Aluminum metallization of III-V semiconductors for the study of proximity superconductivity

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Reactivity issues and the required mitigating growth conditions encumber molecular beam epitaxy of precise superconductor/semiconductor interfaces. In this work we study metallurgical transitions between Al and various III-As(Sb) binary and ternary semiconductors. To minimize reactivity, we deposit Al at slow growth rates onto cold (less than 0 °C) substrates. Since the interface's crystallinity affects the electronic/optical properties (i.e. Schottky barrier heights [1], etc.), we conduct extensive structural characterization studies with transmission electron microscopy (examples shown in Figure 1). The close proximity of the superconductor may negatively affect the neighboring semiconductor [2], compelling the use of very thin intermediate layers. Certain intermediate layers have a secondary desirous effect of preventing the Al metal layer from interacting with the underlying semiconductor [3], and may control electrostatic potentials and local carrier densities.

Our primary semiconductor of interest is InAsSb. Over recent years, we demonstrated unstrained, unrelaxed InAsSb grown on virtual substrates and metamorphic buffer layers [4-5]. For compositions near 50%, InAsSb exhibits a very strong g-factor [6]. In hybrid InAsSb-Al structures, we observed superconducting proximity effect in InAsSb films where the product of supercurrent and normal resistance reaches the Al superconducting gap, as expected from theory. In this paper, we discuss the tradeoffs between different Al deposition conditions and the selection and optimization of intermediate layers.

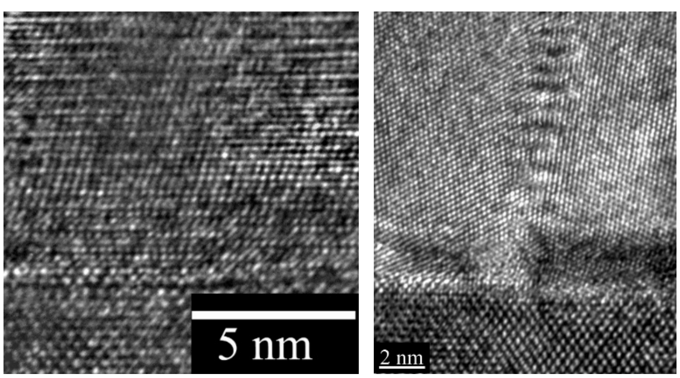

Figure 1. (left) Interface between AlSb intermediate layer and Al. (right) Interface between InAsSb and Al with no intermediate layer.

[1] R. Tung, et al, Appl. Phys Rev **1**, 011304 (2014).
[2] W. Cole, et al, Phys. Rev. B **92**,174511 (2015).
[3] W.L. Sarney, et al, J Vac Sci & Technol B **36**, 062903 (2018).
[4] G. Belenky, et al, Proc. SPIE 8012, 80120W (2011).
[5] W.L. Sarney, et al, J. Vac. Sci. Technol. B **30**, 02B109 (2012).
[6] M. Hatefipour, et al, Bulletin of the American Physical Society, (2019).

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Supplementary Pages

Examples of recent data from this study are included below.

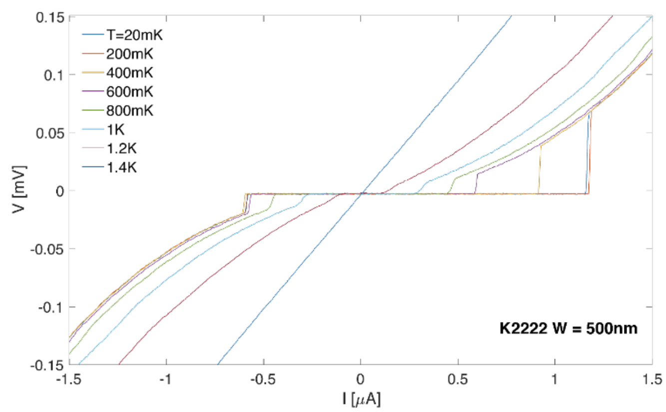

Figure S1. The current-voltage characteristics of Josephson junctions fabricated on our Al-InAsSb materials shows supercurrent. The temperature dependence of the supercurrent suggests high interface contact transparency.

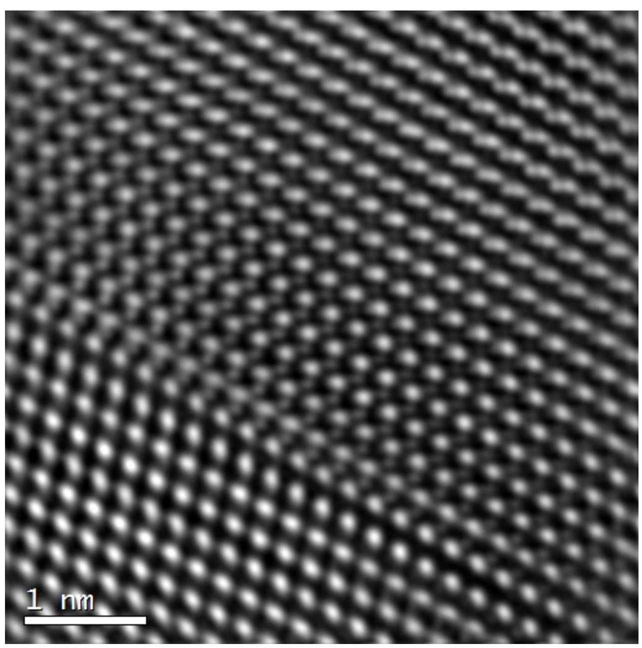

Figure S2. TEM image of twinned Al film grown on InAsSb.

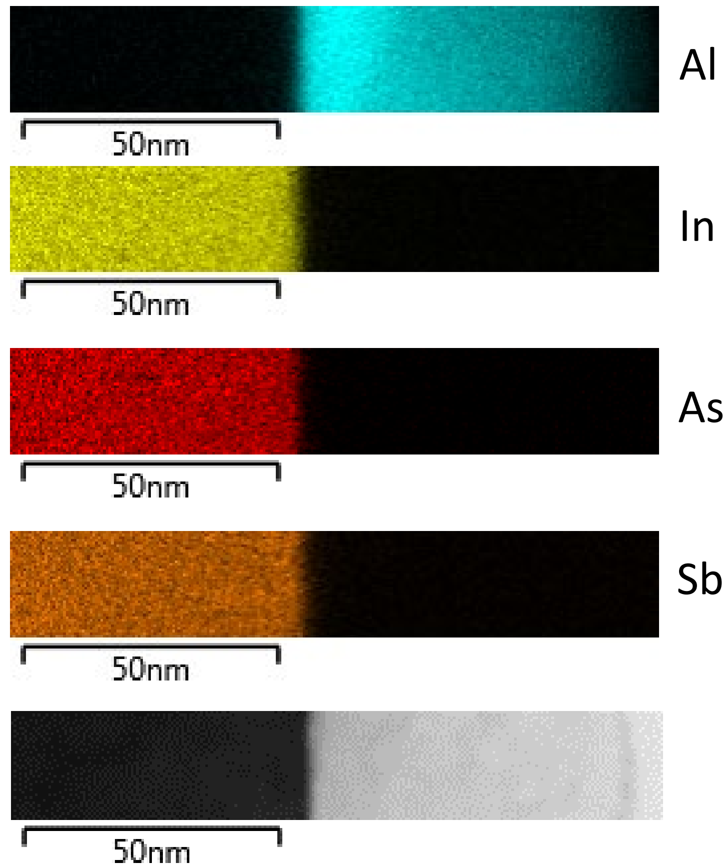

Figure S3 Energy-dispersive spectroscopy map of Al – InAsSb interface.