nm/A). The use of a fiber with metal coating allows homogeneous thermal coupling between the fiber and the electric current conductor, improving the stability of the measurement. This sensor measures the true *rms* current value and can be a simple alternative solution compared to the traditional optical fiber current sensors.

References

[1] K. Bohnert, P. Gabus, J. Kostovic and H. Brändle. "*Optical fiber sensors for the electric power industry*". Optics and Lasers in Engineering, Vol. 43, (2005), 511-526.

[2] P.-A. Nicati and Ph. Robert. "*Stabilized Sagnac Optical Fiber Current Sensor Using One Phase And Two Amplitude Modulations*". Optical Fiber Sensors Conference, (1992), 402-405

[3] P.-A. Nicati and Ph. Robert. "*Stabilised current sensor using Sagnac interferometer*". J. Phys. E: Sci. Instrum. 21, (1988), 791-796

[4] Y. Liu, B. Liu, X. Feng, W. Zhang, G. Zhou, S. Yuan, G. Kai and X. Dong,. "*High-birefringence fiber loop mirrors and their applications as sensors*". Applied Optics, 40 (2005), 2382-2390.

[5] Xiurong Ma, Guiyun Kai, Zhifang Wu, Honglei Guo, Yange Liu, Shuzhong Yuan, and Xiaoyi Dong. "*Study of polarization independence for high birefringence fiber Sagnac interferometers*". Microwave and Optical Technology Letters, Vol. 46, No. 2 (2006), 183-185.