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Optical Widefield Nuclear Magnetic Resonance Microscopy

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Optical nuclear Magnetic Resonance Microscopy (OMRM) bridges the gap between magnetic resonance imaging (MRI) and optical microscopy by using nitrogen-vacancy (NV) centers in diamond to transcode nuclear magnetic resonance (NMR) signals into camera-detectable fluorescence signals [1]. Unlike conventional MRI, which requires magnetic field gradients for spatial encoding, OMRM enables direct, real-space NMR imaging over a wide field of view. In our approach, NV centers are optically initialized and read out, while microwave (MW) pulses control their spin states to couple them to external ^{1}H NMR signals [2]. These signals are excited using radiofrequency (RF) coils and detected via a high-speed camera (Fig. 1 a-c). The system incorporates a custom-designed microfluidic chip [3], integrated MW and RF components [4], and a highly homogeneous permanent magnet (Fig. 1 d). Using this setup and applying the Coherently Averaged Synchronized Readout (CASR) protocol, we achieved widefield imaging of water protons with a spatial resolution of approximately 10 µm across a field of view of ~235 × 150 µm², with each camera pixel capturing multicompnent NMR data (Fig. 1 e-f), allowing the analysis of amplitude, frequency, phase, and linewidth [1]. OMRM combines the strengths of optical imaging with the molecular specificity of NMR spectroscopy, opening new possibilities for a wide range of applications in the physical and life sciences. These applications include imaging metabolic activity in single cells or tissue slices, analyzing battery materials, and facilitating high-throughput NMR analysis.

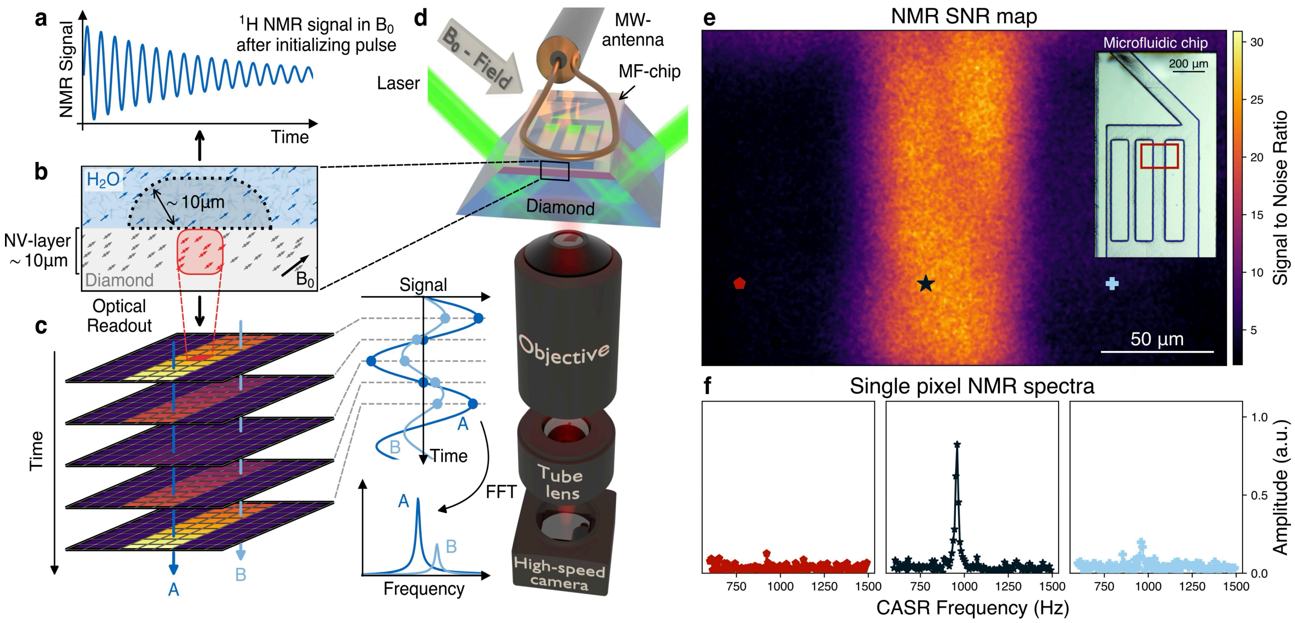

Fig. 1: Nuclear magnetic resonance (NMR) signals (a) are detected optically using a diamond containing a 10 µm layer of nitrogen-vacancy (NV) centers (b). These signals are imaged with a high-speed streaming camera where each pixel time trace corresponds to a location on the diamond and can be fast Fourier transformed (FFT) individually into frequency spectra (c,e,f). The experimental setup consists of the NV diamond, attached to a microfluidic structure, a microwave antenna and an objective with a tube lens to image the fluorescence onto a high-speed streaming camera sensor. The probehead is positioned inside a permanent magnet at ~84 mT (d).

References: [1] Briegel, Nat. Commun. (2025). [2] Degen, Rev. Mod. Phys. (2017). [3] Allert Lab. Chip. (2022). [4] Bucher, Nat Protoc. (2019).