Atomic Layer Etching for Etching, Smoothing, and Precise Thinning of High Temperature/Large Gap Superconductors

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Program: Spontaneous Concept

Project Objective:

Atomic Layer Etch (ALE) is a novel semiconductor etching process that is beginning to become widely utilized in the semiconductor industry. In semiconductor processing, ALE is highly favored because it results in extremely smooth nano- and microscale features as compared to conventional etching techniques. JPL/MDL recently invested in an research etching tool that is capable of ALE.

Through our investigations, we have found that, in addition to producing smooth surfaces at the end of an etch, MDL's ALE processes are capable of smoothing previously rough surfaces that we produced by more conventional etching and deposition steps. Thus, this spontaneous concept was tasked with developing ALE processes for YBCO and MgB2 that display precise, carefully controlled, highly uniform etch rates that smooth the YBCO or MgB2 material and greatly improves the selectivity to masks. Those materials were chosen because there is no good conventional etching process available and therefore, an ALE smooth etch for them would be a home run. Through the RTD work, other materials and films were investigated as well, and all were observed to benefit from ALE.

FY18/19 Results:

Developed and demonstrated several ALD processes that smooth a wide variety of surfaces including

- Yttrium Barium Copper Oxide
- Silicon Dioxide
- Amorphous silicon
- Indium Phosphide (Funded under a different task. Included for informational purposes)

Developed and demonstrated a precise process for thinning superconducting materials

- Tungsten Silicide

It is noted that, in the available time on the system, an ALE process for etching MgB2 was not able to be developed. The ALE system was mechanically down for more than a month due to a power supply issue. The vendor ultimately corrected the problem.

Benefits to NASA and JPL (or significance of results):

Recent developments in thin film technology, fabrication techniques, and device innovation have led to a resurgence of potential applications for high temperature/large gap superconductors like YBCO (T_c ~ 90 K) and MgB_2 (T_c ~ 40 K). For example, thin film developments with MgB_2 have been used to create THz mixers with an IF bandwidth 3 times larger than state-of-the-art. Further advancements in these films (namely the maximum area and average roughness) should lead to single photon detectors operating at 20 K, enabling ground-to-space optical communications. Fabrication techniques using YBCO have enabled state-of-the-art direct detectors in Kinetic Inductance Bolometers by making membrane-isolated superconducting inductors. The utilization of the He^+ Focus Ion Beam has enabled nano-scale features in YBCO thin films without degradation of superconducting properties. This includes direct-writing of Josephson Junction barriers for a plethora of electronics applications (detectors, amplifiers, etc.) One obstacle to furthering the usefulness of these materials and advancing the TRL of existing technologies lies in the etching of the films during processing. The high deposition temperature of the materials means that a lift-off technique cannot be used to pattern the films, and direct etching of either material can only be done ballistically with Ar ions. This method has poor selectivity with photoresists and even hard masks (e.g. SiN) and even has the potential to burn the mask, irreversibly damaging the sample. It is also extremely sensitive to fluctuations in the system parameters leading to poor process reproducibility. Some potential etch chemistries have been identified for each of these material systems, however, a significant effort is required to scrutinize the efficacy of these processes. Synergistically, the Microdevices lab at JPL has just invested in an Atomic Layer Etch system which is an ideal system to develop new etch processes in these novel materials. Additionally, the conformal etching of a single atomic layer at a time has significant potential to smooth the surface of these films. This Atomic Layer Etch system is state of the art and is one of only a few systems in the entire world. This cutting edge technology has the potential of unlocking the true potential of these High Temperature/Large Gap Superconductors through better process control and film morphology.

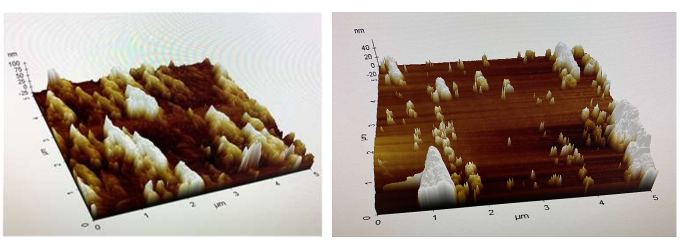

Fig. 1: Post growth smoothing of YBCO surfaces using atomic layer etching. Sample at left is the surface after a gold capping layer is sputtered away. Image at right is the same surface after the ALE process is applied.

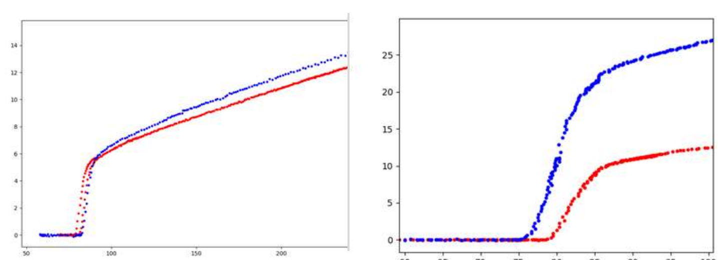

Fig. 2: Superconducting transition temperature measurements of YBCO samples with and without atomic layer etching based smoothing process. Graph at left shows YBCO without ALE smoothing. Graph at right shows the behavior after the ALE process is applied. A small reduction in transition temperature is observed, but is still acceptable for devices, especially in light of the tremendous control of the etch rate that is achievable by ALE.

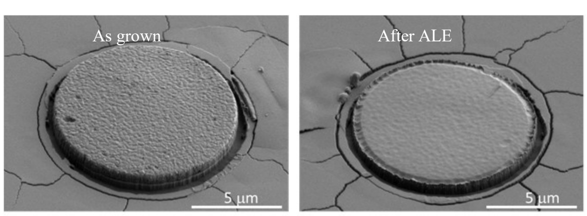

Fig. 3: Post growth smoothing of InP surfaces using atomic layer etching - Provided for information only. This work was funded under a separate task.

Publications:

N/A

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