Mechanically Driven Electron Spins with a Diamond Thin-Film Bulk Acoustic Resonator

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Primary CNF Tools Used: OEM Endeavor M1, Westbond 7400A ultrasonic wire bonder

Abstract:

Lattice strain has been demonstrated to be an effective method of coherently manipulating electron spins in solid state defect centers such as the diamond nitrogen-vacancy center. In previous experiments, strain is introduced into the diamond lattice through a high overtone bulk acoustic resonator (HBAR). To improve the strain and power efficiency of bulk acoustic resonators for quantum control, we develop and characterize a diamond thin-film bulk acoustic resonator. We measure the electromechanical performance of the device and demonstrate coherent driving of a double quantum transition a nitrogen-vacancy center (NV) of electron spin ensemble.

Summary of Research:

The diamond nitrogen-vacancy (NV) center is a well characterized solid state defect center consisting of a substitutional nitrogen impurity adjacent to a lattice vacancy. The NV center electron spin interacts with many external fields (magnetic, electric, etc.), making it an excellent platform for quantum sensing. In addition to the electron spin, the NV center has a native nitrogen nuclear spin, which is coupled to the electronic spin through a hyperfine interaction. This provides an opportunity to use the nuclear spin for sensing applications, with state preparation and readout facilitated by the electron spin. However, the hyperfine interaction also provides an additional source of decoherence for the nuclear spin, limiting the sensitivity of any potential quantum sensing protocols employing these spins. It has been shown that strong driving of the electron spin can help protect the coherence of the nuclear spin [1]. Previous experiments with high overtone bulk acoustic resonators (HBAR) on diamond have demonstrated electron spin driving with lattice strain for coherent control [2], and continuous dynamical decoupling for protecting electron spin coherence [3].

To achieve strong driving of the electron spin with lattice strain, we fabricate thin-film bulk acoustic resonators (FBAR) on single crystal diamond (Figure 1). The FBAR resonators consist of a 1.5 μm AlN transducer, with a bottom (Al) electrode and a top (Pt) electrode. The transducer is deposited onto a 10 μm thick optical grade diamond, which is created through reactive ion etching. The AlN film is sputtered using the OEM Endeavor M1 tool at CNF. Compared to previous generations of ZnO HBAR on diamond, the AlN diamond FBAR has better power handling, which allows for much stronger acoustic driving of electron spins by simply applying more power. To provide microwave control of the spins, we also fabricate a loop antenna, which surrounds the FBAR.

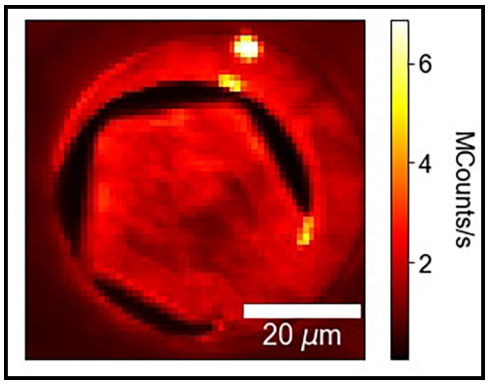

Figure 1: Photoluminescence image of an AlN FBAR on diamond. The FBAR (pentagonal feature) consists of a 1.5 μm AlN film that is sandwiched by an Al bottom electrode and a Ti/Pt top electrode. This stack is on top on a 10 μm diamond membrane.

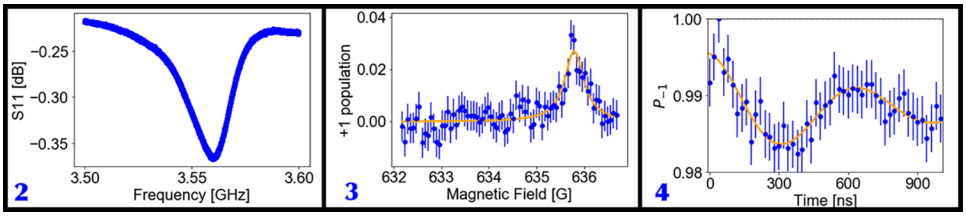

Figure 2, left: S11 measurement of the 3.56 GHz acoustic mode of the AlN FBAR. Figure 3, middle: Spectroscopy of the double quantum transition. The resonator frequency is fixed at 3.56 GHz while the Zeeman splitting between the ms = -1 and ms = +1 states is swept. The peak at approximately 636 G gives the external field necessary to tune the double quantum transition in resonance with the acoustic mode. Figure 4, right: Rabi driving of the double quantum transition with a Rabi field of 1.7 MHz.

We measure the electromechanical resonances of the AlN FBAR by measuring the S11 response with a vector network analyzer. To characterize the device, we focus on an acoustic mode at 3.56 GHz (Figure 1) with a low quality factor (~10). We coherently drive a double quantum transition (ms = -1 to ms = +1) with this mode to measure the lattice strain in the diamond. To ensure that the acoustic mode is resonantly driving the electron spin, we perform spectroscopy where the Zeeman splitting between ms = -1 to ms = +1 is swept [3]. This locates the correct external magnetic field to apply along the NV symmetry axis, which will tune the electron spin transition in resonance with the acoustic mode. Using this field, we drive Rabi oscillations of the electron spin using acoustic pulses and measure the strain in the FBAR through the Rabi frequency [4]. In this device, we drive the electron spin using an electromechanical mode at 3.5 GHz. The measured Rabi field from the oscillations is 1.7 MHz, which is comparable with the hyperfine splitting of the NV center (2.1 MHz).

Conclusions and Future Steps:

We have developed a process for fabricating AlN FBARs on diamond to drive electron spins. To improve the acoustic driving, we aim to improve the quality factor of the resonator. This can be achieved by adjusting the dimensions of the resonator and the diamond substrate. In addition, we are looking at optimizing this process for isotopically pure CVD diamond. Isotopically pure diamond can host NV centers with phase coherence times on the order of 10 μs, making it an excellent substrate for developing a quantum sensor.

References:

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