Characterizing Diamond Thin-Film Bulk Acoustic Resonators for Quantum Control

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Primary CNF Tools Used: OEM Endeavor M1, Westbond 7400A Ultrasonic Wire Bonder

Abstract:

Electro-mechanical resonators have been used to coherently control electron spins in solid-state defect centers such as the nitrogen-vacancy center in diamond. These resonators introduce strain into the diamond lattice, which can be used to drive magnetically-forbidden transitions of the defect center. Strong AC stain driving with these resonators can enhance the spin coherence of the electron spins. To achieve strong AC strain driving, we fabricate a diamond thin-film bulk acoustic resonator and characterize its electromechanical performance. In addition, we use x-ray diffraction to image the ac strain produced by our device, to better understand the device performance.

Summary of Research:

The diamond nitrogen-vacancy (NV) center is a point defect center in the diamond lattice that consists of a substitutional nitrogen atom adjacent to a lattice vacancy. The NV center has been demonstrated to couple to external fields, making it an excellent platform for quantum sensing (e.g., magnetometry, thermometry, strain). In previous experiments, it has been demonstrated that ac lattice strain is an effective mechanism for manipulating the electron spin of the nitrogen-vacancy center. Oscillating lattice strain has been used to coherently drive the electron spin between magnetically forbidden transitions [1,2], which can dynamically decouple the NV center from magnetic noise to enhance its spin coherence [3]. To achieve this dynamical decoupling in a variety of NV center applications, we require strong ac strain driving, which we implement using a diamond thin-film bulk acoustic resonator.

We fabricate a thin-film bulk acoustic resonator (FBAR) on single crystal diamond (Figure 1). The FBAR consists of a transducer stack of AlN (1.5 µm) that is sandwiched between a bottom and top Pt electrode. This transducer sits on a 10 µm optical-grade diamond membrane that is thinned through reactive-ion etching. The AlN film is deposited with the OEM Endeavor M1 tool at CNF.

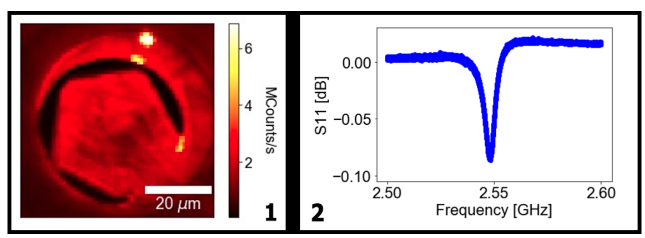

Figure 1, left: Photoluminescence image of the diamond FBAR. The FBAR sits on top of a pentagonal diamond membrane (10 µm) and consists of a Pt bottom electrode, AlN film (1.5 µm), and a top Al electrode. Figure 2, right: S11 measurement of the 2.54 GHz acoustic mode of the AlN FBAR.

In addition, we fabricate an antenna surrounding the FBAR, which allows for magnetic control of the NV center spins in the diamond membrane.

We characterize the electromechanical properties of the FBAR device by measuring the S11 response with a vector network analyzer. We measure a resonance mode at 2.54 GHz, which has a quality factor of 200 (Figure 2). To demonstrate coherent strain driving of a mechanically-forbidden double quantum transition (m_s=-1 to m_s=+1), we first perform spectroscopy to identify the resonant external magnetic field. We sweep the external field,

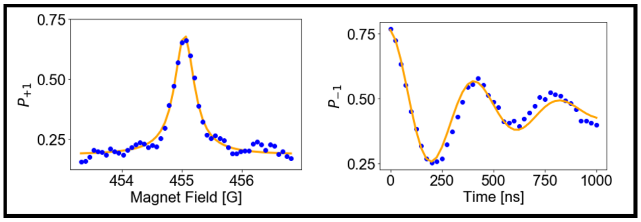

Figure 3: Spectroscopy of the magnetically-forbidden double quantum transition and coherent Rabi driving of the double quantum transition. The spectroscopy sweeps the external magnetic field to tune the Zeeman splitting between m = -1 and m = +1 to be resonant with the FBAR mode. Rabi oscillations are measured at this field with a Rabi frequency of 2.5 MHz.

which tunes the Zeeman splitting between m_s = -1 and m_s = +1, while driving the FBAR mode. At this resonant field, we use the FBAR to drive Rabi oscillations between the m = -1 and m = +1 transition (Figure 3). For this mode, we achieve a Rabi frequency of 2.5 MHz.

We use the Advanced Photon Source at Argonne National Laboratory to measure the strain in the bulk of our FBARs directly with x-rays. We measure the x-ray diffraction of the diamond device using pulsed synchrotron x-rays. We quantify the static strain created during fabrication by comparing the collected diffraction patterns on and off the FBAR region. We can also measure the dynamic ac strain while actively driving the transducer. We collect throughout the entire bulk of the diamond with the X-ray diffraction, which has two full oscillations of the strain wave due to the diamond thickness and mode frequency. As we change the phase of the driving voltage, we observe a peak separate and recombine in the detector images, which quantifies the stroboscopic strain within the device. Figure 4 shows the mode confinement at the center of the FBAR, which is found by computing the lateral variance subtracted from a reference image for each phase value

Conclusions and Future Steps:

We fabricate and characterize an electro-mechanical mode an AlN diamond thin-film acoustic resonator. We perform spectroscopy to tune double quantum transition of the NV center to be resonant with the FBAR mode and demonstrate coherent strain driving with a Rabi frequency of 1.7 MHz. In addition, to understand the spatial distribution of strain in the FBAR device, we image the FBAR mode with X-ray diffraction and show mode confinement. To improve the performance of our device, we are increasing the size of the device to improve the quality factor and impedance matching.

References:

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MECHANICAL DEVICES

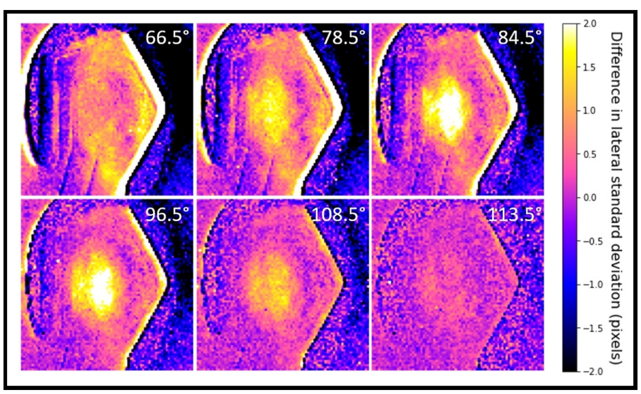

Figure 4: X-ray diffraction imaging of the FBAR. At each pixel of these two-dimensional images, there is a detector image. The standard deviation of the data in the lateral dimension is calculated. Each of the images are taken at various phases of the driving voltage to the transducer. The images are subtracted from a reference image at another phase value at 125.5°. These difference images show the mode confinement in the center of the FBAR region that appears as we introduce strain through the bulk of the diamond.