

ATOMIC LAYER DEPOSITION OF NANOSCALE ALUMINUM SUPERCONDUCTING MATERIAL

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論 文 名 : ATOMIC LAYER DEPOSITION OF NANOSCALE ALUMINUM

SUPERCONDUCTING MATERIAL (ナノスケール・アルミニウム超伝導材料の原子層堆積)

Title

区 分 : 甲

Category

論 文 内 容 の 要 旨

Thesis Summary

This thesis outlines the growth of thin aluminum films and aluminum nanoparticles through the use of atomic layer deposition (ALD) and the subsequent characterization of these films and nanoparticles. We utilized dimethylethylamine alan (DMEAA) as the aluminum precursor. Our investigations focused on the morphology and crystal orientation of both the thin films and nanoparticles, and we also examined the superconducting properties of the thin aluminum films. Our key findings are as follows:

1. The ALD growth conditions were optimized for achieving approximately a single layer using DMEAA for aluminum films.
2. It was found that the DMEAA precursor requires a metallic underlayer to enable the growth of aluminum films on silicon (Si) substrates. This property can be used for area-defined thin film growth. Furthermore, the growth of an aluminum film on very thin insulators, as thin as 2 nm can be achieved to obtain the tunnel effect.
3. In the absence of a metallic underlayer, we found that aluminum nanoparticles can be grown on Si substrates under certain conditions, and they exhibit distinct crystal structures.
4. Both thin aluminum films and aluminum nanoparticles exhibit a (111) orientation on Si (100) substrates.
5. Remarkably, the grown thin films of aluminum exhibited the same superconducting transition temperature and critical magnetic field as bulk aluminum. In usual aluminum films by other growth methods thin aluminum films tend to show enhanced superconductivity resulted from lattice stress and impurity effects. Our result may imply that thin aluminum films are ideal.
6. These findings regarding aluminum films suggest that ALD growth using the DMEAA precursor can be employed to fabricate lateral small Josephson junctions with controlled junction areas achieved through a metallic underlayer. This development could solve the scalability challenges associated with current superconducting qubits, which are traditionally based on shadow evaporation with a suspended bridge.
7. Furthermore, aluminum nanoparticles have the potential to serve as energy materials and in nanosensing applications.

To provide a clearer structure for the thesis, the chapters are organized as follows:

Chapter 1: Introduction to Atomic Layer Deposition (ALD) Growth, encompassing both oxide materials and metals.

Chapter 2: Explanation of Superconducting Quantum Bits (Qubits) and an in-depth examination of current fabrication methods. We explore how ALD growth offers a novel approach to fabricate superconducting qubits.

Chapter 3: Detailed insights into aluminum growth using ALD, focusing on the selection of the DMEAA precursor. We clarify the importance of a conductive layer for initiating aluminum film growth, which could have implications for fabricating vertical qubits composed of Al/Al₂O₃/Al. We also highlight the (111) orientation of Al films through X-ray diffraction measurements.

Chapter 4: Exploration of the superconducting properties of thin aluminum films grown via ALD using DMEAA. We compare ALD growth, demonstrating that ALD provides ideal aluminum films comparable to bulk aluminum.

Chapter 5: Investigation of the ALD growth of polyhedral crystallites formed by isolated aluminum (111) nanoparticles using the DMEAA precursor. We detail the growth process, the use of the passivation agent Trimethylaluminum (TMA) as an initiator, and the methods used for characterizing the aluminum nanoparticles, including SEM, X-ray diffraction, and statistical analysis using ImageJ. Our findings reveal the formation of well-oriented aluminum nanoparticles in tetrahedral shapes with (111) orientation, which subsequently evolve into polyhedral crystallites, including octahedra.

Chapter 6: Summary and Conclusions, encapsulating the key insights presented in the previous chapters.