From Implantation to Disorder: Ion Beam Engineering of Superconducting Quantum Circuits

Ion beams have been central to the scaling of modern semiconductor electronics, enabling precise control of materials and device properties at the nanoscale. Extending these capabilities to superconducting materials offers a direct route to locally engineer device functionality while enabling new pathways for device. Here, we demonstrate ion-beam-driven modification of superconductors in both low-temperature (Nb) and high-temperature (YBCO) systems, using chemical, magnetic, and disorder-based mechanisms to define functional quantum devices within continuous films.

Using a liquid metal alloy ion source (LMAIS), we employ targeted implantation to chemically and magnetically modify superconductors, including Si implantation in Nb and Co implantation in YBCO. Beyond composition-driven suppression of superconductivity, Co implantation introduces local ferromagnetic regions, enabling control of superconducting behavior through proximity and magnetic effects. In parallel, helium ion beams provide a complementary regime in which nanoscale disorder, rather than chemical modification, is used to precisely tune superconducting properties, enabling the definition of Josephson junctions and superconducting quantum interference devices (SQUIDs) with nanometer-scale resolution.

Together, these approaches establish a unified framework in which ion species, dose, and beam conditions act as control parameters spanning chemical, magnetic, and disorder-driven modification regimes across multiple superconducting platforms. This enables a transition from conventional vertically stacked Josephson junctions to laterally defined, in-plane device architectures, reducing footprint constraints and simplifying interconnect routing. These results position ion beams as a scalable, materials-agnostic approach for direct-write engineering of superconducting quantum circuits.