Spin-Coated Piezoelectric-Polymer Composite based Acoustic Resonators and Transducers

Pallabi Das and Siddharth Tallur
Department of Electrical Engineering, IIT Bombay
Mumbai, India
daspallabi@ee.iitb.ac.in, stallur@ee.iitb.ac.in

Abstract—We present a novel composite comprised of piezoelectric PMN-PT nanoparticles embedded in a SU8 polymer matrix that can be spin coated on any substrate to realize acoustic resonators and transducers. High Overtone Bulk Acoustic Resonators (HBARs) are fabricated using this novel composite on a low acoustic loss silicon substrate. Initial experimental results yield piezoelectric coefficient (d33) as high as 216pm/V for the composite, indicating the possibility of designing efficient acoustic transducers.

Keywords—Piezoelectric-polymer composite, PMN-PT, HBAR, polymer

I. INTRODUCTION

Surface Acoustic Wave (SAW) based devices form the basis of high resolution sensors in various applications [1]–[3]. Another common type of acoustic resonator used in bio-sensing in liquid environments is the thickness shear mode (TSM) resonator [4], [5]. The materials commonly employed for SAW devices and for sensors are quartz (SiO2), lithium niobate (LiNbO3), and lithium tantalate (LiTaO3). The propagation of the SAW depends on the geometry of the substrate, and the crystal cut angle and quality of the film are important determinants of the sensor performance. While zinc oxide (ZnO) films sputtered at room temperature are efficient transducers for High Overtone Bulk Acoustic Resonators (HBARs) [6], other deposition techniques involve higher temperature processing or specialized equipment, in addition to specific requirements on the material and crystallographic orientation of the substrate.

In this paper, we present a novel approach based on fabricating polymer based high frequency acoustic transducers, by embedding nanoparticles of a piezoelectric material in the polymer. The piezoelectric-polymer composite can be deposited on a variety of substrates via spin coating, thus allowing us the flexibility to work with a broad range of materials. Here we report the fabrication of a silicon substrate HBAR using lead magnesium niobate-lead titanate (PMN-PT)/SU8 nanocomposite. Initial experimental results suggest a high d33 of 216pm/V for the composite, indicating that it could be a useful material for designing high efficiency transducers.

II. DEVICE DESIGN AND FABRICATION

HBARs are comprised of thin film piezoelectric materials sandwiched between metal electrodes which are solidly mounted on low acoustic loss substrates. We choose silicon as the low loss acoustic substrate, and chromium/gold bilayer for the metal electrodes. The PMN-PT/SU8 as the piezoelectric film, to study the efficiency of using a polymer based material for such a transducer. In our devices, we do not pattern the bottom metal. The PMN-PT/SU8 composite is patterned to define circular shaped transducers, and the top metal is patterned to align with the composite.

The composite solution is created by first ball-milling PMN-PT relaxor ferroelectric bulk crystals with SU8 2002 for 12 hours. This facilitates the PMN-PT powder to be dispersed in the solvent. Following this step, we probe sonicate the solution with SU8 thinner to get 7% by volume PMN-PT/SU8 composite. The fabrication process starts with growth of 200nm silicon dioxide on a <100> oriented double-side polished high resistivity n-type silicon wafer, to ensure no substrate leakage. Then we sputter 20nm/200nm chromium/gold as the bottom metal. The PMN-PT/SU8 composite is deposited on the bottom metal via spin coating to form a 3μm thick layer. SU8 is a negative photoresist, and hence the composite is patterned using photolithography and resist developer. For better dispersion of the composite layer on the gold we use Omnicoat as an adhesive layer. The top metal is deposited by sputtering 15nm/150nm thick chromium/gold, which is patterned by performing lift-off photolithography. Figure 1 shows a sketch of the fabrication process flow. Figure 2 shows the SEM image of the fabricated device and X-Ray Diffraction (XRD) spectrum of the composite, where the various crystalline planes of PMN-PT are visible in the matrix.
III. EXPERIMENTAL RESULTS

We perform domain engineering (poling) of the piezoelectric PMN-PT particles in the polymer matrix using an Asylum MFP3D Origin conductive Atomic Force Microscope (c-AFM).

![Image of HBAR device](image1)

Fig. 2. (Left) Scanning electron micrograph (SEM) image of HBAR device. (Right) X-ray diffraction spectrum of PMN-PT/SU8 composite showing various crystalline planes of PMN-PT in the polymer matrix.

The tip is scanned repeatedly across the sample to align the domains in every particle to maximize the piezoelectric coefficient ($d_{33}$). The $d_{33}$ is measured by performing Piezoresponse Force Microscopy (PFM) in the same setup. PFM is based on the detection of local deformation of a ferroelectric material induced by an external electric field. In our experiment, we apply 10V DC voltage to the tip and scan across a 20$\mu$m x 20$\mu$m area of the film. The $d_{33}$ is obtained as slope of the PFM response curve, and is recorded following every scan. The largest $d_{33}$ recorded on our sample was 216pm/V, as seen in Figure 3. Other values of bias voltage are to be explored to maximize the piezoelectric coefficient. RF experiment is performed after poling the device at 40V for 15 minutes using dc source meter. The reflection coefficient $S_{11}$ was then obtained on a poled device by the use of a vector network analyser. The measured reflection coefficient in dB is shown in Figure 5. The sharp dips in the $S_{11}$ data shows the resonance peaks at different frequencies.

![Image of PFM results](image2)

![Image of reflection coefficient](image3)

Fig. 3. High $d_{33}$ of 216pm/V recorded on PMN-PT/SU8 composite.

Fig. 4. Reflection coefficient $S_{11}$ plotted as a function of frequency. The sharp dips show the resonant frequencies. To confirm this dips are indeed of mechanical origin we lifted the probe and performed the same measurement shown in red curve which doesn’t show the resonances.

IV. CONCLUSION

We present a novel piezoelectric-polymer composite based on PMN-PT nanoparticles embedded in a SU8 polymer matrix. The polymer serves as a binder for the piezoelectric particles, and can be deposited via spin coating. The composite is also easily patternable via photolithography. Using a conductive AFM, we were able to successfully demonstrate domain engineering of the PMN-PT particles and recorded $d_{33}$ as high as 216pm/V. We also successfully fabricated HBAR transducers using the composite film on a low acoustic loss silicon wafer substrate. RF measurements of this HBAR resonator using polymer film shows mechanical modes present at multiple-GHz frequencies.

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REFERENCES