SENSITIVITY ENHANCEMENT OF MAGNETIC SENSORS BASED ON METGLAS/PVDF LAMINATES USING THE FLUX CONCENTRATION EFFECT

Zhao Fang[1,2], Shengguo Lu[2], Feng Li[1], Ninad Mokhariwale[1,2], Suman Datta[1], Qiming Zhang[1,2] and Mario El Tahchi[3]

[1] Department of Electrical Engineering and [2] Materials Research Institute,
The Pennsylvania State University, University Park, Pennsylvania 16802, USA
[3] LPA-GBMI, Department of Physics, Lebanese University – Faculty of Sciences II,
PO Box 90656 Jdeidet, Lebanon

SUMMARY: In this paper the magnetic flux density concentration of Metglas as a function of its sheet aspect ratio was investigated for Metglas/Polyvinylidene fluoride (PVDF) laminar composites. The magnetic flux density inside a Metglas sheet increases when its aspect ratio (cross-section width/length) is reduced. Both simulations and experimental results verified it. Consequently the magnetostriction of Metglas and the magnetoelectric (ME) voltage coefficients of the laminar composites are enhanced for a small aspect ratio of the Metglas sheet. The ME voltage coefficient for a laminar composite with 1 mm wide and 30 mm long Metglas sheet (25 μm thick) is 21.46 V/cm*Oe, much higher than those reported earlier in similar laminar composites without making use of the flux concentration effect. The results demonstrate an effective means to significantly enhance the sensitivity of the magnetostrictive/piezoelectric composites, thus promoting them as weak magnetic field sensors. For comparison, both a custom-made voltage mode read-out IC and a charge mode read-out circuit were integrated with the laminar composites to form magnetic sensors.

For magnetic materials with very high permeability such as Metglas (μ_r > 45,000), the magnetic flux concentration effect can be quite significant. In other words, the flux density inside Metglas is much higher than that in the free space. As will be shown in this paper, this effect can be exploited to markedly enhance the ME voltage coefficient of Metglas based ME laminates and thus to improve the sensitivity of magnetic field sensors based on ME laminates. In this paper, the ME laminates with Metglas and PVDF piezoelectric polymer were investigated. It is shown that there is a marked enhancement of flux concentration in Metglas with very small aspect ratio, owing to its high magnetic permeability, and consequently a giant ME response in these composites.

Figure 1 presents a schematic diagram of the ME laminar composite, consisting of a piezoelectric layer with thickness t_p =25μm bonded to a magnetostrictive layer of thickness t_m=25 μm. To probe the magnetic flux concentration effect on the ME coupling coefficient of the composite, the length L_m of Metglas is fixed at 30 mm while the width W_m is varied from 20 mm down to 1 mm. The flux concentration is highest in the central region of the Metglas, where the PVDF piezoelectric polymer is bonded to realize the highest ME coupling.

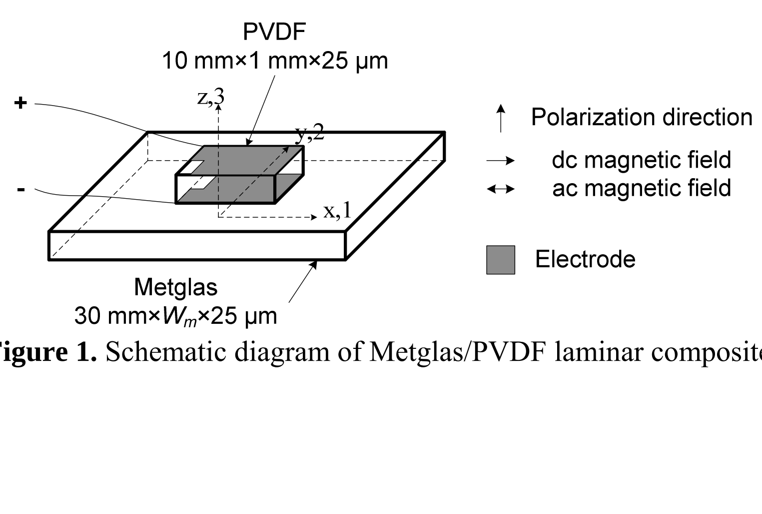


Figure 1. Schematic diagram of Metglas/PVDF laminar composites.

By bonding a 25 μm thick PVDF with length L_p=10 mm and width W_p=1 mm at the center region of a 25 μm thick Metglas sheet with a fixed length L_m=30 mm and varying W_m, we investigated the effect of flux concentration on the ME response of the composite laminate. Figure 2 presents the experimental data of α_{ME} ($\alpha_{ME} = \Delta E/\Delta H$, where E is the electrical field generated in the piezoelectric layer and H is the externally applied magnetic field) for the Metglas/PVDF laminates with various W_m (from 20 mm to 1 mm). As can be seen α_{ME} increases with decreasing W_m, while peaking at a lower dc bias field. Both the phenomena are a result of an increased magnetic flux concentration in Metglas and hence, the ratio of α_{ME} (W_m=1 mm)/ α_{ME} (W_m=20 mm) ~ 2 is the same as the ratio of H_{peak} (W_m=20 mm)/H_{peak} (W_m=1 mm). An α_{ME} of 21.46 V/cm*Oe at W_m=1 mm is noteworthy.

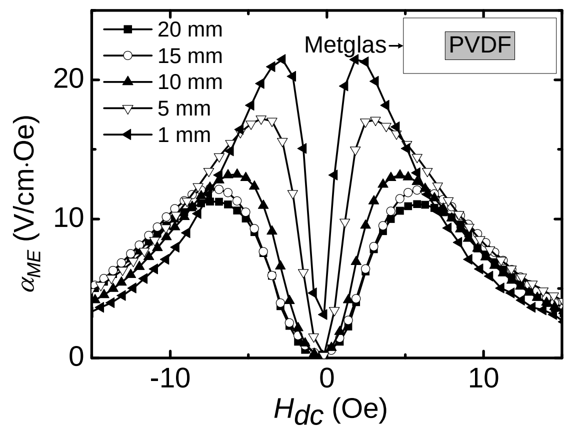
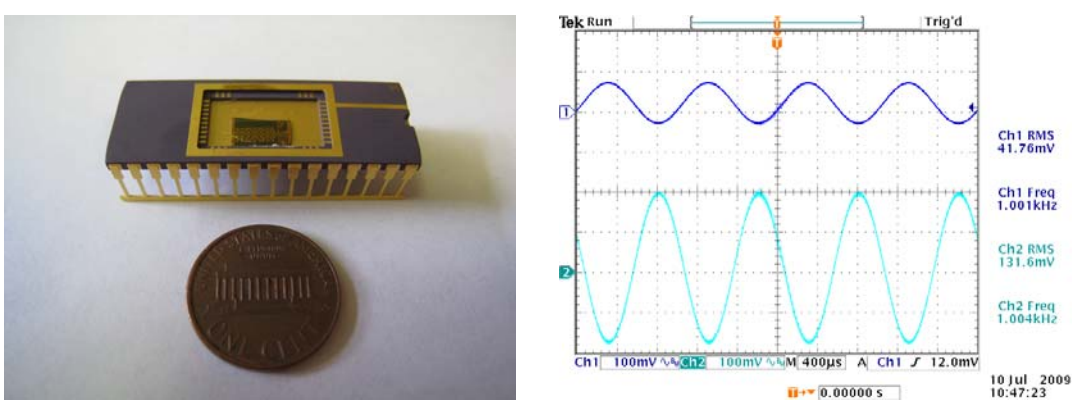


Figure 2. α_{ME} as a function of dc bias magnetic field for Metglas/PVDF laminates with different widths. The data was measured at 20 Hz and H_{ac} = 0.38 Oe.

A custom-made voltage mode read-out IC (Figure 3(a)) was designed and fabricated using conventional Si fabrication process. The circuit is designed for low noise, and acts as a moderately high input impedance buffer. The experimental results show that the small signal gain is 4 (Figure 3(b)) and the input impedance is 3.3 MΩ. The input referred noise power density was measured to be 10^{-11} V^2/Hz at 100Hz. A quantum well SiGe MOSFET, which is a buried channel device will eventually substitute Si to reduce the input referred noise, especially at low frequencies. For comparison with the voltage mode read-out IC, a charge mode read-out circuit was also integrated with the laminar composites.



(a) (b)

Figure 3. (a) The custom-made voltage mode read-out IC; (b) Oscilloscope capture of small signal gain (The top waveform is the input and the bottom waveform is the output).