Patterning Ferroelectric Polymers for Wireless Flexible Electronics

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Abstract:
We fabricate large arrays of highly-crystalline, single-domain nano-islands of the ferroelectric polymer PVDF. Thin films of the polymer are patterned using nano-imprint lithography and characterized using an atomic force microscopy (AFM) in piezo-response force (PFM) mode. The resulting structures form a low-loss, nonlinear dielectric suitable for microwave devices in flexible electronics.

Description:
The novel impulse-radio architecture recently developed in our group shows strong potential for short-range, low-power wireless communications [1,2], however its performance is limited by substrate losses in complementary metal oxide semiconductor (CMOS). The advantages of this architecture are best realized in a material system such as flexible electronics, where transistors are relatively slow, but passives (inductors and capacitors) have high quality factors. Implementing such a radio requires high-quality voltage-variable capacitors to be fabricated with a thermal budget less than 200°C to avoid damaging the substrate.

Our target material is the ferroelectric polymer, polyvinylidene fluoride (PVDF), which behaves as a nonlinear dielectric up to optical frequencies, but has strong losses in the 10 MHz-1 GHz range due to dielectric relaxation. However, these relaxation processes have been associated with the amorphous regions and amorphous-crystalline boundaries which exist in a continuous thin-film [3,4]. Therefore, the ability to fabricate fully-crystalline, single-domain PVDF should enable high-frequency applications in flexible electronics.

In this project, we attempt to fabricate and characterize metal-insulator-metal capacitors using large area arrays of single-domain PVDF islands as the dielectric. The islands are patterned using nano-imprint lithography, Figure 1, where a template is pressed into a PVDF thin film under heat and pressure sufficient for plastic deformation of the polymer. The template consists 20 nm lines and 100-200 nm spaces over a large area and is created by e-beam
lithography (JEOL 9300) with an HSQ negative resist. The template can then pattern several PVDF films in the NX-2500 nano-imprint tool. Figure 2 shows part of a large array of islands on silicon. Figure 3 shows a partially successful imprint onto gold/chrome metal.

Initial characterization of the islands (before deposition of the top metal layer) uses an AFM technique called Piezo-response force microscopy (PFM) to measure the PVDF’s electro-mechanical response. (Because the ferroelectric effect also induces piezoelectricity in PVDF, the electro-mechanical and dielectric responses correspond closely.) PFM applies an AC voltage to the AFM tip and monitors the magnitude and phase of the cantilever deflection to measure the piezoelectric displacement and domain orientation, respectively. Figure 4 shows a PFM phase image of individually-poled PVDF islands; the PFM measurements are performed on the Icon AFM, as well as CCMR’s Dimension 3100 AFM.

The ability to polarize individual PVDF islands suggests that highly-crystalline, low-loss material has been formed. Future process development will complete metal-insulator-metal capacitors and allow microwave frequency electrical measurements and implementation of impulse radio devices.

References: