

Magnon-Exciton Coupling in the Van der Waals Antiferromagnet CrSBr

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Abstract:

Hybrid devices combining magnetic materials with superconducting microwave resonators provide a platform for quantum transduction, sensing, and nonlinear magnonics[1–3]. In this project, we developed niobium coplanar waveguide resonators for microwave excitation of magnons in the layered antiferromagnetic semiconductor CrSBr. The ultimate design target is a high-quality-factor resonator operating near 30 GHz, corresponding to the zero-field magnon frequency range of the CrSBr samples studied. Resonator performance was optimized by varying the niobium-film thickness and device geometry, including the signal-line width, dielectric-gap width, and signal-line pattern.

The fabricated devices currently exhibit resonances near 20 GHz. A dielectric-gap-to-signal-width ratio of approximately 2:1 produced suitable microwave impedance and strong magnetic-field concentration near the resonator gaps. Field-dependent microwave measurements revealed anticrossings between the resonator and CrSBr magnon modes, demonstrating magnon–photon coupling. The resonator platform also enables optical measurements of the driven magnetic response through the excitonic properties of CrSBr.

Summary of Research:

Hybrid magnetic devices enable coupling between spin dynamic and photon in microwave resonators[1–3]. Such systems are promising for microwave-to-spin transduction, studies of coherent light–matter interaction, magnetic sensing, and the development of hybrid quantum technologies. CrSBr is particularly useful for this purpose because it is a layered 2D magnetic semiconductor with both strong magnetic excitations and an optical response that is sensitive to its magnetic state. This combination allows the same magnon dynamics to be investigated through microwave transmission and optical measurements.

The objective of this project was to fabricate superconducting coplanar waveguide resonators that efficiently excite CrSBr magnons while remaining compatible with optical access to the CrSBr flake. The resonator frequency must overlap with a magnon branch to produce measurable coupling. Because the zero-field magnon response of the studied CrSBr samples occurs in the tens-of-gigahertz range, the long-term design goal is a resonator frequency near 30 GHz. The present devices were designed near 20 GHz so that the magnon frequency could be tuned through the resonator frequency using an external magnetic field.

Niobium coplanar waveguide resonators with different film thicknesses and geometries were fabricated using CNF facilities. The fabrication process included niobium-film preparation, lithographic patterning of the microwave circuit, plasma etching of the niobium, and characterization of the resulting film and device dimensions. Several geometric parameters were varied, including resonator length, signal-line width, dielectric-gap width, and the shape of the signal-line pattern.

The resonator length was selected to set the fundamental microwave mode near 30 GHz. A dielectric-gap-to-signal-width ratio of approximately 2:1 was used to maintain impedance matching near 50 ohms while producing a strong microwave magnetic field in the dielectric-gap regions. Electromagnetic simulations were used to evaluate the resonant frequency, microwave-field distribution, and expected overlap between the resonator field and the CrSBr sample. These simulations showed that the strongest microwave magnetic field is concentrated near the dielectric gaps. CrSBr flakes were therefore positioned to maximize their overlap with these regions.

The fabricated resonators were characterized using a vector network analyzer. Magnetic-field-dependent microwave transmission measurements were performed in a Physical Property Measurement System. When a

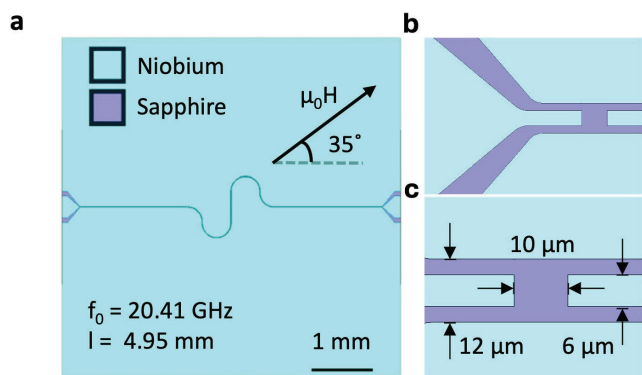


Figure 1: Design and HFSS simulation of the on-chip microwave resonator. Geometry of the on-chip microwave resonator[4].

field-tunable CrSBr magnon mode approached the resonator frequency, the microwave transmission spectrum showed an anticrossing rather than a simple crossing. This spectral splitting indicates hybridization between the magnon and microwave-photon modes and demonstrates that the on-chip niobium resonator can effectively drive magnons in relatively thick CrSBr flakes.

The devices were also designed to support optical access to the CrSBr sample. Optical measurements provide information that is not available from microwave transmission alone. A vector network analyzer measures the spatially averaged response of the entire hybrid device, whereas the excitonic optical response of CrSBr can probe the locally driven magnetic dynamics. Differential-reflectance measurements can therefore be used to determine where the resonator most strongly excites the material and how the optical response changes when the microwave frequency overlaps with a magnon resonance.

CNF fabrication was essential for producing reproducible superconducting structures with controlled film thicknesses, micron-scale gaps, and accurately defined resonator lengths. These capabilities increased the microwave magnetic-field amplitude at the CrSBr position and improved the measurable magnon response. The fabricated platform connects superconducting microwave-circuit engineering with spatially resolved optical detection of spin dynamics in a van der Waals magnetic semiconductor.

Conclusions and Future Steps:

The fabricated niobium coplanar resonators successfully excited magnons in thick CrSBr samples, and field-dependent microwave transmission measurements revealed anticrossings consistent with magnon–photon coupling. The results show that resonator geometry and sample placement can be engineered to enhance the microwave magnetic field interacting with CrSBr.

Future work will optimize the geometry and configuration to increase sensitivity to thinner CrSBr flakes and lower spin densities. Combining these improved resonators with spatially resolved optical measurements will enable quantitative imaging of microwave-driven magnon dynamics.

References:

- [1] A. Osada, Phys. Rev. Lett. 116, 223601 (2016), DOI 10.1103/PhysRevLett.116.223601.
- [2] D. Lachance-Quirion, Y. Tabuchi, A. Gloppe, K. Usami, Y. Nakamura, Appl. Phys. Express 12, 070101 (2019).
- [3] Y. J. Bae, J. Wang, A. Scheie, J. Xu, D. G. Chica, G. M. Diederich, J. Cenker, M. E. Ziebel, Y. Bai, H. Ren, C. R. Dean, M. Delor, X. Xu, X. Roy, A. D. Kent, X. Zhu, Nature 609, 282 (2022).
- [4] J. Tang, A. Singh, N. J. Brennan, D. G. Chica, Y. Li, X. Roy, F. Rana, Y. J. Bae, Nano Lett. 25, 10912 (2025).