Integration of Nitrogen Vacancy Diamond for Quantum Sensing of Quantum Materials

Luca Basso[1,2], Pauli M. Kehayias[1], Michael Titze[2], Maziar Saleh Ziabari[1,2,3], Jacob Henshaw[1,2], Heejun Byeon[1,2], Deanna M. Campbell[2], Ezra Bussmann[1], Tzu-Ming Lu[1,2], Edward Bielejec[2], Shashank Misra[2], Michael P. Lilly[1,2], Andrew M. Mounce[1,2]

[1]Center for Integrated Nanotechnologies, [2]Sandia National Laboratories, [3]University of New Mexico

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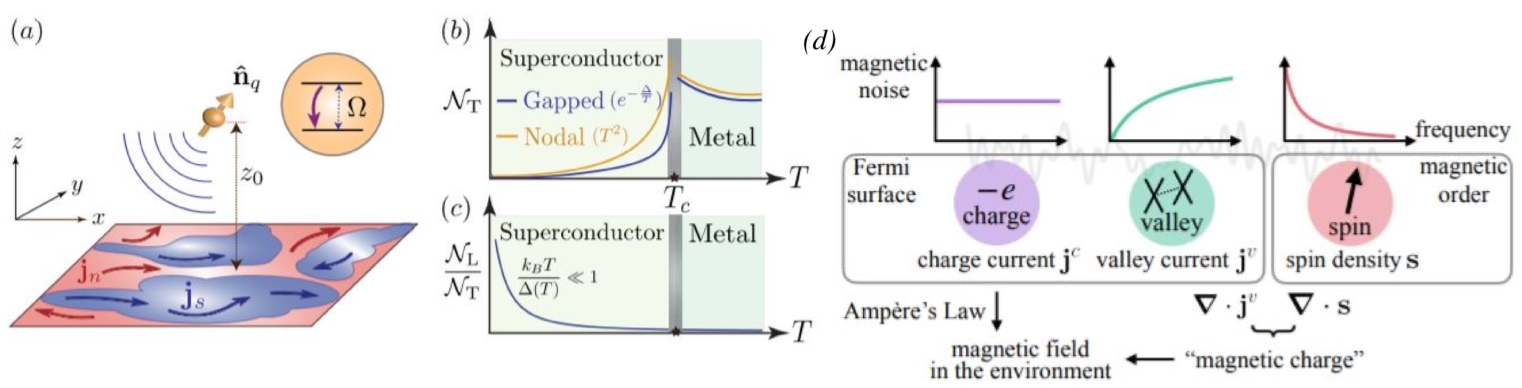
Introduction and Motivation

Nitrogen-vacancy (NV) centers in diamond are a unique tool for imaging magnetic fields in a variety of different samples, from integrated circuits to quantum materials.

With the aim of measuring spin noise of novel electronic phases (Fig. 1), new diamond-sample integration techniques need to be developed, in order to reduce the stand-off distance between the diamond sensor and the material of interest.



(a) Spin noise measurement over a superconductive sample. (b-c) Spin noise spectrum as function of T for a superconductor. (d) Spin noise spectra of different magnetic noise sources on Weyl semimetals. (a-b-c) Chatterjee et al. ArXiv 2021 (d) Zhang et al. ArXiv 2021

Goals:

Develop diamond integration techniques, each appropriate for different length-scales:

1. NV-ensemble in bulk diamond for millimeter field of view.
2. NVs in ~100nm thick diamond membrane to reduce stand-off distance.
3. NVAFM for single NV quantum sensing (~30 nm spatial resolution).

NV ensemble wide-field imaging

- Wide-field NV Magnetometry is non-invasive and provides a large field of view with high resolution.
- Currents flowing in atomic precision advanced manufactured (APAM) wires (Fig. 1) are imaged with NVs in bulk diamond in a wide field microscope (Fig.2).

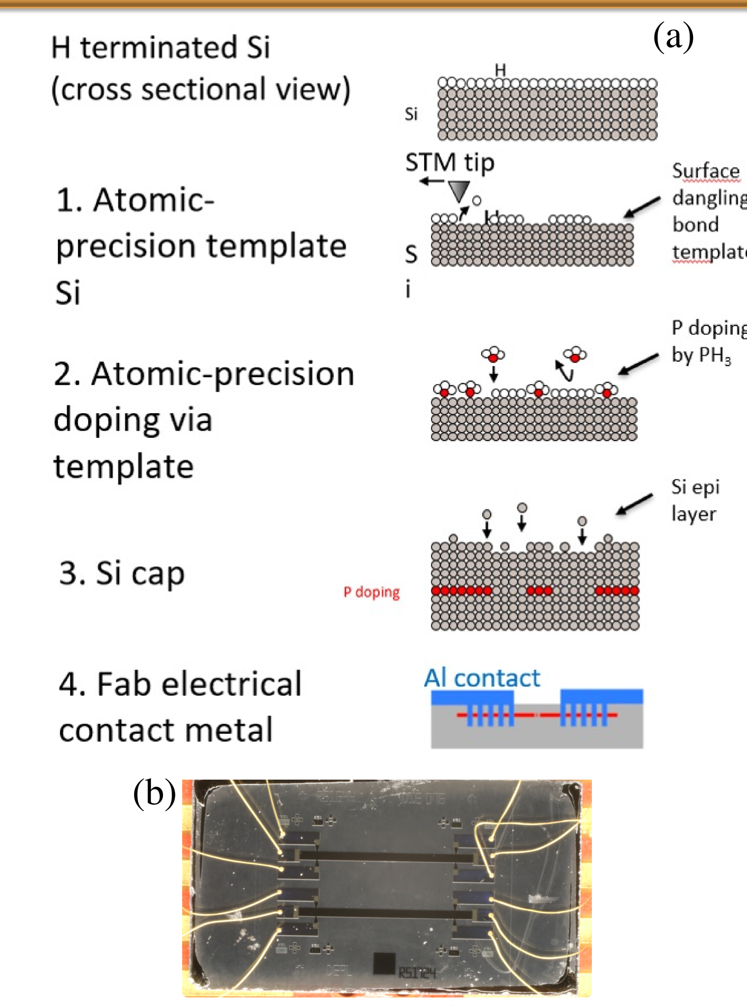


Fig. 1: (a) APAM fabrication process and (b) APAM wires

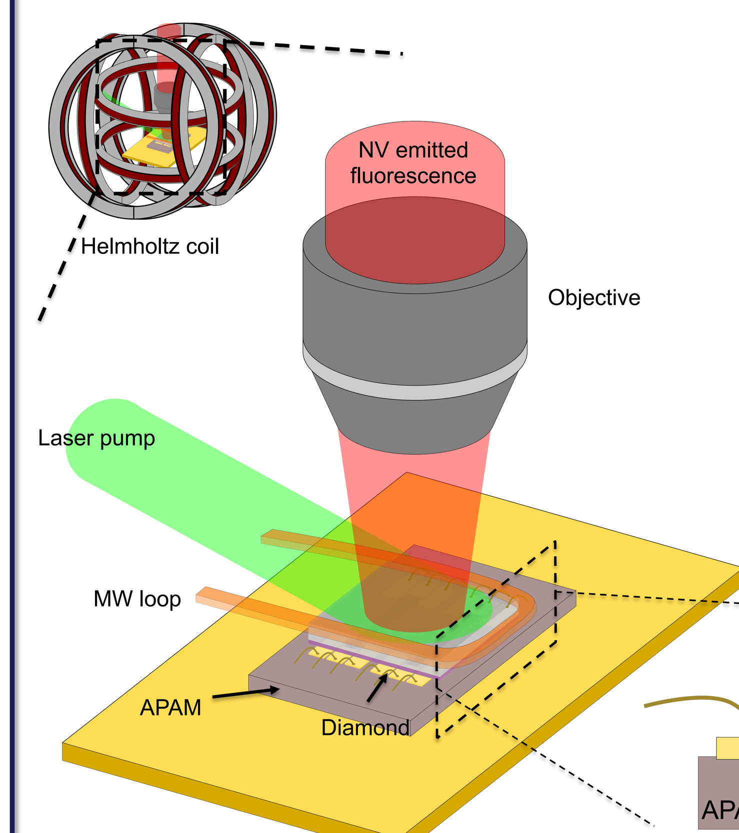


Fig. 2: Wide-field microscope

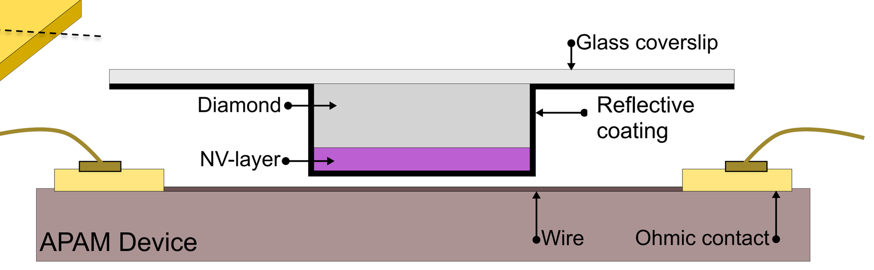
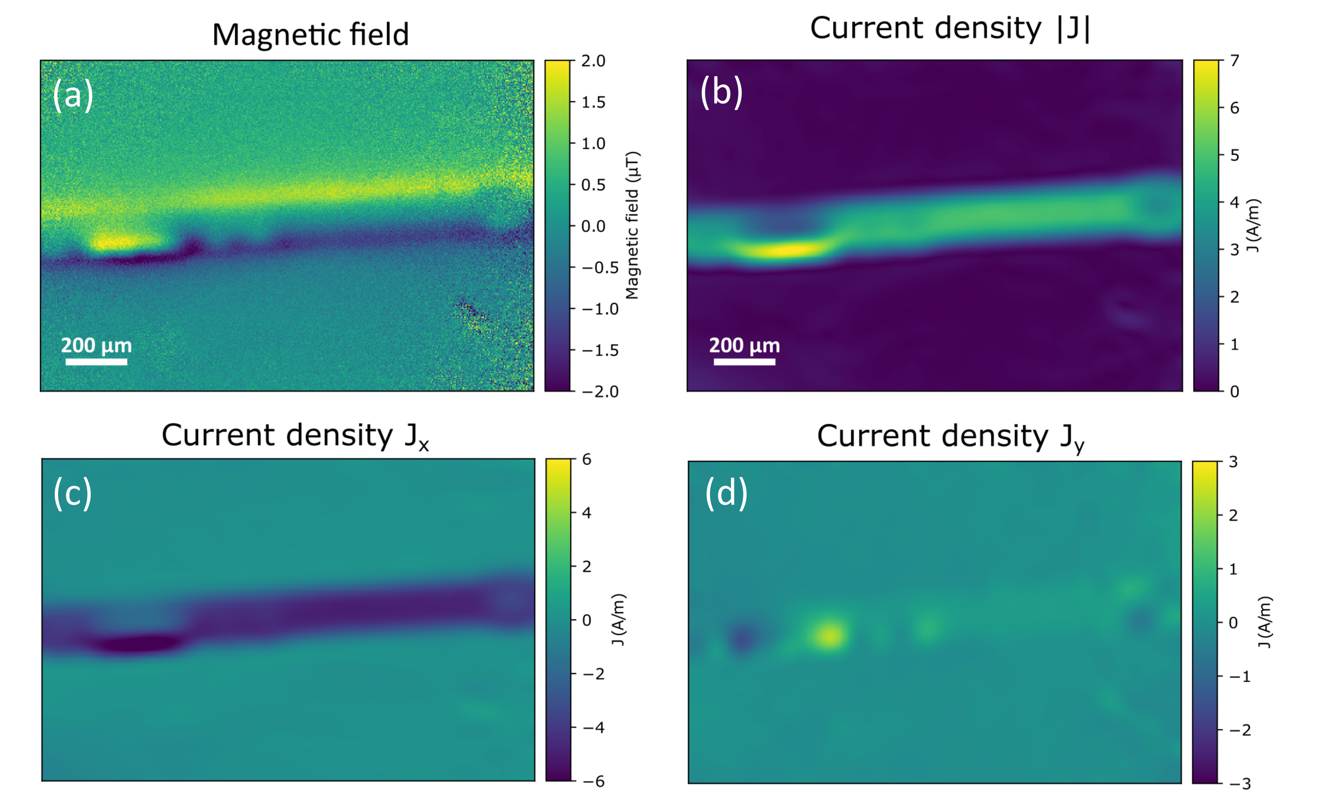


Fig. 3: APAM and diamond integration

Magnetic field imaging

From the NV detected magnetic field map (Fig. 4a), the current density can be reconstructed (Fig. 4b)



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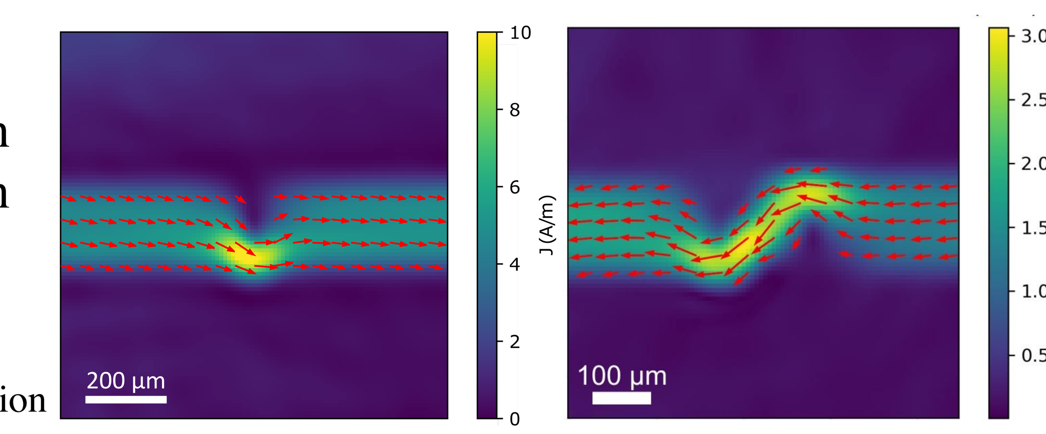
Device failures, such as choke points, can be observed (Fig. 5)



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Diamond membranes - Fabrication

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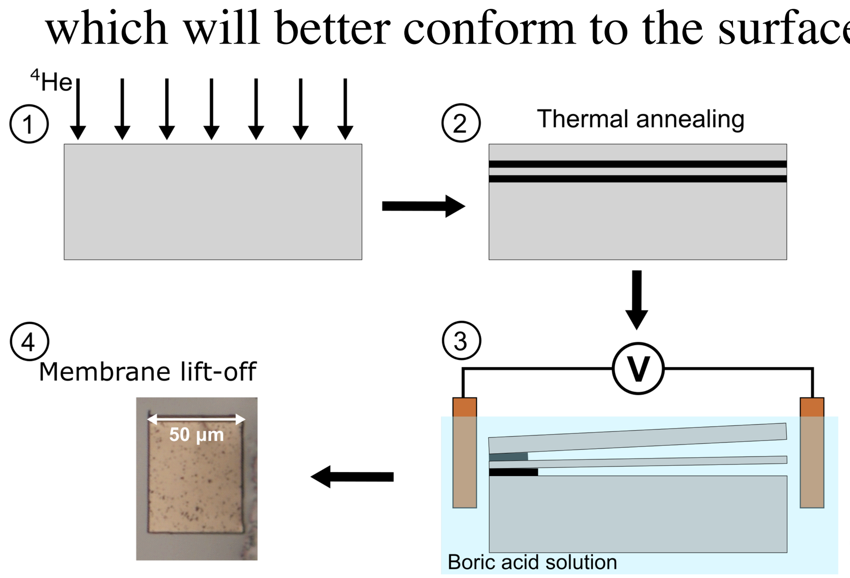
- To solve this problem we fabricate ~100nm diamond membranes, which will better conform to the surface of the sample



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1. High dose double He implant
2. Amorphization of implanted regions: the membrane is the sandwiched diamond layer.
3. Electrochemical etching to remove non diamond phase
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- Moving forward, we will use N δ-doped ^{12}C overgrowth to form a strain-free NV surface with better sensitivity (Fig. 7)

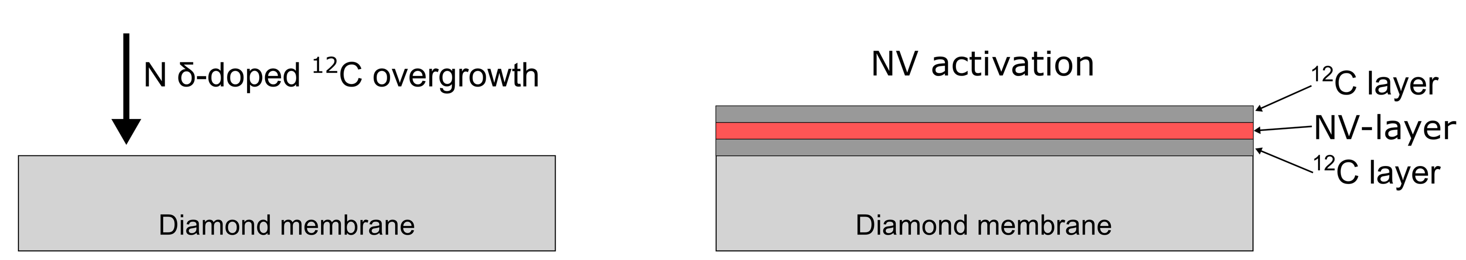

Fig. 7: N δ-doped ^{12}C overgrowth

Diamond membranes

Experimental results Fig. 8: (a) result of He implants. (b) Sample after electrochemical etching. (c) 50 µm FIB-cut membrane lift-off. (d) Resulting membrane thickness

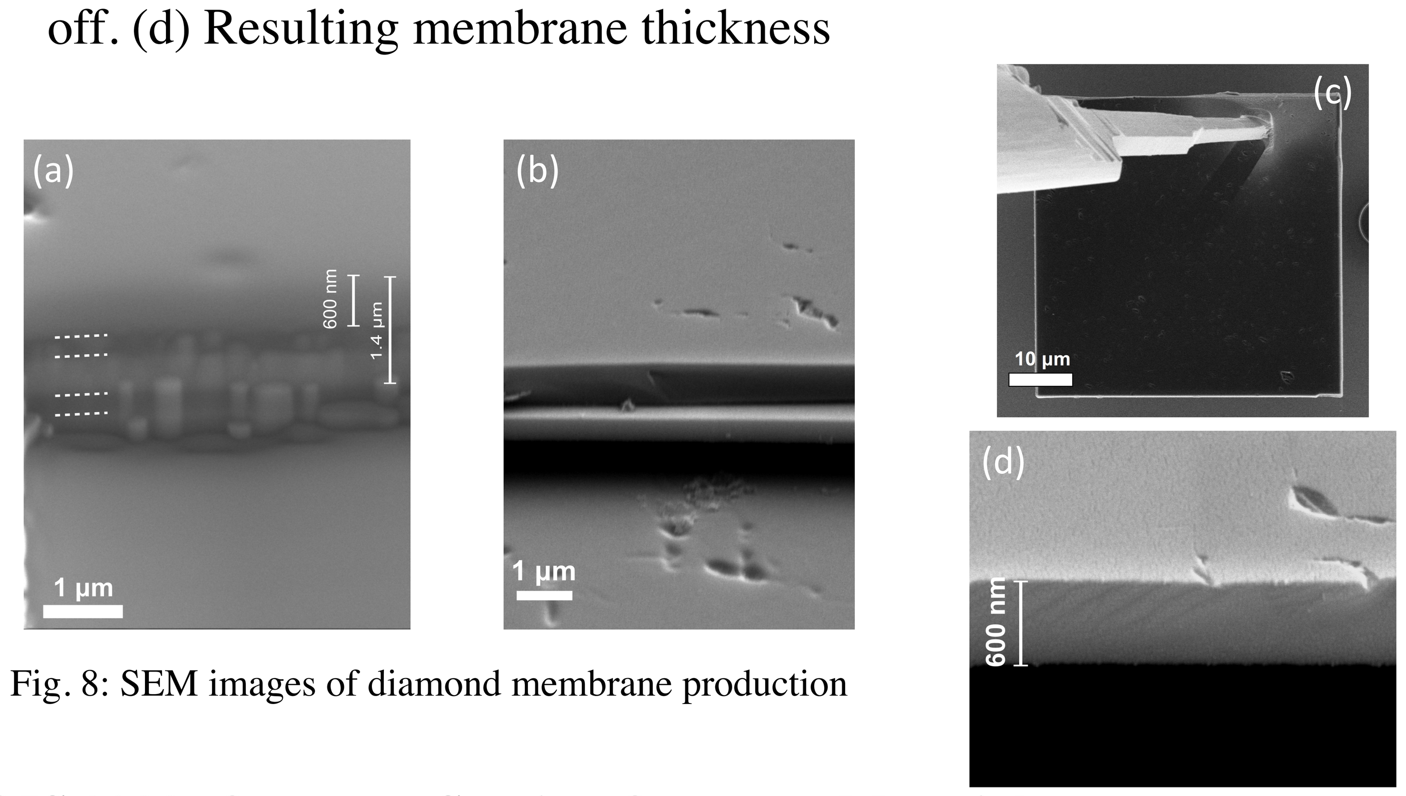

Fig. 8: SEM images of diamond membrane production

QIS 2022: Quantum Sensing Quantum Materials.

New NVAFM capabilities: Probe fabrication, local N implant and NV activation, high magnetic field sensing in RT-100mK temp range.

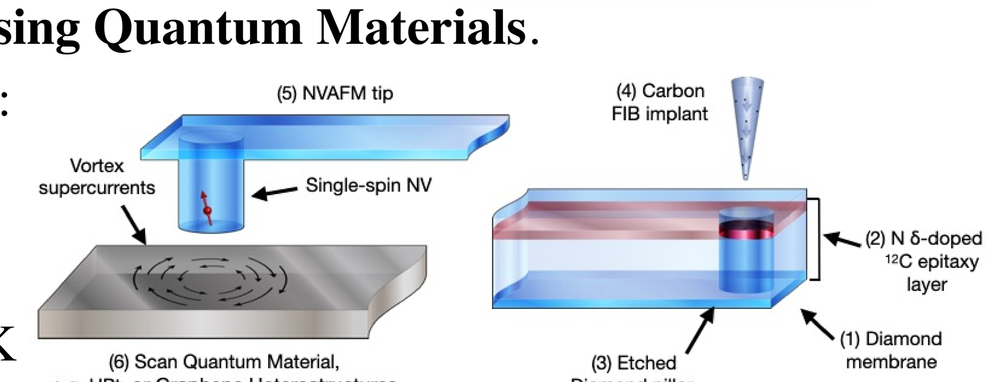

Fig. 9: NVAFM for quantum sensing

Conclusions and outlook

Conclusions:

- NV-ensemble bulk diamond imaging for micron-scale resolution wide-field magnetic sensing, with a diamond integration technique developed in Sandia [1].
- Successful magnetic field imaging of APAM wires and current density reconstruction, allowing detection of manufacturing flaws.
- Development of ~100nm diamond membrane fabrication process.
- Ongoing work to build NVAFM infrastructure and capabilities in the QIS 2022-2024 Quantum sensing in quantum materials project framework.

Outlook:

- Probing magnetic noise generated by a quantum material to reveal information on its excitation dynamics and transport properties.
- Next step: measure spin noise of correlated electronic phases after depositing diamond membranes on quantum materials or through NVAFM.

[1] Kehayias et al. to be submitted

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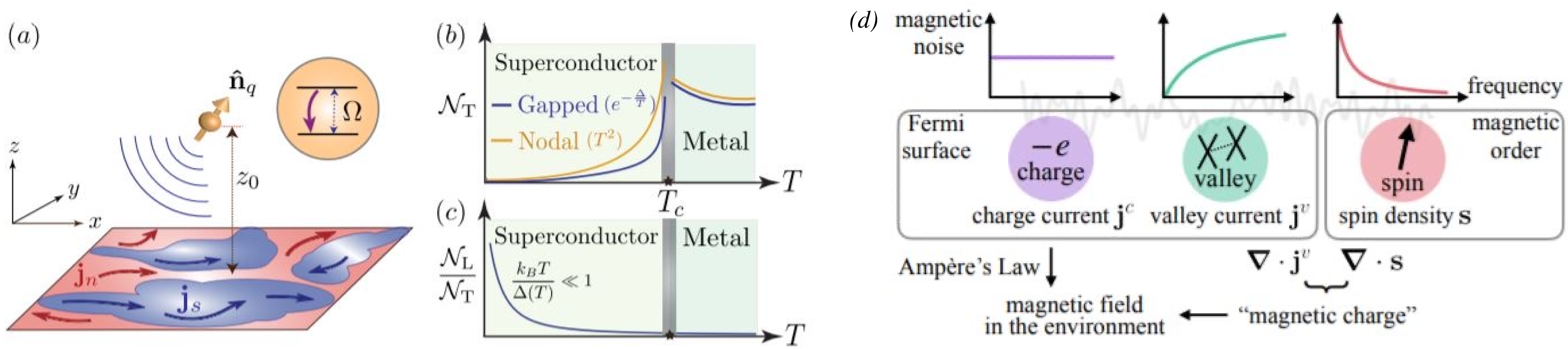

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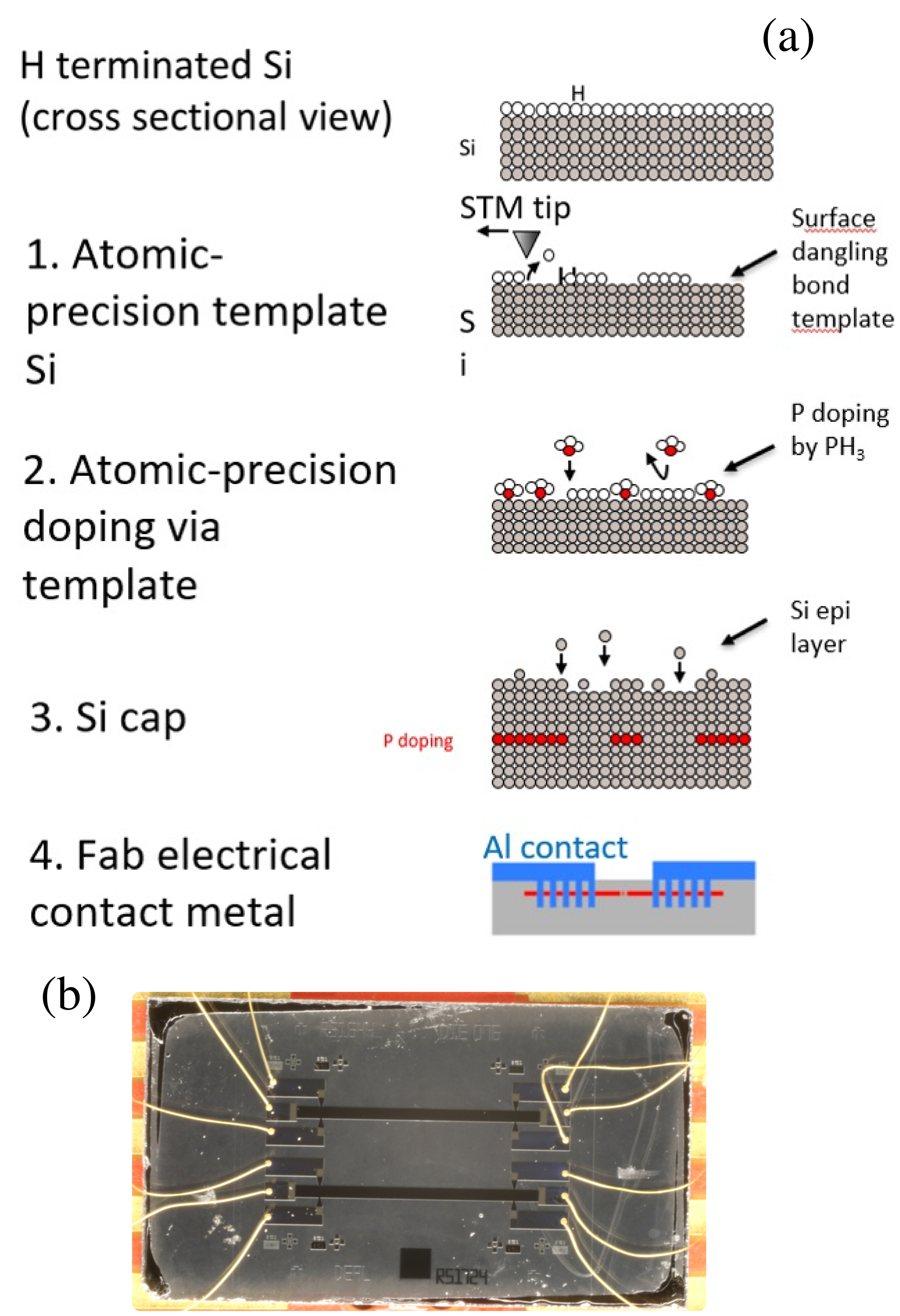

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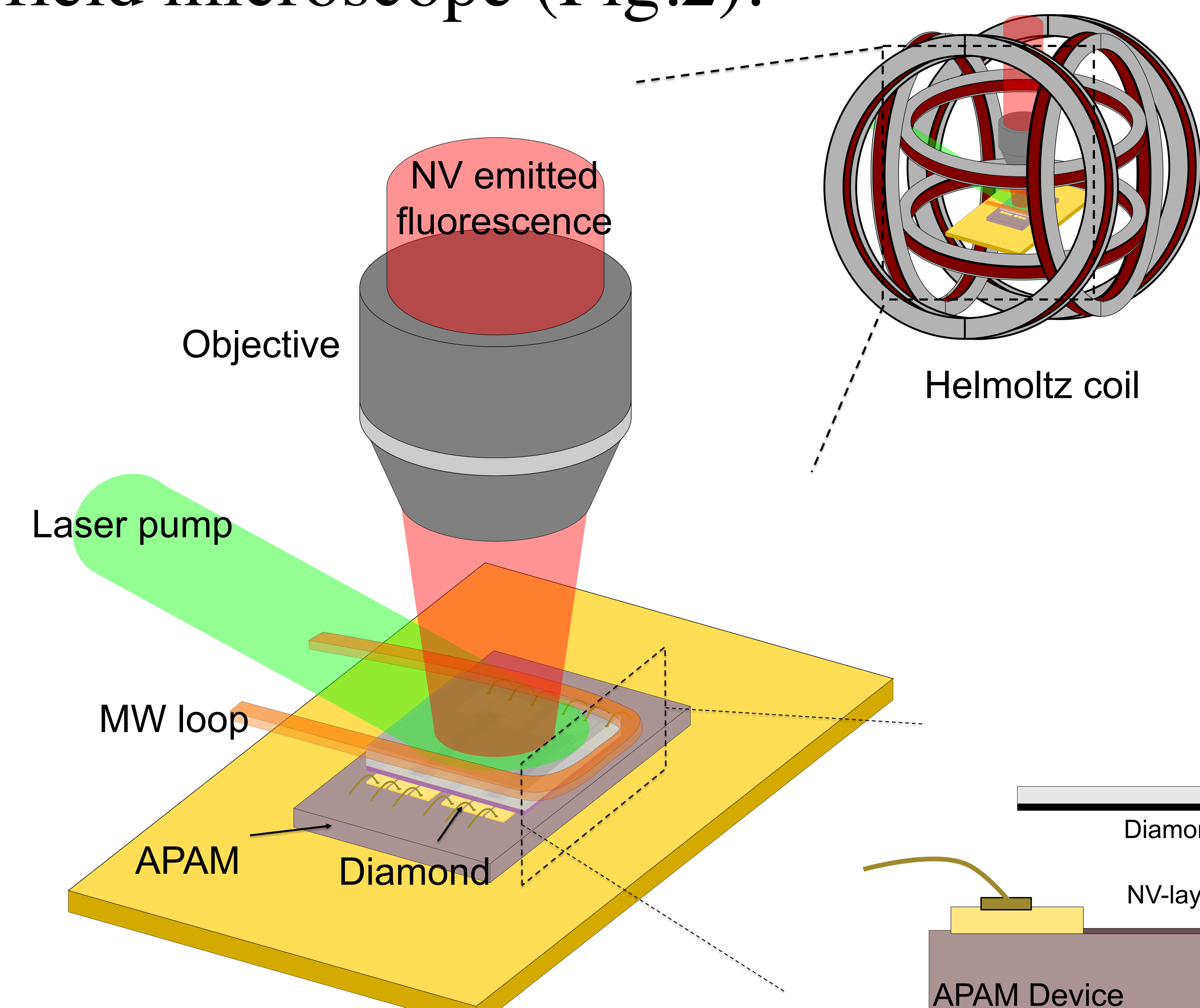

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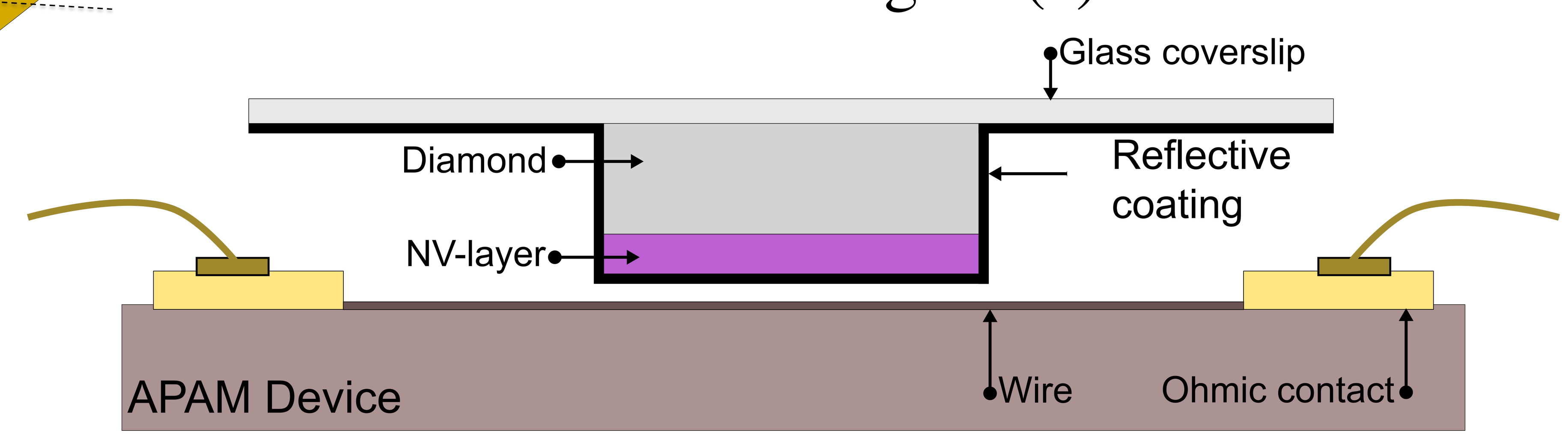

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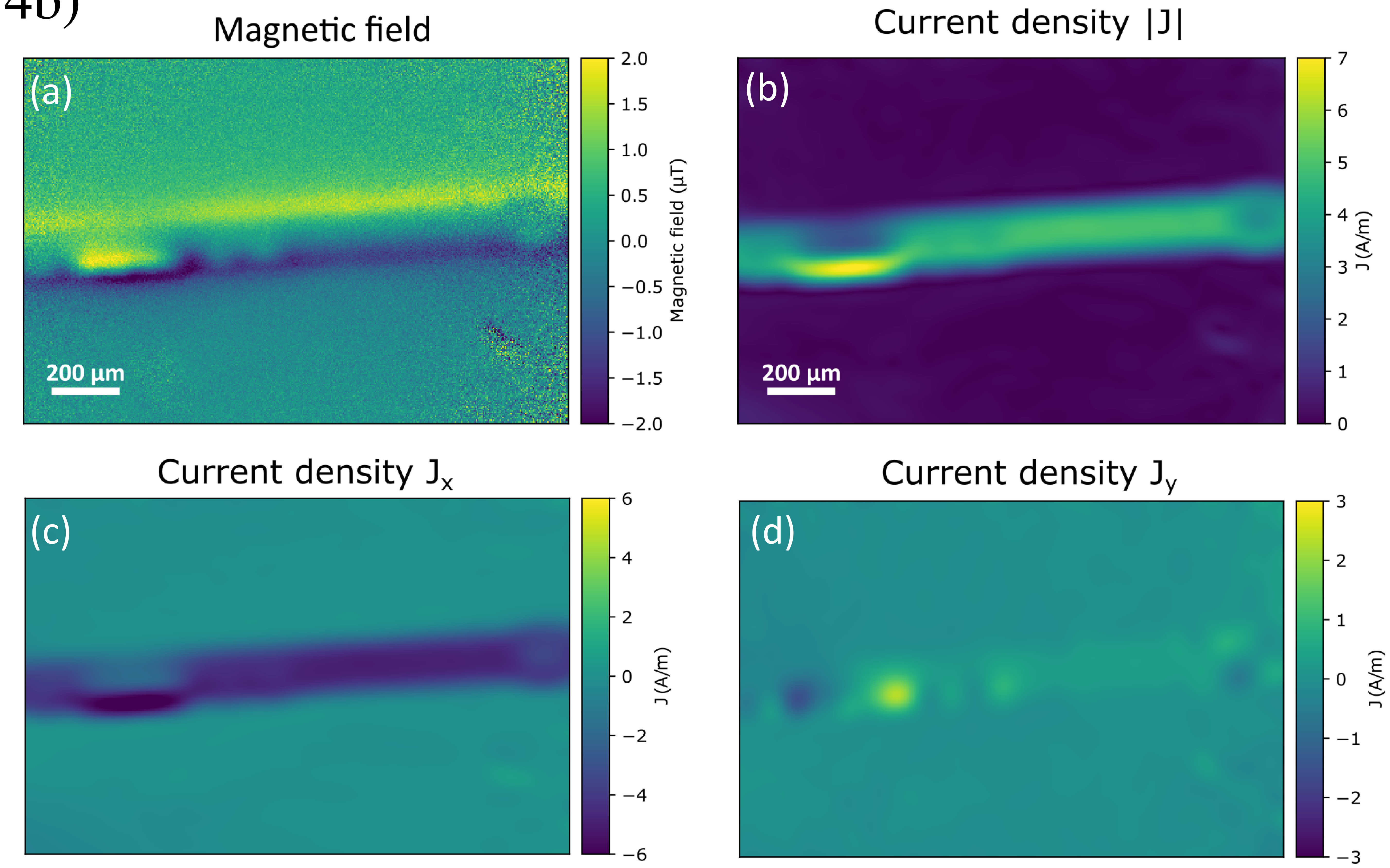

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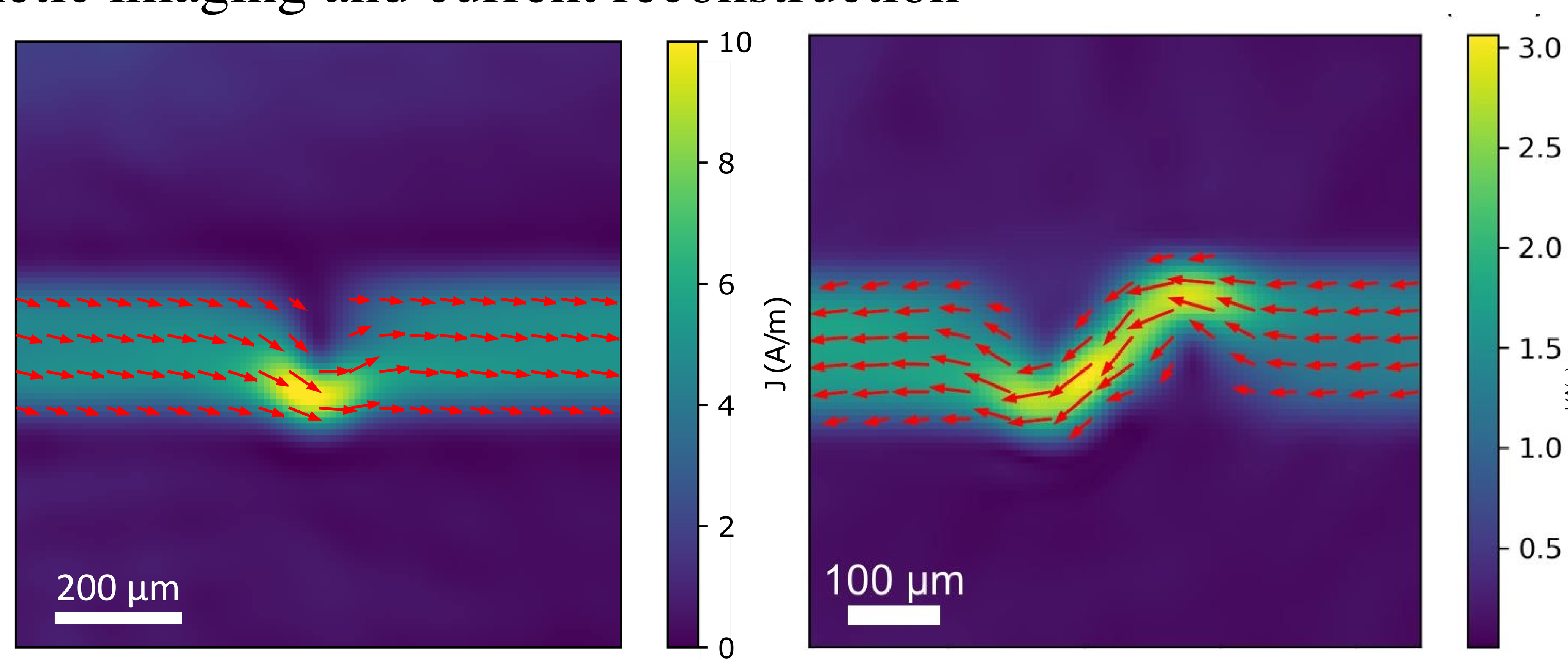

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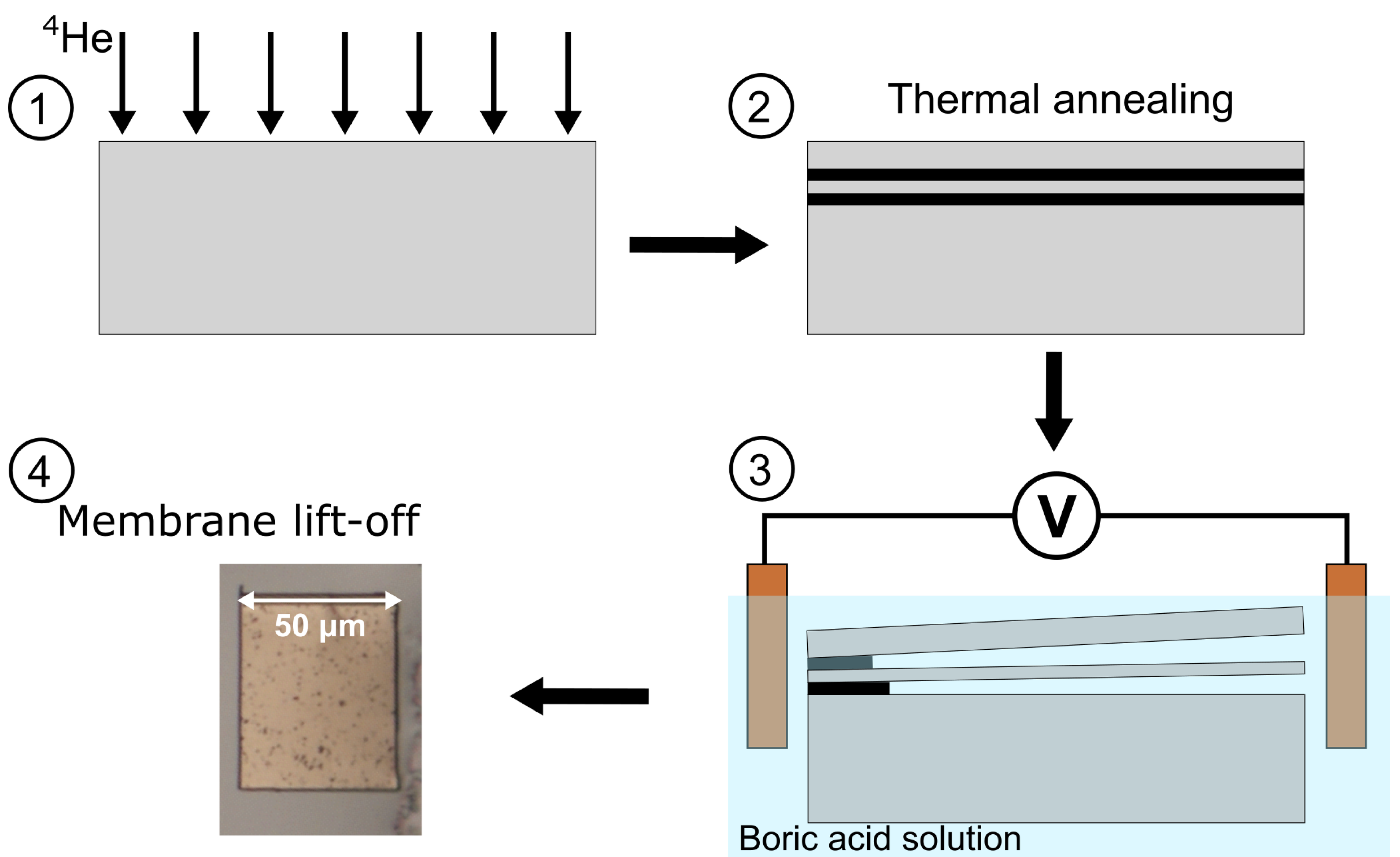

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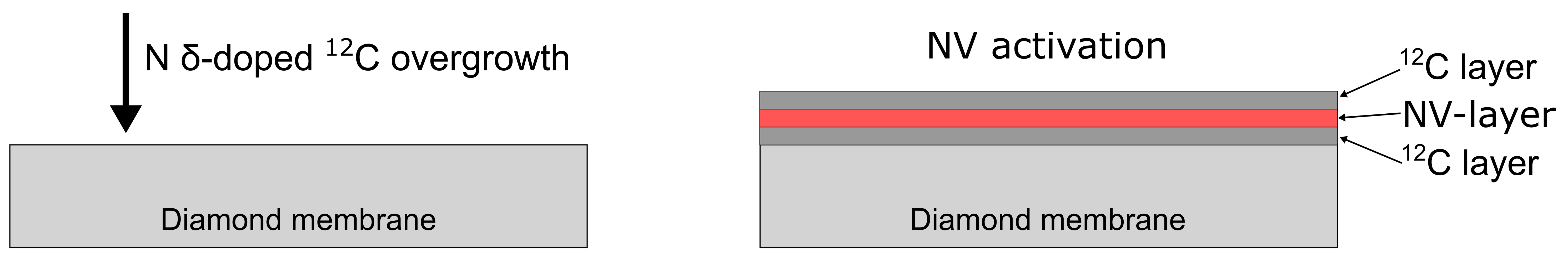

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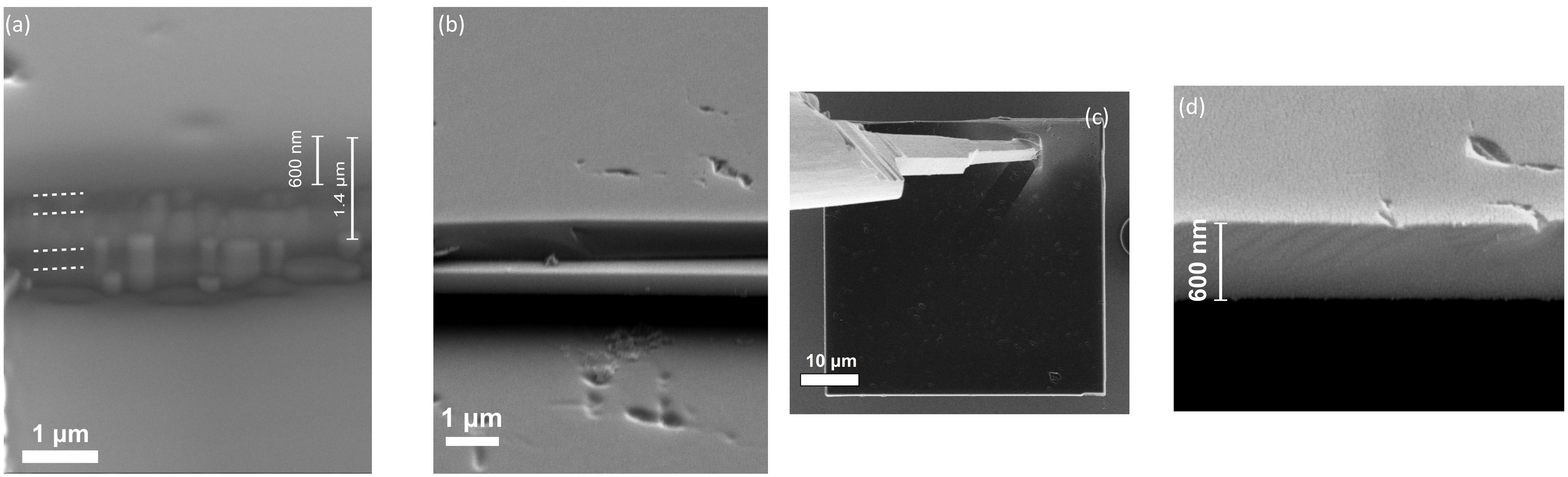

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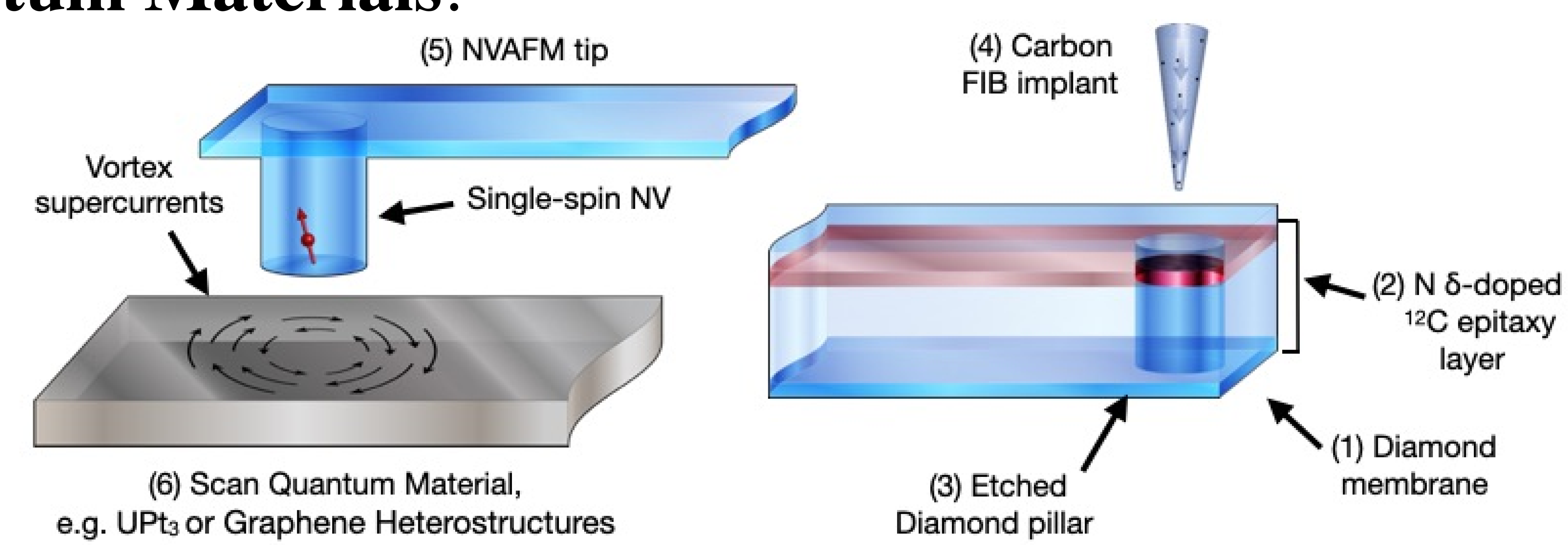

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