Fabrication of All-Thin-Film Magnetoelectric Devices on Micromachined Silicon Cantilevers

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Abstract:

The current surge of activities in multiferroic materials and structures has lead the way for development of a new generation of devices based upon magnetoelectric (ME) effects, where conversion of magnetic field (H) to electric field (E) takes place at the interface. The ME composites have attracted attention as magnetic field sensors due to their extremely high sensitivity and their ability to operate at room temperature with almost zero power consumption on the device. A fabrication method for making magnetostrictive/piezoelectric magnetic field sensor devices based on a microfabricated MEMS platform is presented.

Summary of Research:

To date, the structure almost exclusively used as a magnetoelectric transducer has been a piezoelectric material sandwiched with two metallic magnetostrictive alloys in a bulk configuration. However, such bulk laminate devices, typically centimeters in lateral dimensions, have shortcomings including unreliable bonding between the magnetostrictive and the piezoelectric bulk components, eddy currents induced in the conducting phase, and low Q-quality factor of the mechanical resonance. To overcome such problems and improve the magnetic field detection capability of magnetostrictive/piezoelectric multilayer based devices, a Si cantilever, based on all thin film structures, has been developed.

The sensors consist of free-standing Pb(Zr$_{1-x}$Ti$_x$)O$_3$ (PZT) magnetostrictive cantilevers. The cantilever dimensions can be tuned to define the desired resonant frequency at which the magnetoelectric measurements are performed. The thin-film heterostructure is on a Si substrate with a plasma-enhanced chemical vapor deposited (PECVD) oxide/nitride/oxide (ONO) stack. The thickness of ONO stack layers is designed to tune the stress at the base of the cantilevers, controlling in this way the final bow of the cantilevers. A Ti/Pt layer is sputtered at a high temperature to form the bottom electrode of the piezoelectric part of devices. A PZT layer is spun by a sol-gel process. The PZT layer is then covered by another Pt buffer layer and a FeGa layer. Figure 1 shows a cross-section illustration of our sensor design.

![Figure 1: The designed heterostructure of the composite cantilevers used as magnetic field sensors. The ONO stack contains mostly silicon oxide with thin layers of silicon nitride.](image-url)

A four-mask photo-lithographic process is used to make the cantilevers. The first litho step defines the cantilever patterns and is used for Pt and FeGa ion milling processes shaping the blanket top electrode and the magnetostrictive layer. The second litho step is used for the PZT ion milling process to define the actuator and the bottom electrode while protecting the top electrode. The PZT wet etch to open via to the bottom electrode is carried out using a pattern defined by the third mask. Using the fourth litho step, a RIE process (CF$_3$ etch chemistry in an Oxford 100 system) through the ONO stack is performed to define the edges of actuators and...
open access for XeF₂-based Si etching (in a XACTIX xenon difluoride etcher) to release the cantilevers. The result is depicted in Figure 2 and Figure 3.

The ME measurements were performed in a custom made set-up consisting of two pairs of Helmholtz coils (for AC and DC magnetic fields). The chip with devices was installed in a small vacuum chamber between the coils. In dynamic measurements of the ME effect, one device at a time was connected to a lock-in amplifier for voltage measurements when an external AC magnetic field was applied and frequencies were swept. The peak occurs at the mechanical resonance of the device (Figure 4). The $Q$-factor of the devices is ~1200 in vacuum. One of the most important figures of merit for this type of measurements is the ME coefficient. For the shown device (Figure 2), the ME coefficient of the shown device is ~25 V/(cm · Oe) at the resonant frequency and can be determine using both AC and DC magnetic field measurements. The detection limit of these individual magnetic sensors is 2 nT at room temperature.

Future work may include fabrication of arrays of multiferroic sensors which are relevant for noise reduction configurations. The increase in the number of cantilevers in the sensing device will lead to the decrease in the normalized noise per sensor. Another issue is making cantilevers with stress concentrators. Such new configurations can enhance the ability to detect lower magnetic fields at room temperature.

References:

