

Co-Fabricated Diamond Acoustic Resonators for Nitrogen-Vacancy Spin Control and Rotation Sensing

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Principal Investigator(s): Greg Fuchs

User(s): Chao Shang, Anuj Ashok

Affiliation(s): Applied and Engineering Physics, Cornell University, Electrical and Computer Engineering, Purdue University

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Contact: gdf9@cornell.edu, cs2485@cornell.edu, ashok12@purdue.edu

Primary CNF Tools Used: AJA Sputter 1; OEM M1 Aluminum Nitride Sputter System; HB16 Semi-Automatic Wire Bonder

Abstract:

This work co-fabricates high-overtone bulk acoustic resonators (HBARs) and film bulk acoustic resonators (FBARs) on a single-crystal diamond chip to provide complementary acoustic drive channels for a nitrogen-vacancy (NV) center ensemble. The HBAR mechanically drives the NV electron-spin double-quantum transition, while the FBAR is designed for future spectrally selective control of the three nitrogen-14 hyperfine sublevels in a nuclear-spin-based gyroscope. The report describes fabrication of a multi-geometry resonator die at the Cornell NanoScale Science and Technology Facility and the Birck Nanotechnology Center, together with one-port reflection measurements from 0.5 to 5.0 GHz. The HBAR exhibits a dense comb of sharp resonance dips that reach -18.3 dB, whereas the FBAR exhibits a weaker and sparser response over the same frequency range. These contrasting spectra are consistent with the different acoustic cavities formed by the two device geometries on the shared diamond substrate.

Summary of Research:

Nitrogen-vacancy centers in diamond are optically addressable solid-state spin qubits. Their ground-state electron-spin sublevels, $m_s = 0, +1$, and -1 , are coherently controlled by microwave magnetic fields, acoustic strain, or a combination of both. Acoustic driving directly addresses the $m_s = -1$ to $+1$ double-quantum transition, which is inaccessible to a conventional magnetic-dipole microwave drive [1]. Each nitrogen-vacancy center also contains a nitrogen-14 nuclear spin with $I = 1$. Hyperfine coupling splits each electron-spin transition into three lines. Because the nuclear spin can retain coherence much longer than the electron spin, it provides an attractive sensing degree of freedom for rotation measurements based on geometric phase accumulation [2,3].

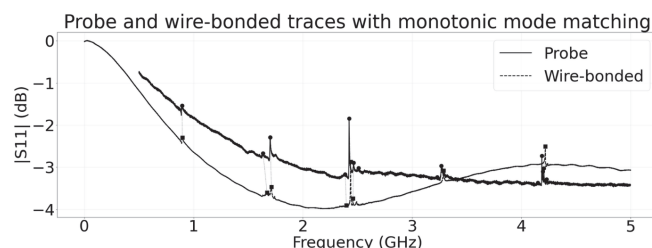


Figure 1: One-port S_{11} magnitude from 0.5 to 5.0 GHz for an FBAR device on the co-fabricated diamond chip before and after gold wire bonding.

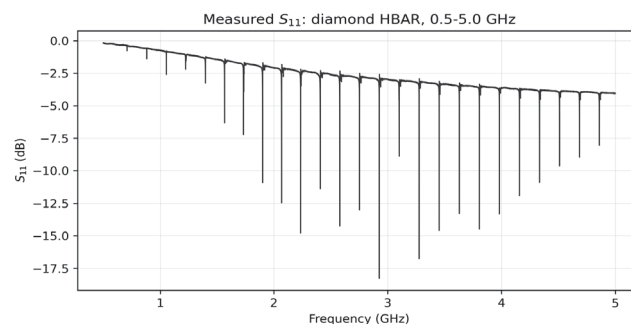


Figure 2: One-port S_{11} magnitude from 0.5 to 5.0 GHz for an HBAR device on the same diamond chip. The spectrum contains a dense comb of high-overtone resonances under a 50-ohm calibrated measurement.

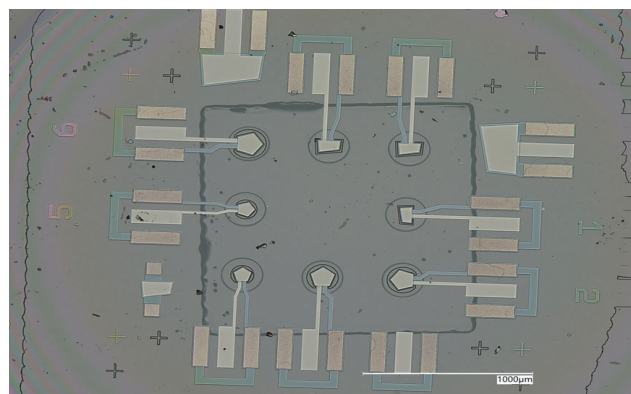


Figure 3: Optical micrograph of the fabricated diamond die. Multiple co-fabricated FBAR and HBAR electrode geometries connect through independent coplanar routing traces to bond pads at the die periphery. The scale bar is 1000 micrometers.

The diamond die integrates HBAR and FBAR structures side by side. In the HBAR geometry, a thin aluminum nitride transducer excites acoustic modes through the full diamond thickness, which acts as a Fabry-Perot cavity. In the FBAR geometry, the acoustic mode is more strongly localized near the transducer. Both device types use a 1 micrometer aluminum nitride piezoelectric film between a continuous bottom ground electrode and a patterned top signal electrode. The die includes tapered fan-shaped, pentagonal, and compact rounded top-electrode geometries. Independent coplanar traces connect each device to peripheral bond pads for individual electrical probing.

The fabrication workflow is divided between two facilities. At the Cornell NanoScale Science and Technology Facility, the AJA Sputter 1 deposits the metal electrode layers, and the OEM M1 Aluminum Nitride Sputter System deposits the 1 micrometer piezoelectric film. Photolithography, pattern transfer, and dry etching are completed at the Birck Nanotechnology Center at Purdue University. Figure 3 shows the completed diamond die, including the co-fabricated electrode geometries, coplanar feed traces, and bond pads. Device packaging uses the HB16 semi-automatic wire bonder with gold wire. Figure 3 shows the devices after the wire bounding.

One-port S11 reflection measurements are performed from 0.5 to 5.0 GHz with a vector network analyzer after a full one-port calibration. Figure 1 compares the FBAR response before and after wire bonding. The spectrum contains a small number of relatively shallow resonance features on a comparatively smooth background. Figure 2 presents the HBAR response over the same frequency range. The HBAR produces a dense sequence of sharp resonance dips that reach -18.3 dB, consistent with the high overtone density of a full-thickness diamond acoustic cavity. Measurements from the two device types use the same die and comparable calibration conditions, which supports comparison of the effects of electrode and cavity geometry.

Conclusions and Future Work:

The co-fabricated HBAR and FBAR devices show distinct one-port acoustic responses that support their complementary roles. The HBAR provides a dense set of mechanical resonances for electron-spin double-quantum control, while the FBAR provides a more localized platform for hyperfine-selective nuclear-spin control. The nitrogen-14 hyperfine lines are separated by approximately 2.16 MHz for a single-quantum transition and approximately 4.32 MHz for a double-quantum transition. Ongoing work characterizes the

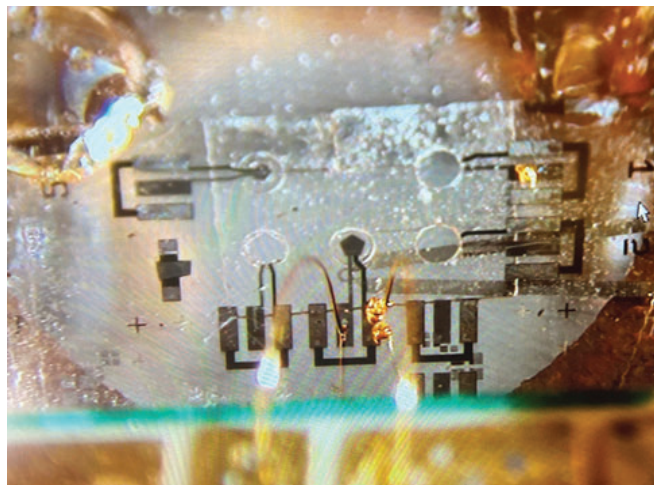


Figure 4: Optical micrograph of the wire bounded devices.

target FBAR mode, including its resonance frequency, -3 dB bandwidth, and stability, to determine whether it supports selective addressing of individual hyperfine lines or deliberate single-tone coverage of the full hyperfine manifold. Subsequent experiments integrate the selected resonator mode with optical nitrogen-vacancy initialization and readout for on-chip rotation sensing.

References:

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- [2] E. R. MacQuarrie, T. A. Gosavi, S. A. Bhawe, and G. D. Fuchs, "Continuous dynamical decoupling of a single diamond nitrogen-vacancy center spin with a mechanical resonator," *Optica* 2, 233 (2015).
- [3] M. P. Ledbetter et al., "Gyroscopes based on nitrogen-vacancy centers in diamond," *Physical Review A* 86, 052116 (2012).