Application of Sputtering Technology for Superconducting Circuit Fabrication

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A particularly important theory of quantum mechanics, quantum tunneling, can be shown using superconductors separated by an especially thin insulating layer. Production of these circuits requires use of technologies capable of growing layers of metals and insulators which are nanometers thick. We provide an overview of two devices, a magnetron sputtering chamber and a vapor deposition chamber, in the context of superconducting circuit fabrication.

INTRODUCTION

Alongside developments in superconducting materials, development and use of fabrication technologies are a necessity in overcoming the difficulties in producing superconducting circuits. The difficulties behind fabricating useful superconducting junctions such as tunneling junctions comes from the small scales of quantum tunneling. According to Bardeen–Cooper–Schrieffer (BCS) theory, electrons may tunnel through insulators in the form of cooper pairs or quasiparticles, a feat which is impossible to classical mechanics [1]. However, observing this effect requires using extremely thin insulators and small voltages. Ivar Giaever, the first to show this effect experimentally, used layers of aluminum oxide only a few nanometers thick [2]. As such, any efforts to fabricate such junctions requires machinery which can produce extremely thin and precise layers of metals. In our experimentation, we investigated two such methods, vapor deposition and magnetron sputtering, as methods of producing these circuits. Vapor deposition is primarily split into two forms: Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD) [3]. CVD uses a chemical agent and heating to break down the target material, whereas PVD relies on physical processes. Sputtering is considered a form of PVD. One of the simplest forms of CVD is cold-wall deposition, where heat is applied directly to the sample material resistively through induction or passing current through the sample. Hot molecules boil off of the sample and drift through the chamber onto the substrate, where they cool and solidify into an even layer. A mask is used to ensure the layer is of the correct shape. CVD chambers are typically held at low pressure during deposition to prevent impurities from being trapped in the thin layers of deposited metal [4]. For metals which have too high a boiling point for vapor deposition, sputtering can be used to 'chip off' atoms of a target material and apply enough kinetic energy for them to embed in the substrate. This is done by bombarding the target with high-momentum particles, which transfer their momentum to surface atoms, allowing them to overcome their physical bonds [5]. Magnetron sputtering produces these high-momentum particles using charged particles and a voltage gradient, where the magnetron itself is used to separate an input gas into positive ions and electron gas. Like in the case of vapor deposition, the pressure within a sputtering chamber is kept low to prevent impurities, but also to prevent the target material from being scattered away from the substrate by colliding with gasses in the way [6].

METHODS

Magnetron Sputtering. Magnetron Sputtering makes use of RF fields to excite a gas into plasma within a vacuum chamber. As ions in plasma are positively charged, they can be accelerated by an electric field and be used to bombard the target metal. This metal is then ejected from the target at high energies, and collides with and embeds in the substrate. Before sputtering can begin, the silicon chip bed must be inserted into the sputtering chamber, which involves moving from atmospheric pressure to vacuum. Our sputtering device is composed of two primary chambers, the load-lock chamber and the sputtering chamber. These are connected to each other and several pumps and gas canisters through a system of gate valves. [Diagram] The load-lock chamber and sputtering chamber can be separated by gate valve B. The sputtering chamber mechanical pump is only used during maintenance, and the turbopump is more sensitive to impurities than the load-lock turbopump. The load-lock chamber is used to prevent impurities from entering the sputtering chamber by allowing an initial pump down from atmospheric pressure to around 10-3 Torr using a roughing pump followed by turbopump. Metals are deposited on a square silicon wafer about an inch in size. This is placed in a holder on a rod which can be slid and rotated using a magnet. The holder has an sliding mask which can switch between three different masks to create the desired junction. Initially, the load lock is allowed to come to atmospheric pressure while the sputtering chamber is held around 10-3 torr, with its turbopump isolated to prevent damage. Once the blank is placed into the holder, the load-lock gate (and practically every other gate) is sealed and the roughing pump brings internal pressure to 10-2 Torr. An ion gauge monitor is used to observe the internal pressure. The turbopump then brings the pressure down to 10-3 Torr. At this point gate valve B is opened and the two chambers are brought to equilibrium. The load-lock turbopump is shut and the sputtering chamber turbopump pumps the system down to around 10-7 Torr. At this point the sputtering process can begin. Sputtering uses plasma to etch away at the material and launch it up into the substrate. However, to reach the substrate the Niobium or Aluminum must first pass through the plasmized argon, which can scatter the metal. Argon concentration must be held at a point such that there isn't so much that all metal is scattered, but not too low that there isn't enough ions to bombard the target to cause ejection. As such, argon is allowed to flow into and out of the chamber during sputtering. The turbopump main gate valve is shut, while a gauge valve is opened and set such that pressure in the sputtering chamber is held around 5*10-3 Torr, which was found to be ideal to maintain sputtering prior to use of the equipment. Using the Magnetron Sputtering system, we constructed three different superconducting circuits: SSS (Superconductor, Superconductor, Superconductor), NIS (Normal, Insulator, Superconductor), and SIS (Superconductor, Insulator, Superconductor). The Vapor deposition. Our vapor deposition device uses a strong current to evaporate metals and allow them to freely float up to solidify onto the substrate. Niobium, which has a boiling point of 4744 °C cannot reasonably be used in this sort of setup. Instead, lead-bismuth alloy is used with a boiling point around 1670 °C [7]. The alloy is put on a tungsten boat, and raised into the deposition chamber. A current of 40-70A is used to heat the sample. Current is turned up slowly from 0A to heat up the lead to its boiling point. If it is heated too quickly, it may vaporize and create a much thicker layer than planned. Unlike sputtering, vaporization will create layers very quickly. Once reaching boiling, the thickness measurement system can be used to track layer thickness. Like in sputtering, intensity is proportional to the distance ratio between the thickness measurement system and the substrate, which we calculated to be approximately triple that of the thickness monitor. The oxidizing gas was again 5:1 N2:O2, and our insulator was aluminum, which was oxidized within the chamber. We constructed a single SIS chip using the vapor deposition system. We did not test this chip due to time constraints, however another chip produced using the same methods was able to show the properties of the Josephson Junction.

DISCUSSION

CONCLUSION

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