Cryogenic Metal Evaporation System for Nanoscale Device Fabrication

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Aluminium migration is a significant problem in the fabrication and operation of nano-scale devices such as single electron transistors. In addition, grain size is a limiting factor on the size of tiny components such as quantum gates. The cryogenic evaporation system developed in this thesis has been successful in reducing aluminium migration and grain size. This is another important step toward the creation of a solid state quantum computer.

Quantum Computation

Quantum computation is a powerful new paradigm of computing based on quantum mechanical principles such as superposition. In the Kane architecture, quantum information is stored on the nuclear spin of an array of phosphorus atoms embedded in silicon. Quantum gates are used to process the information by coupling the spins of adjacent phosphorus nuclei. The state of the quantum computer is read out using extremely sensitive electrometers known as Single Electron Transistors (SET).

The quantum computer is fabricated using a double angle shadow mask evaporation technique. This technique involves two layers of resist being spun onto the silicon wafer. After the resist is developed, an undercut cavity results through which aluminium is evaporated at two different angles.

Fabrication Problems

Aluminium Migration

Some of the aluminium atoms entering the bilayer cavity have enough kinetic energy to bounce off the deposition region. These atoms deposit elsewhere in the cavity and this is known as aluminium migration. Aluminium migration is a source of charge traps which reduce the effectiveness of SETs.

Grain size

As the aluminium is deposited, it grows into grains. The size of these grains is a limiting factor on the size of quantum gates.

In addition, large grains can make the edges of the wires jagged and imprecise.

Results

Cryogenic Cooling with the SET evaporator

The evaporator used to create SETs has been set up to evaporate at cryogenic temperatures. It uses a liquid nitrogen source to cool the sample stage by conduction through a copper braid.

Fabrication

The SET evaporator was used to fabricate samples at a range of temperatures. These samples were then analysed using the scanning electron microscope and the atomic force microscope. The results showed that cryogenic evaporation reduces the aluminium migration and grain size.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>% of observations with obvious migration</th>
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</thead>
<tbody>
<tr>
<td>-105°C</td>
<td>0%</td>
</tr>
<tr>
<td>-50°C</td>
<td>37%</td>
</tr>
<tr>
<td>-25°C</td>
<td>77%</td>
</tr>
<tr>
<td>-22°C</td>
<td>97%</td>
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</tbody>
</table>

The samples shown were evaporated at -105°C. When compared to previous images (evaporated at 22°C), they show no sign of migration and the grains are much smaller.

Conclusion

The cryogenic system set up and tested in this thesis has shown an elimination of aluminium migration and a reduction in grain size. This is an excellent result which can be used to improve the efficiency of SETs and the size of the quantum gates used in a quantum computer.