Fabrication of Nitride SQUID on Tip Probes by Reactive Magnetron Sputtering

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Miniaturizing superconducting quantum interference devices (SQUIDs) allow for the investigation of the magnetic properties of nanoscale objects with an ultra-high magnetic moment sensitivity capable of detecting a few Bohr magnetrons per unit bandwidth. Significant effort has been dedicated to the development of nano-SQUIDs using planar processes based on electron beam lithography[1] and focused ion beam milling[2]. Recent attention has been focused on novel manufacturing processes using three-dimensional templates suitable for scanning microscope probes (e.g., silicon cantilevers[3] and quartz nano-pipettes[4]).

The three-step self-alignment method is an innovative technology that enables the fabrication of a SQUID on the tip (SOT) of a sharpened glass tube without the need for microfabrication[4]. Single electron spin sensitivity has been achieved with Pb and Sn SOTs[5,6] that have effective diameters of 39-56 nm. Further studies have demonstrated the efficiency of SOTs as highly sensitive thermal probes, with the capacity to detect minute temperature changes as low as several μK[7]. The utilization of SOT as a scanning microscope probe facilitates the visualization of diverse quantum phenomena, including the fundamental process of vortex pinning in superconductors[8]. However, the nanobridges of SOTs made of elemental superconductors (Pb, Sn, In) are susceptible to rapid degradation likely due to oxidation, which complicates their handling.

In this study, we report a method that incorporates reactive DC magnetron sputtering, which enables the deposition of chemically stable nitride superconductors, into the three-step self-aligned deposition process[9]. We have successfully fabricated nitride SOTs for the first time. The NbTiN SOT devices with effective diameter of ø110 nm have superconducting transition temperatures of 13 K, magnetic flux noise down to 0.7 $\Phi\mu_0/\sqrt{\mathrm{Hz}}$ (4 K), and operating temperatures as high as 10 K, which is the highest operating temperature ever recorded for SOTs. The newly developed deposition technique allows for the synthesis of other nitride superconductors with high second critical field/ high critical temperature, thereby expanding the range of materials available for SOTs.

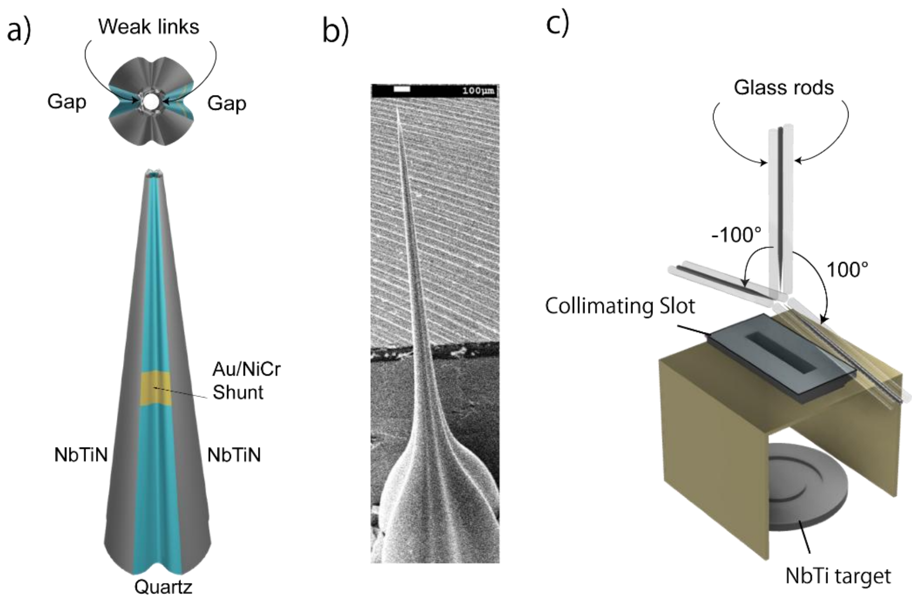

Figure 1 (a) Schematic of a pulled grooved capillary from both the lateral and end views. They show two NbTiN superconducting leads and a NbTiN loop with weak links (nanobridges) at the tip. A strip of Au/NiCr film deposited on a gap is also shown. (b) Scanning electron microscopy image of a NbTiN SOT with an effective diameter of 110 nm. (c) Three deposition steps through a collimating rectangular slot above the sputter target. Glass rods are positioned parallel to each side of the capillary to mask the deposition flux directed to the gaps between the superconducting leads.

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