Journal of Optoelectronics and Advanced Materials Vol. 6, No. 2, June 2004, p. 685 - 688

PRESSURE SENSING USING MAGNETOSTRICTIVE DELAY LINES

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In this paper we present new results on pressure and pressure distribution sensors based on the magnetostrictive delay line technique. An amorphous ribbon is used as a magnetostrictive delay line, which is excited by a conductor, transmitting pulsed current orthogonal to the ribbon. The generated elastic pulse propagates along the length of the ribbon and is detected by means of a search coil at the end of it. Applying pressure on the surface of the ribbon between the excitation and the receiving area results in a distortion of the propagating elastic pulse and therefore a decrease of the output signal. We propose a device according to which such response is optimized. Pressure distribution is realized by applying pressure on the ribbon surface, which is out of the excitation and the receiving area. The sensor sensitivity is 100 ppm and the spatial resolution is of the order of 0.1 mm.

(Received April 26, 2004; accepted June 3, 2003)

Keywords: Pressure sensors, Magnetostrictive delay lines, Amorphous ribbon, Pressure distribution

1. Introduction

Pressure sensing is important in several applications. Silicon diaphragm techniques, piezoelectric film techniques or magnetic techniques using the changing of materials permeability due to any stress applied on their surface [1,2] have been used to realize force sensing devices. Pressure gauges have also been proposed, based mainly on thin-film arrangements, using the piezomagnetic effect.

A number of sensing devices has been presented in the past using the magnetostrictive delay line technique [3], 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 [4-12]. Recently, the MDL technique has been used for some interesting applications of load and derivative size measurements.

Sensitivity usually increases sensor cost; therefore the development of inexpensive and sensitive sensors is an interesting task. In this paper we present new results on pressure and pressure distribution sensors based on the MDL technique. Due to the low cost of materials and electronics needed and the ease of assembling, these sensors combine low cost and increased sensitivity.

2. Experimental results

The proposed sensors are based on pulsed operation of the MDL. The pressure sensor arrangement is presented in Fig. 1 [13,14]. An amorphous ribbon is used as the MDL (1). A straight conductor (2) is set orthogonal to the MDL and is used for pulsed current transmission.

Due to this current, an elastic pulse is generated at the region of the MDL nearest to the conductor (called hereinafter acoustic pulse point of origin, PO) and propagates along the length of

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the MDL. This pulse is detected via a search coil (3) placed around the one end of the MDL. Permanent magnets (4) are used to provide bias field at both PO and receiving area. The MDL is properly terminated at both ends (5) by using latex adhesive. A mechanical force, F, is applied on the MDL at any point (sensing point, 6) between the pulse origin (PO) and the search coil.

Sensor operation is based on the distortion of the elastic wave due to the applied force, as illustrated in Fig. 2. In this case, the MDL operates as an acoustic waveguide. The pulsed magnetic field caused by the exciting current generates a mechanical microstrain which, in turn, generates acoustic waves propagating towards both ends of the MDL. At the sensing point, the acoustic wave propagating to the right (4) is partially reflected and distorted. The remaining, distorted part of this wave (6) propagates towards the receiving area of the MDL. Thus, any applied force F on the MDL causes a reduction on the magnitude of the detected pulse, which is proportional to this force. Therefore, measuring the sensor output it is possible to determine the magnitude of the applied force, provided that it is small enough not to diminish the output voltage. The same effect can be observed by applying isostatic pressure along the length of the MDL.

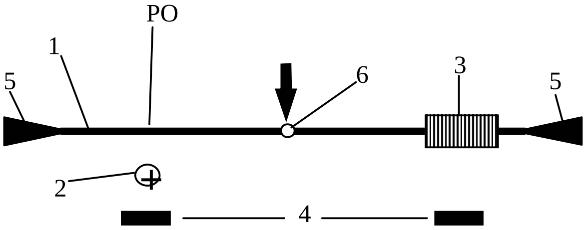

Fig. 1. Pressure sensor arrangement: (1) MDL, (2) Pulsed current conductor, (3) search coil, (4) Permanent biasing magnets, (5) MDL terminations, (6) Sensing point.

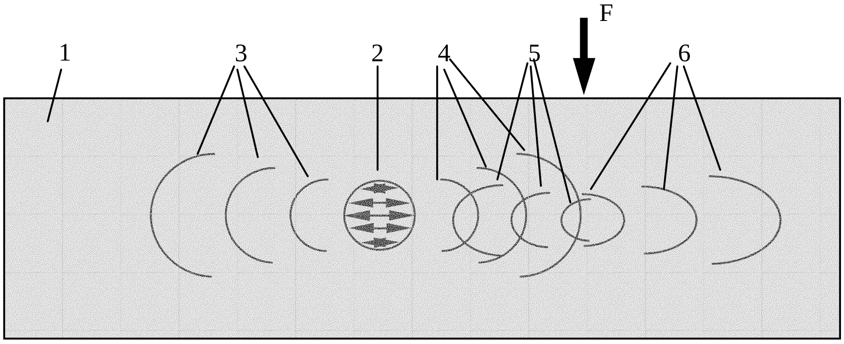

Fig. 2. Sensor operation: (1) MDL, (2) Mechanical strain caused by the pulsed magnetic field, (3) acoustic wave propagating to the left, (4) acoustic wave propagating to the right, (5) reflected acoustic wave due to force F, (6) distorted acoustic wave due to force F, propagating to the right.

Sensor response is measured using a liquid isostatic pressure facility with oil, since oil does not affect the MDL response. Measurements are realized using FeSiB amorphous ribbons in the as - cast form, after heat annealing the ribbon in 350 ^{0}C for 30 min in Ar atmosphere and after stress current annealing the ribbon by passing 1 A DC current through it for 10 ms under 500 MPa tensile stress and allowing 10 s relaxation time. The sensor output for these cases is presented in Figs. 3, 4 and 5 respectively.

A force digitizer based on this discrete kind of sensor can be realized by applying force at the region outside the MDL area defined by the PO and the search coil [14-17]. In this case, the propagating electric pulse also splits in two parts, but now the detected signal is the reflected one. The amplitude of the detected reflection can determine the amplitude of the applied force, while the delay time between original and reflected pulse equals double the distance between PO and point of reflection.

Figs. 6 – 8 present the digitizer output for the ribbon being in the as-cast form, after heat annealing the ribbon in 350 ^{0}C for 30 min in Ar atmosphere and after stress current annealing the ribbon by passing 1 A DC current through it for 10 ms under 500 MPa tensile stress and allowing 10 s relaxation time.

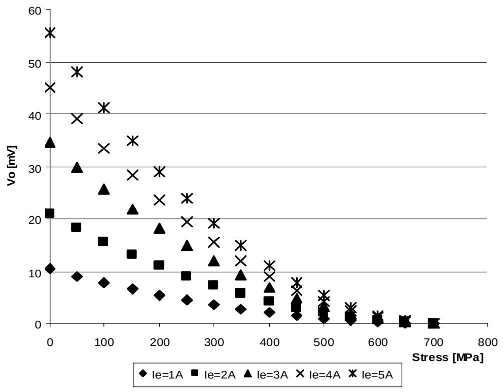

Fig. 3. Sensor output using as-cast amorphous ribbon.

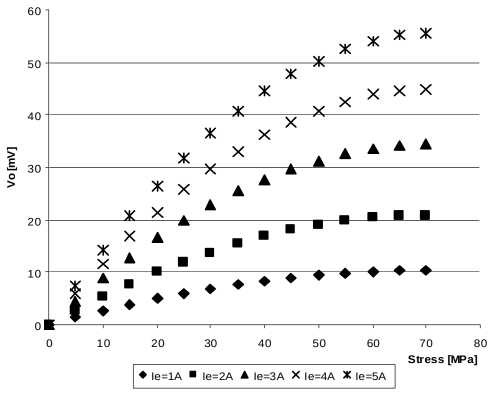

Fig. 6. Digitizer output using as-cast amorphous ribbon.

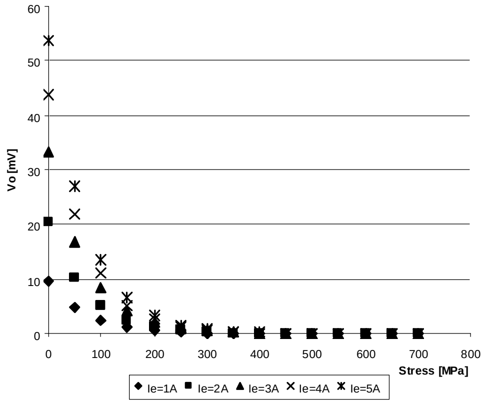

Fig. 4. Sensor output after heat annealing.

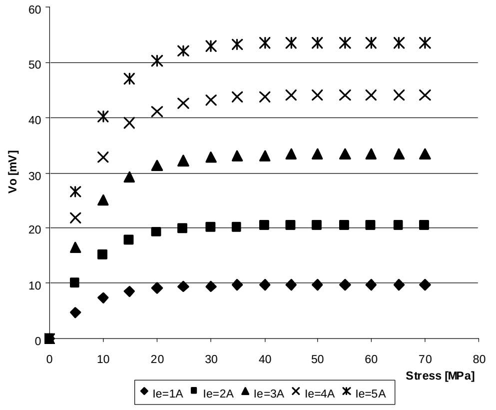

Fig. 7. Digitizer output after heat annealing.

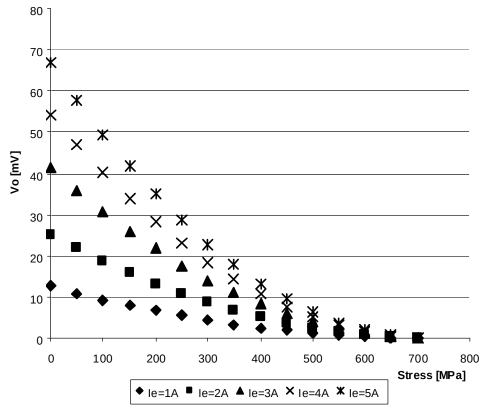

Fig. 5. Sensor output after flash stress current annealing.

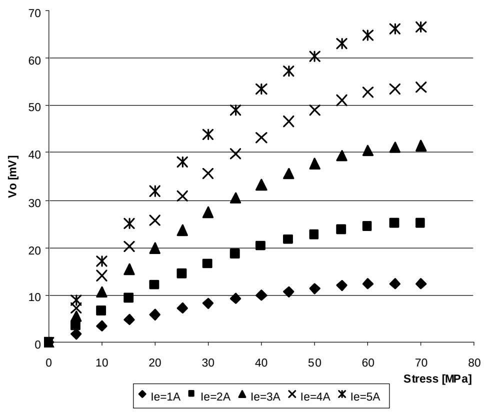

Fig. 8. Digitizer output after flash stress current annealing

3. Conclusions

The motivation of this work was to develop a device able to detect liquid pressure surrounding the magnetic material, ie the magnetostrictive delay line. As the pressure of the liquid increases, the surface tension on the MDL also increases. This surface tension orientates the magnetic dipoles of the MDL towards its geometric anisotropy axis due to the fact that the used MDL is a positive magnetostrictive element ($Fe_{76}Si_7B_{15}$). Therefore, the amplitude of the elastic wave and the corresponding pulsed voltage output decreases monotonically.

The results obtained indicate that heat annealing improves sensitivity and reduces measurement range of the sensor and the digitizer as well. However, stress current annealing the ribbon results in an improved sensitivity for both the sensor and the digitizer, leaving measurement range unchanged.

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 [16,17]. For the case of ribbon MDLs, it has been established that a first solution to this is the normalization process. Such a problem has been eliminated for the case of amorphous wires even in the as-cast form, while heat and magnetic annealing greatly improves their sensitivity and magneto-elastic uniformity.

Using thin film technology, this sensor arrangement could be miniaturized in order to decrease production cost and probably improve sensitivity and uncertainty [18-20].

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