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Publication date
2024

Document Version
Final published version

Published in
Quantum Sensing and Metrology, QSM 2024

Optica Sensing Congress (AIS, LACSEA, Sensors, QSM) © Optica Publishing Group 2024

A Scanning Magnetometer with Nitrogen-Vacancy Spins in a Fiber-Coupled Diamond Nanobeam

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Abstract: We demonstrate scanning nitrogen-vacancy center magnetometry using a tapered diamond nanobeam optically coupled to a tapered optical fiber as the scanning probe, facilitating implementation of NV magnetometry in low-temperature setups and other challenging environments.

1. Introduction

Magnetic imaging with nitrogen-vacancy (NV) centers in diamond is a powerful technique for studying nanoscale physics in condensed-matter materials. In particular, scanning-probe magnetometry based on NV spins in diamond nanotips has provided 2D imaging of spins and currents in materials with spatial resolution down to ~50 nm. However, an important challenge for its application in challenging environments such as millikelvin cryostats is the optical access to the NV spins. The required free-space optical access leads to additional heat load from optical components inside the cryostat, as well as increased complexity of cryostat design.

In this work, we present a fiber-based approach of scanning NV center magnetometry, using a tapered diamond nanobeam optically coupled to a tapered optical fiber as the scanning probe. Such fiber-based NV nanobeam sensors could facilitate implementation in low-temperature setups, opening another possibility for imaging weak magnetic effects at low temperature.

2. Fiber-coupled diamond nanobeams as scanning probes

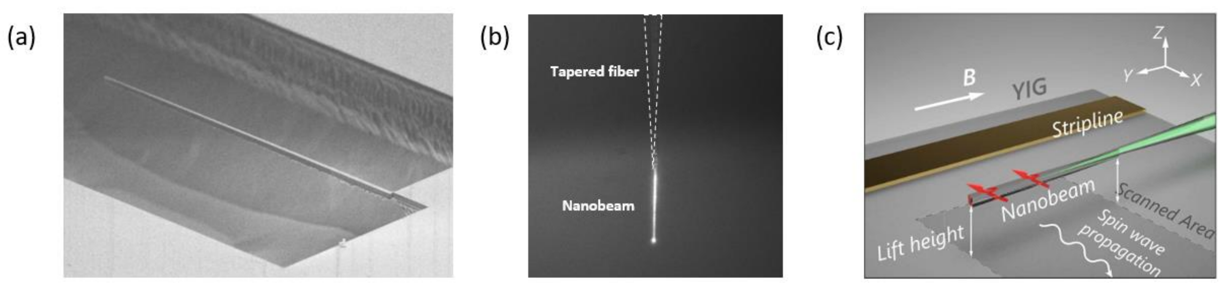

Fig. 1. Fiber-coupled diamond nanobeam probe. (a) SEM image of a 40×0.5×0.5 μm^3 free-hanging diamond nanobeam after quasi-isotropic etching; (b) Microscope images of a fiber-coupled diamond nanobeam under laser excitation through fiber; (c) Schematics of measuring spin waves with the nanobeam probe in 1D [1];

We fabricate the diamond nanobeams out of a single-crystal diamond chip using the quasi-isotropic etching method demonstrated in [2]. After the fabrication process, the nanobeams are free-hanging and are attached to the bulk with a single thin connection point as shown in figure 1(a). To couple the nanobeams to a tapered optical fiber, we push the fiber against the nanobeam using a slip-stick positioner until the connection point breaks and the nanobeam sticks to the fiber, presumably due to van der Waals forces. Figure 1(b) shows microscope images of a fiber-coupled diamond nanobeam. We can then send in excitation and read out the fluorescence of the NV centers through the fiber-nanobeam coupling interface with an estimated efficiency of 8.6(4)% [1]. To demonstrate the magnetic imaging capability, we scan a nanobeam sensor with ensemble NV centers parallel to the surface of a thin film magnet yttrium-iron-garnet (YIG), and imaged in 1D the planar wavefront of propagating spin waves in YIG through the spatial variation of the NV electron-spin resonance (ESR) contrast.

3. Towards fiber-based nanoscale magnetic imaging

With the fiber-coupled diamond nanobeam sensors, we aim to realize 2D magnetic image by scanning with the nanobeam vertical to the sample surface (fig. 2(a)). Therefore it is necessary to place the NV centers only at the end of the diamond nanobeams instead of a homogeneous distribution along the beam. We will discuss the ongoing effort of masked nitrogen implantation for deterministic NV center placement.

A height control mechanism is also crucial in order to scan in close proximity to the sample surface. In existing scanning NV systems, this is usually achieved by integrating the diamond cantilever into a tuning-fork based AFM system, in which the cantilever is glued to a prong of the tuning fork. While for our fiber-based sensor, this is significantly more challenging due to the fragility of the fiber tip combined with the required gluing precision.

To mitigate the challenge, we designed a prototype scan head (fig.2 (b)-(d)) where an integrated micro-positioner brings the tip of the fiber into mechanical contact with a prong of the tuning fork. This way the tip-sample distance can be detected and controlled through the shift in resonance frequency of the tuning fork without the need of gluing, as already demonstrated with scanning SQUID measurements [3].

To further exploit the vector nature of NV center magnetometry, we also incorporate a rotating mount into the scan head, adding a rotational degree of freedom with respect to the fiber axis. This allows us to conveniently align the NV centers to different orientations in space, making our sensor an even more versatile probe that can adapt to samples with different magnetic field profiles. We are now working towards incorporating the scan head into a home-built room temperature AFM system, and making a first proof-of-principle scan with our proposed scheme.

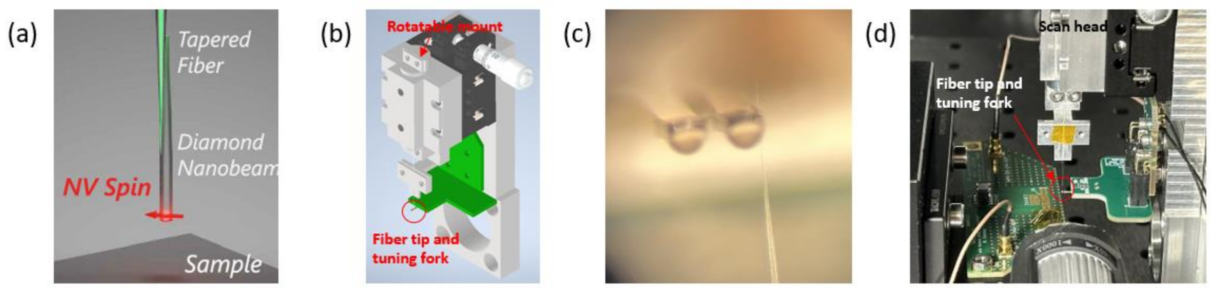

Fig. 2. Prototype scan head design for AFM incorporation. (a) Envisioned scheme for 2D scanning with the nanobeam sensor [1]; (b) Design of the scan head. Red circle indicates the position of the tip and the tuning fork; (c) Microscope image of a tapered fiber in contact with the tuning fork prong; (d) Photo of the scan head mounted in a home-built room-temperature AFM system.

4. References

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