Journal of Optoelectronics and Advanced Materials Vol. 6, No. 2, June 2004, p. 677 - 680

TEMPERATURE DISTRIBUTION SENSOR BASED ON MAGNETOSTRICTIVE DELAY LINES

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In this paper we propose a new family of temperature distribution sensors based on the magnetostrictive delay line technique. An array of parallel conductors is set orthogonal to the delay line and used for pulsed current transmission. A coil is set around the one end of the delay line in order to receive the magneto-elastic pulses. A platinum wire or a thermistor is electrically connected to the end of each pulsed current conductor, being subjected to temperature changes. Variation of temperature changes the resistance of each platinum wire or thermistor and therefore changes the amplitude of the pulsed current, used to generate elastic pulse along the magnetostrictive delay line. We achieved a mechanically flexible temperature distribution system with 0.1 K temperature sensitivity at each sensing point as well as a 5 cm spatial resolution in a range of 10 m.

(Received April 26, 2004; accepted June 3, 2004)

Keywords: Temperature sensor, Temperature distribution sensor, Magnetostrictive delay lines

1. Introduction

Measuring temperature and temperature distribution is important in both industrial and biomedical applications [1]. A number of temperature sensors, based on various techniques [2-6] can be found in the literature. Temperature distribution measurement can be realized using discrete sensing elements and multiplexing techniques.

Magnetostrictive delay lines (MDLs) offer inherent multiplexing capability thus can be used to realize such a sensor. A number of sensing devices has been presented in the past using the MDL technique [7], taking advantage of the high magnetomechanical coupling factor of Fe-rich amorphous ribbons and wires. These sensing devices are based on modification of the elastomagnetic waves due to a given input either at their point of origin or at the region of the receiving means or finally along the MDL itself, considered as an elastomagnetic waveguide [8-22]. Due to the low cost of materials and electronics needed and the ease of assembling, these sensors combine low cost and increased sensitivity. Taking into account the above mentioned advantages of the MDL technique we decided to employ it for the construction of new family of temperature distribution sensors.

2. Experimental results

The sensor arrangement is presented in Fig. 1. A FeSiB amorphous wire, (1) is used as the magnetostrictive delay line (MDL). An array of parallel straight conductors (2) is set orthogonal to the MDL and is used for pulsed current transmission, which in turn produces elastic waves at the corresponding nearest area of the MDL (points of origin, PO). The sensing elements (3), platinum wires or thermistors are electrically connected at the one end of each straight conductor. Identical, synchronized pulsed voltages are applied to each combination of sensing element – conductor. The amount of current delivered through each conductor depends on the total resistance of the corresponding combination sensing element – conductor. Temperature changes affect the resistance of the sensing elements, thus modifying the transmitted pulsed current through each conductor and

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therefore the elastic wave generated on the MDL, which is recorded as a voltage pulse at the receiving coil (4) placed around the one end of the MDL. The recording device is triggered by the pulsed voltage applied on the conductors in terms of delay time, thus allowing the determination of the above mentioned elastic wave point of origin (PO) corresponding to each recorded pulse; as a result, the temperature at each sensing element can be determined.

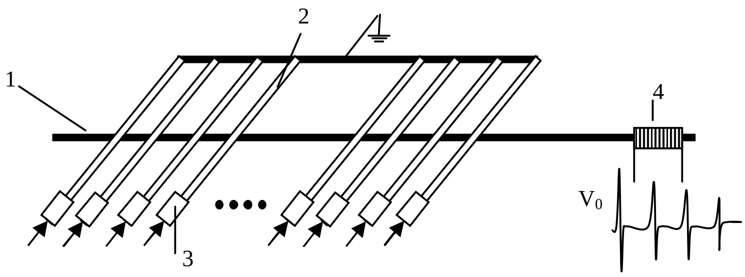

Fig. 1. Sensor arrangement: (1) MDL, (2) straight conductors, (3) sensing elements, (4) receiving coil.

Amorphous FeSiB magnetostrictive wires were used as MDL elements. Copper tapes were used as pulsed current conductors. Platinum wires of 99.99% purity were used as platinum sensing elements. $BaTiO_3$ thermistors doped with 30% Sr were used as thermistor elements. The MDL elements were used in the as cast form, after stress relief and after flash stress current annealing.
Heat annealing was realized by setting the wire at 350^0 C in Ar atmosphere for 30 min. Stress current annealing was realized by passing 1 A square waveform current of 50% duty cycle having 10 ms period for 3 s under 500 MPa tensile stress.

The dependence of the MDL voltage output, V_0, on the temperature at the platinum sensing elements for as cast, stress relieved and stress current annealed wires are illustrated in Figs. 2-4.

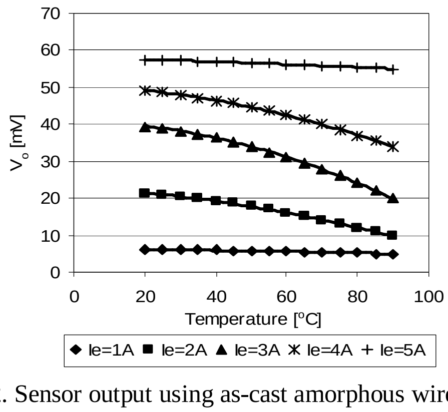

Fig. 2. Sensor output using as-cast amorphous wire; platinum wires used as sensing elements.

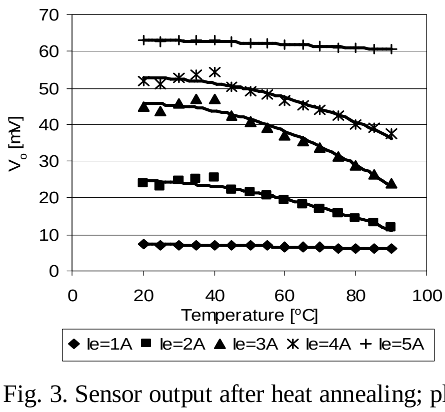

Fig. 3. Sensor output after heat annealing; platinum wires used as sensing elements.

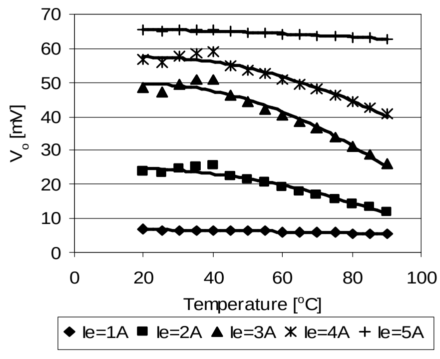

Fig. 4. Sensor output after flash stress current annealing; platinum wires used as sensing elements.

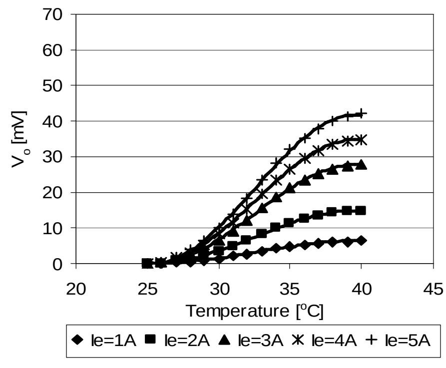

Fig. 5. Sensor output using as-cast amorphous wire; thermistors used as sensing elements.

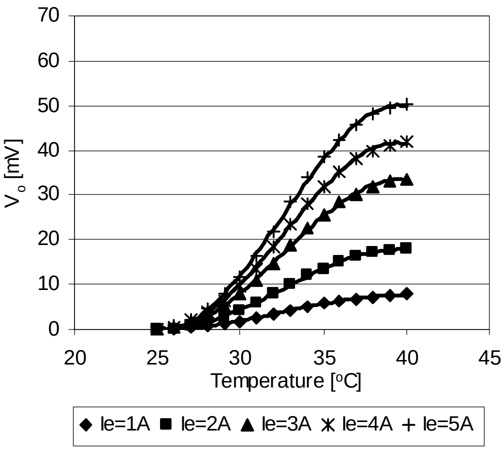

Fig. 6. Sensor output after heat annealing; thermistors used as sensing elements.

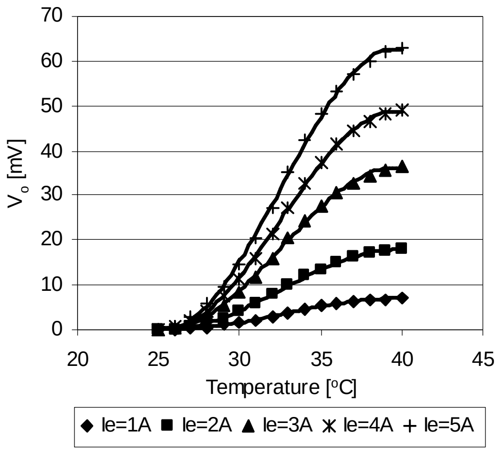

Fig. 7. Sensor output after flash stress current annealing; thermistors used as sensing elements.

Figs. 5 – 7 present the results obtained in the case of using thermistors as sensing elements under the conditions described above. In all these figures, the output voltage is due to a single sensing element.

The output voltage of other elements should be the same as the illustrated response. However, the problem of magnetoelastic non-uniformity is responsible for a non-monotonic and rather random output response. Such a problem of magnetoelastic non-uniformity can be eliminated by using stress-current annealing or field annealing as mentioned in [24]. I_e corresponds to the peak amplitude of the current in the conductors. The duration of the current pulses is 1 μs, while their period is 1 ms.

3. Discussion and conclusions

The proposed sensor design offers negligible temporal and hysteresis errors. We have repeated experiments as illustrated in [7, 24-26] and we determined a total uncertainty of 100 ppm.

Sensor sensitivity and range of measurement depend on the sensing element used. Platinum wires offer a wider measurement range thus being more preferable for industrial applications, while thermistors offer better sensitivity in a smaller temperature range, thus being preferable in biomedical or narrow range applications.

Concerning a sensing system consisting of 100 MDLs and 100 current conductors, the estimated power consumption is of the order of 10 μW.

Since the current conductors could be fabricated on a substrate of 2-3 mm thickness, thus ensuring mechanical flexibility and amorphous wires are also flexible, the proposed sensing system presents mechanical flexibility.

It has been reported that MDL non-uniformity response, determined as the fluctuation of amplitude of readings along the length of the line, is a non-standardized function [24, 25]. It can be seen that magnetoelastic uniformity is critical for the same reason. We have repeated the experiments of magnetoelastic uniformity [24, 25] resulting in an uncertainty of 100 ppm and 300 ppm for the case of wires and ribbons respectively. For the case of ribbon MDLs, using the normalization procedure presented in [24] resulted in improving the mentioned uncertainty.

The described temperature distribution sensors could be miniaturized by using thin film techniques [27- 29]. Research activity is under way to realize such a sensor system.

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