

## Surface Study of Aluminum Films Grown by Atomic Layer Deposition for Superconducting Tunnel Junction

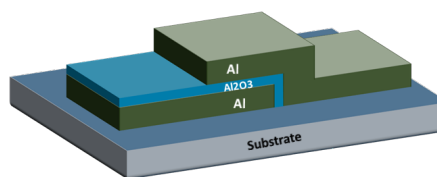
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### Abstract

The Technology of atomic layer deposition (ALD) can deposit an ultra-thin layer of different metals and metals oxide down to monolayer depending on the number of cycles at a relatively lower temperature. It is a promising technique to replace some current techniques such as shadow evaporation which is used in a small Josephson junction (J.J.) fabrication. J.J. is composed of a very thin tunnel barrier (~2nm) sandwiched by superconducting electrodes with a standard junction size of 100 x 100 nm<sup>2</sup> such as Al/Al<sub>2</sub>O<sub>3</sub>/Al. The shadow evaporation technique with a suspended bridge is a standard method used for fabricating small Josephson junctions. Although it is well known, however, it has many disadvantages, such as the complexity of scaling up many junctions and limiting circuit layouts. Our work is to deposit aluminum thin film using ALD by the precursor of dimethylethylamine alane (DMEAA) for the fabrication of small Josephson junctions. Scanning electron microscope (SEM) was used to characterizes the surface morphology and thickness of the aluminum film, while X-rays diffraction (XRD) explored its contamination and crystal orientation. The results study showed the aluminum grains morphology, pure aluminum thin film success deposition, and alane thin film deposition along with aluminum.



**Figure 1.** A schematic view of Josephson tunnel junction structure.

### 1. Introduction

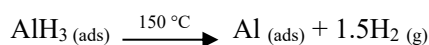
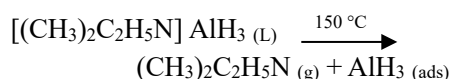
The atomic layer deposition (ALD) technique can deposit a conformal single layer on each growth cycle at a rather low temperature and also give a sharp interface between different materials.<sup>1</sup> This feature of the ALD technique is very promising to fabricate a small Josephson junction which is composed of a very thin tunnel barrier (~2nm) sandwiched by superconducting electrodes with a typical junction size of 100 x 100 nm<sup>2</sup>, such as aluminum/aluminum oxide Al/Al<sub>2</sub>O<sub>3</sub>/Al.<sup>2,3</sup> The shadow evaporation technique with a suspended bridge is commonly used fabricating small Josephson junctions as the standard.<sup>4,5,6</sup> This technique is well established, however, it has several drawbacks, such as difficulty to scale up to several junctions and restrictions of

circuit layouts.

We propose an ALD technique to use for the fabrication of small Josephson junctions. Al<sub>2</sub>O<sub>3</sub> thin films are commonly grown by ALD, but so far few reports exist for the growth of aluminum thin films by ALD. In this study, we grew aluminum thin films by the precursor of dimethylethylamine alane (DMEAA) and studied its surface morphology as the first step of the fabrication of small Josephson junctions.

### 2. Experimental and characterization

Di-Methyl-EthylAmine-Alane (DMEAA)<sup>7</sup> precursor is selected among other precursors, such as TMA1 and DMAH8. DMEAA has several advantages. One of those is a low decomposition temperature as follows:



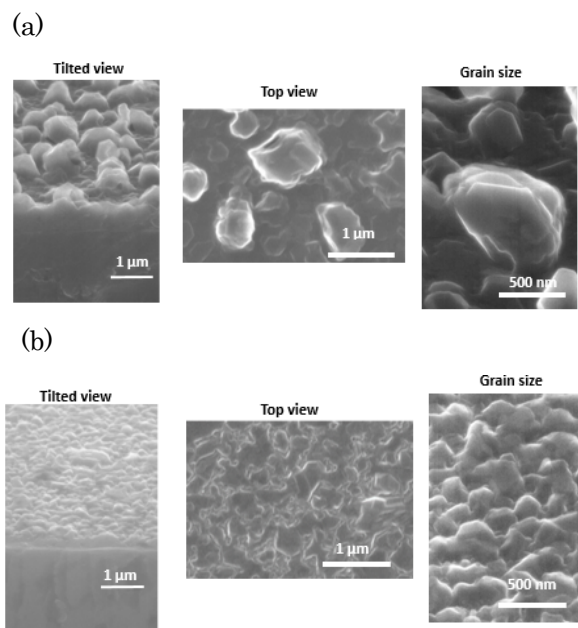
The growth of aluminum thin films on the silicon substrate by DMEAA is carried out in the following ways. At first, the silicon substrate is cleaned by the standard degrease process, while the surface oxide layer and adsorbed materials are removed by Semico clean 23. Then, the silicon substrate is immediately loaded into the e-gun evaporator and a 1.5 nm thick of titanium film is deposited on the substrate. We found out that the growth of aluminum films by DMEAA has to have a metallic layer. After that, the substrate is loaded into the ALD reaction chamber with a temperature of 150 degrees Celsius. The growth of aluminum films was performed with 0.3 seconds of pulsing time and 3 seconds of purging time for three hundred cycles.

Its surface morphology and thickness of the aluminum film are characterized by SEM, while its contaminations, as well as crystal orientation, is examined by XRD. Process imaging software is used for the analysis of grain size and film thickness statistically.

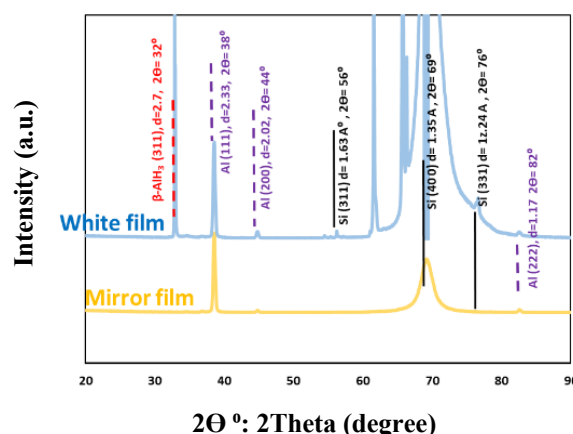
### 3. Results and discussion

Due to the non-uniformity of gas flow, its surface has a mirror and white parts as shown in Fig. 2. The mirror part is composed of smaller grains and shows the (111) orientation. However, the white part is composed of larger grains and shows more roughness of the same orientation. By using the image processing analysis of SEM images by GATAN software, it is estimated that the average thickness of both mirror and white parts is (220) nm and (760) nm, respectively. Furthermore, the white part contains beta-alane ( $\beta\text{-AlH}_3$ ) from the X-ray diffraction (XRD) analysis as shown in Fig. 3. We observed that the aluminum film has mainly (111) orientation with a small amount of (100) due to chemical bond deposition of chemical reaction<sup>9</sup>. The surface roughness of

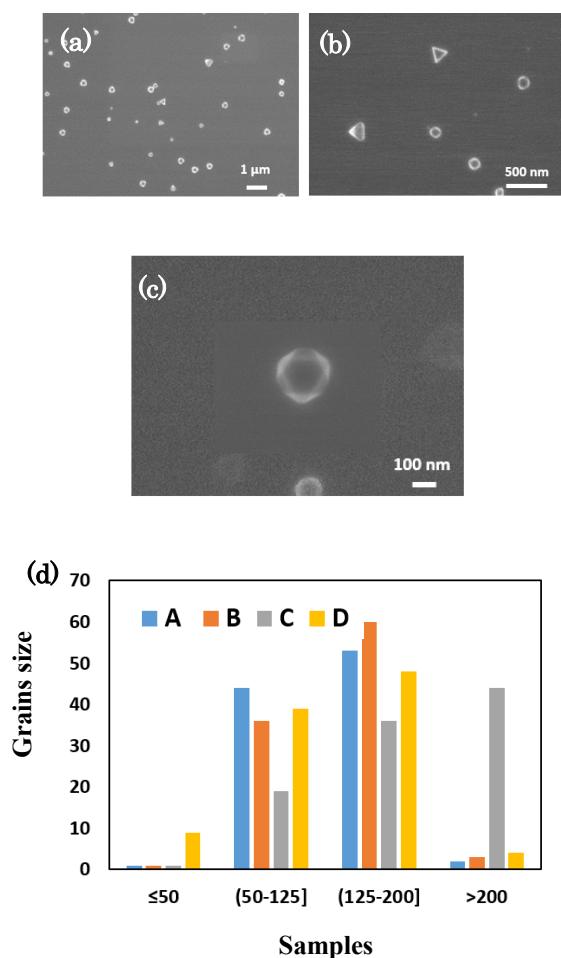
the white part is related to the existence of alane ( $\text{AlH}_3$ ),<sup>10-12</sup> which contributes to increasing the size of the gains due to its large cell parameters comparing to aluminum enhancing Stranski–Krastanow growth<sup>13</sup>. An X-ray diffraction (XRD) analysis shows the dominance of beta-alane ( $\beta\text{-AlH}_3$ ) contamination of (311) orientation. It exists because of incomplete dehydration reaction at 150 degrees Celsius on Si surface<sup>9,12</sup>.



**Figure 2.** (a) White and (b) mirror parts in the aluminum thin film.

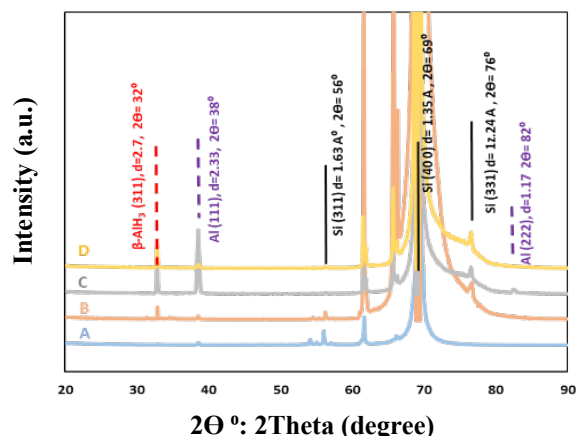


**Figure 3.** XRD of  $\beta$ -alane contaminant in white part.



**Figure 4.** Aluminum grain morphologies (a) top view of grains distribution. (b) grain morphologies of triangle, droplet and square. (c) single grain of aluminum consists of two triangles above each other. (d) average grains size using underlayer of TMA or water.

It reveals that the new deposited relatively cold surface layer of precursor could prevent the occurrence of a complete dehydrating reaction of  $\text{AlH}_3$  to aluminum which required temperature from 97–197 °C.<sup>12</sup> We also tried to initiate the growth of aluminum by TMA with different cycles in sample (A), (B)&(D), and water in sample (C) instead of the metallic layer. All samples didn't show thin film but grains. The shape of grains shows mainly triangles, but the square shape is observed due to the combination of two triangles as shown in Fig. 4. We observed partial growth of aluminum and alane by XRD as shown in Fig. 5.



**Figure 5.** XRD of  $\beta$ -alane contaminant at trails samples.

## 5. Conclusion

We studied aluminum thin films grown by ALD using DEMAA precursor as the first step to realize Josephson tunnel junctions. We found that a conductive layer is necessary to initiate successfully the thin film growth of aluminum by DEMAA precursor. The grown aluminum films show (111) orientation regardless the substrates. Although we obtained a mirror surface the white surface was also observed, which is due to the large grain size. We speculate that the large grain size in white aluminum films is related to the existence of alane.

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