Magnon–Exciton Coupling for Microwave-Optical Transduction

A quantum network must span four to five orders of magnitude in frequency: Superconducting processors operate at gigahertz frequencies, while low-loss fiber communications operate at hundreds of terahertz. Bridging this gap requires coherent microwave-optical transduction.[1] Despite concerted efforts across electro-optic, optomechanical and atomic-ensemble approaches, combining high efficiency and low added noise with broad bandwidth and compact device integration remains a central challenge. Magnons—the collective spin excitations of magnets—offer broadband, magnetically tunable microwave dynamics. Yet their promise for transduction has been constrained by weak, off-resonant magneto-optical interactions. Coupling magnons to the strong excitonic resonances in a semiconductor opens a new route to conversion.

We realized this resonant connection in chromium sulfide bromide (CrSBr), a van der Waals (vdW) antiferromagnetic semiconductor.[2] CrSBr brings microwave-frequency magnons and strong visible and near-infrared excitonic resonances together in a single material.[3] Crucially, the exciton energies depend on the relative spin orientation of adjacent layers. Microwave-driven spin precession periodically changes this alignment, shifting the exciton energy and modulating the optical response. A reflected probe laser therefore acquires sidebands offset from its carrier by the magnon frequency.

We detected the optical sidebands by homodyne interferometry in bulk crystals on a coplanar waveguide at 2 K. The conversion spans a microwave frequency window of approximately 300 MHz without external cavity enhancement. The signal follows the field-tunable magnon resonance and strengthens near excitonic transitions. We also observed magnon-coupled signals at several exciton–polariton resonances—hybrid states of excitons and light confined within the crystal itself.[4,5] The tunable light–matter composition of the polaritons offers a way to balance sensitivity against loss while broadening the optical operating range.

Our analysis reveals a single-particle coupling rate about three orders of magnitude larger than typical magneto-optical values in yttrium iron garnet. This coupling increases as the magnetic mode volume decreases. In the present bulk device, the optical probe samples only a small part of the extended magnetic mode, limiting conversion efficiency. The vdW structure offers a key advantage: Thin flakes can retain their magnetic and excitonic properties while concentrating the interaction into a smaller volume and enabling a smaller footprint. For idealized bilayers, our calculations predict a single-quantum cooperativity of up to 10^{-4} before pump enhancement. Together with microwave and optical resonators, these features make CrSBr a promising platform for efficient quantum transduction.

By establishing a resonant link between magnetic dynamics and semiconductor optics, this work opens a materials route to compact, tunable microwave–optical interfaces. OPN

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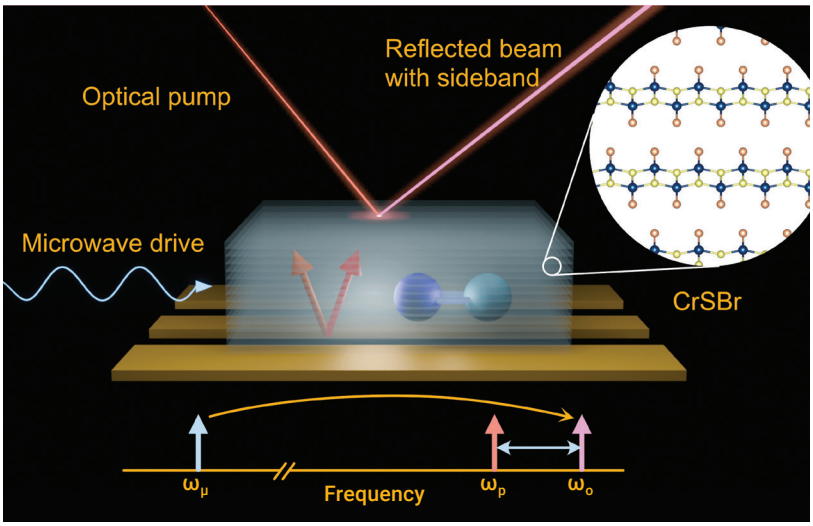
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Microwave-optical conversion in a chromium sulfide bromide (CrSBr) crystal on a coplanar waveguide. Microwave-driven magnons modulate exciton energies, generating an optical sideband offset from the reflected pump by the microwave frequency. Inset: layered crystal structure.