Barrier Reduction and Sub-gap Leakage in Niobium Based SIS Junctions

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Superconductor-insulator-superconductor (SIS) tunnel junctions based on Nb/Al-AlO$_x$/Nb tri-layers (TL) [1] are the standard technology in superconducting electronics. This is owed to the development of a reliable fabrication process that produces junctions with current densities up to j_c = 10 – 15 kA/cm^2 and low sub-gap leakage. Nb/Al-AlN$_x$/Nb TLs offer to make junctions with current densities as high as j_c ~ 70 kA/cm^2 while maintaining low sub-gap leakage [2] but its use has not yet become wide spread. The deposition process for both TLs follows the same approach, with one of the merits being that a high quality insulator can be formed on the thin Al film that covers the Nb base electrode. Junctions made with either barrier type exhibit qualitatively the same behavior: Sub-gap leakage increases with current density. This is commonly seen as a signature of non-uniformity as the barrier`s average thickness decreases.

Since the invention of Nb SIS junction technology in the early 1980s, it has been known that TLs with a second thin Al film near the barrier, e.g. Nb/Al-AlO$_x$/Al/Nb, thus making it a symmetric layer stack, produces junctions with higher resistance *and* lower subgap leakage [1]. Obtained with relatively low current density TLs, j_c ~ 1 kA/cm^2, the results are attributed to the protective function of the Al layer, preventing a chemical reaction between niobium counter electrode (CE) and barrier. This poses the general question whether barrier reduction due to interface chemistry and junction quality are correlated and more specifically whether the choice of a single Nb layer as the CE limits the possibility to realize high quality junctions with current densities j_c > 10 kA/cm^2.

A systematic study to address this issue is ongoing and to that end, we have fabricated junctions based on SIS TLs with Nb/Al base electrodes, AlN$_x$ barriers formed by nitridation, and *three different* CEs: single layer Nb, bilayer Al/Nb, and single layer NbN [3]. Plasma conditions during the nitridation process are identical and time t is varied to realize a range of barrier transparencies. Preliminary results confirm observations made in [1]: A Nb CE appears to reduce the AlN$_x$ barrier resulting in substantially higher current densities than Al/Nb or NbN CEs, see Fig. 1. As for the subgap leakage levels, our results also confirm the general trend of increased sub-gap leakage towards higher current densities. However, a direct comparison between junctions with different CEs is meaningful only if their current densities are similar. To complete the set of data, the next step is to grow asymmetric Nb/Al-AlN$_x$/Nb TLs using longer nitridation times that yield current densities in the regime j_c = 20 – 50 kA/cm^2. Samples based on asymmetric Nb/Al-AlO$_x$/Nb and symmetric Nb/Al-AlO$_x$/Al/Nb TLs are also in preparation. We believe that this study sheds light on the impact the CE material has on barrier performance, especially in high transparency TLs.

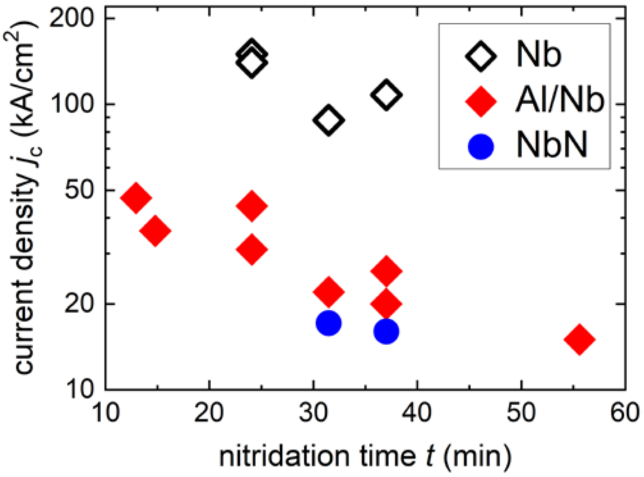

Fig. 1. Current density j_c vs. nitridation time t for AlN$_x$ barrier based TLs with identical base electrode Nb/Al but different counter electrodes (CE). For the same nitridation time a Nb CE (◇) yields a much higher j_c compared to Al/Nb (◆) or NbN (●) CEs.

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References

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