Evidence for Suppressed Superconductivity Across Grain Boundaries in SRF Quality Niobium

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Introduction
Our previous investigations into the influence of the grain boundaries on the DC superconducting properties of high purity Nb for SRF cavity showed that magnetic flux is preferentially admitted to the grain boundary before being admitted into the grain when the GB plane is aligned closely parallel to the external magnetic field vector. It was also shown that topological features produced by surface chemical treatment had only a weak influence on flux penetration. However, although our previous DC $V$-$I$ transport characterizations showed evidence of a transport current perturbation at preferentially etched grain boundaries, the depression of superconducting properties across the GB and the GB angular dependency were not quantified. A major driver for this work is the desire to obtain the departing critical current density for cavity-quality Nb.

Experimental
We measured the DC $V$-$I$ characteristics by transport current for a variety of surface treated Nb bi-crystals and examined the GB angular dependence by varying the angle between the GB plane and $H_{\text{ext}}$. We wanted to find evidence for Abrikosov-Josephson vortices in the GB since this would enable a calculation of the depairing critical current density [1], which is the property that controls the magnitude of the superconducting RF current circulating in a Nb SRF cavity.

Results and Discussion
Fig a. shows the $V$-$J$ response from BCP’ed bi-crystal. The curves obtained from 0.05T to 0.25T indicate that vortices are more weakly pinned at the GB than the grain and that there is preferential flux flow along the grain boundary, as shown by the quasi-ohmic behaviors in the inset of Fig a. This linear tendency occurred for a smooth-polished bi-crystal, but was not found in an artificially grooved single crystal for which the groove was made to simulate a plane with lowered $I_c$. Fig. b shows the field-dependent GB resistance deduced from Fig a. The solid orange curve extracted from the $V$-$I$ response of the inset of Fig a) indicates that a single vortex row with a width of 185nm begins to flow at $H = 0.08$ T, then above $H = 0.2$ T this single row drags the two neighboring vortices found on either side of the GB. The GB angular dependency determined by transport currents is demonstrated in Fig. c. The angle between the GB plane and the vector of $H_{\text{ext}}$ is $0^\circ$, $30^\circ$ or $60^\circ$, as indicated. When we strongly misalign the GB plane with $H_{\text{ext}}$, the pronounced GB resistance found at $0^\circ$ almost disappears.

Conclusions
Our data indicate that pinning of vortices along the GB is weaker than pinning of vortices in the grain, which may indicate suppressed superfluid density at the GB, which can contribute to enhanced rf losses in hotspots on the surface of Nb cavities. Consistent with the previous results from MO imaging, the $V$-$I$ characterizations show that the grain boundary weakness is greatly enhanced when the plane of the GB is parallel to the $H_{\text{ext}}$ vector.

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References