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

CNF Project Number: 2126-12
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Primary Source(s) of Research Funding: Defense Advanced Research Projects Agency- DARPA DRINQS program (Cooperative Agreement #D18AC00024), Q-NEXT (U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers)

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

Abstract:

Lattice strain is an effective method of coherently manipulating electron spins in solid state defect centers such as the diamond nitrogen-vacancy center. To improve the achievable strain and power efficiency of bulk acoustic resonators for quantum control, we develop and characterize a released diamond thin-film bulk acoustic resonator. We demonstrate coherent driving of a double quantum transition of the NV electron spin through acoustically driven Rabi oscillations, achieving a Rabi frequency of 6 MHz. We also study the performance of the device over various powers and find that driving larger than 25 dBm deteriorates the performance of the FBAR.

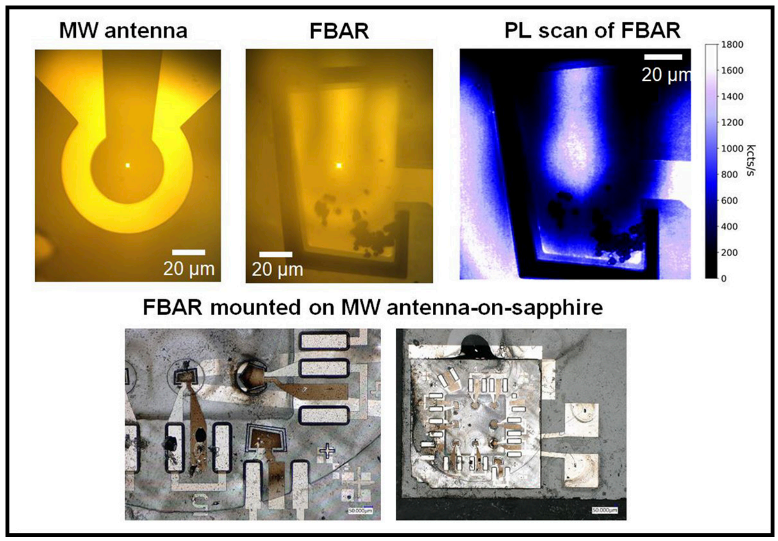

Figure 1: Microscope images of the MW antenna and FBAR device structure during our measurements, as well as a photoluminescence image of an AlN FBAR on diamond. The other two images are pictures taken of the FBAR device and antenna chip aligned on top of each other.

Summary of Research:

The diamond nitrogen-vacancy (NV) center is a solid-state defect consisting of a substitutional nitrogen 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 control and sensing. Acoustic control of the NV center with strain has been achieved with High Overtone Bulk Acoustic Resonators (HBARs) fabricated on diamond. The lattice strain provided by these devices have been used in experiments demonstrating coherent control and continuous dynamical decoupling for protecting electron spin coherence. In addition, strong driving on the electron spin can be used to protect the spin coherence of the native nitrogen spin of the NV center.

Strong driving of the electron spin can temporally average away the hyperfine interaction between the electron and nitrogen spin, effectively decoupling them. This opens avenues for using the nitrogen spin as a sensor, leveraging its long spin coherence time, while using the electron spin for optical initialization and readout.

To achieve strong driving of the electron spin with lattice strain, we fabricated a new generation of 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 electrode and a top Pt electrode. The transducer deposited onto of a 10 μm thin optical grade diamond, which is created through reactive ion etching. The AlN film is sputtered using the OEM

Endeavor M1 tool at CNF. After fabricating the AlN transducer, we release the FBAR from the surrounding diamond via a backside etch. An antenna for magnetic control of the NV centers is fabricated on a separate sapphire chip that is bonded to the diamond before testing.

We perform measurements of this FBAR with an electromechanical mode at 1.9237 GHz. An external magnetic field is applied to tune the electron double quantum transition (ms = -1 to ms = +1) to be resonant with the mode. We coherently drive Rabi oscillations of to measure the strain generated by our device (Figure 2). As we increase the drive power, the oscillation frequency increases linearly. This continues up to a certain point, after which, the electromechanical response of the device is permanently degraded. The exact physical mechanism that is causing the degradation in performance is unclear, but we suspect that thermal heating due to the high power applied to the device plays a strong role, damaging the piezoelectric film and/or the Pt electrodes.

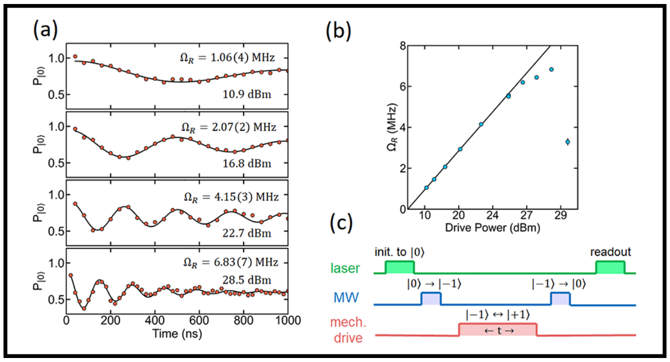

Figure 2: (a) Mechanical Rabi measurements as a function of applied power to the FBAR device. As we increase the power, the Rabi frequency increases. (b) Summary of all the mechanical rabi frequencies as a function of applied power. There is a linear relationship, until the electromechanical response of the device permanently changed with too much applied power. (c) Pulse sequence of the mechanical Rabi sequence used.

Conclusions and Future Steps:

We have developed a process for fabricating released AlN FBAR devices on diamond for NV sensing protocols. The next step is to investigate the cause of the degradation of the device performance at high powers. In addition, we hope to improve the process of depositing AlN on diamond, to mitigate losses introduced during sputtering and to consistently get high quality films.