Improving Superconducting Resonators for use in Quantum Computing

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Abstract:

Superconducting coplanar waveguides (CPWs) are essential elements in building quantum computers [1] and in single photon detectors for astrophysics [2]. Reducing energy loss in these waveguides is critical to improving their performance. One source of energy loss in coplanar waveguides arises from parasitic coupling to unwanted electromagnetic modes that occur where there are asymmetries or discontinuities in the circuit layout. The effect of these asymmetries and discontinuities can be minimized by adding additional wiring ("crossovers") to the waveguide geometry. However, the dielectric materials that serve as structural supports for the crossovers add additional loss through different mechanisms. We will discuss a method of fabricating crossover wiring in the form of freestanding air bridges, which will still suppress unwanted modes, but will not use a lossy dielectric for structural support.

Background:

Quantum computation relies on bits of information being stored as excitations in a quantum mechanical object. Unfortunately, these excitations decay as the object losses energy to its environment. This may be represented as a classical "bit" of information spontaneously changing from a "1" to a "0". The loss of energy/information is one of the biggest obstacles facing all of the proposed quantum computation architectures. Thus, reducing sources of energy loss is vital to building a quantum computer.

Energy loss occurs when moving and storing information in a superconducting circuit. A coplanar waveguide is a type of microwave transmission line that is used to move information in a quantum circuit, similar to how wires move information in an integrated circuit. A waveguide with boundary conditions such as electrical opens or shorts on both of its ends will resonate at a fundamental frequency that is defined by the length of the CPW. These resonators are used to store information for later retrieval as well as to aid in both the communication and isolation of qubits.

The CPW consists of a conducting plane lying on a dielectric substrate. The conducting plane is divided into three sections consisting of a center conductor surrounded on either side by ground planes (Figure 1). This geometry supports several electromagnetic modes, two of which are the desired even mode and the parasitic odd mode. The odd mode is a source of energy loss for the even mode, but it can be suppressed using a superconducting strip to force the ground planes to the same electrical potential. Currently the superconducting strip is supported by a dielectric, hydrogen terminated amorphous silicon. While this crossover method suppresses the odd mode, the supporting dielectric introduces a different source of loss not described here.

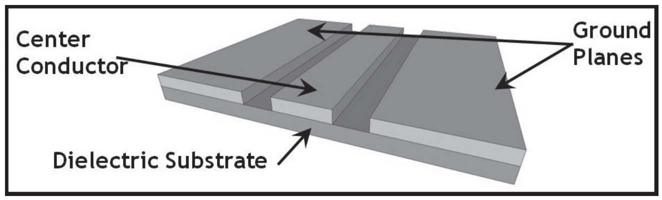

Figure 1: Coplanar Waveguide (CPW).

Methods:

A research group in the Netherlands has developed freestanding air bridges (Figure 2). First, they spin a 3 μm layer of positive photoresist over a CPW. A lithography step leaves behind a rectangular bar of resist covering the CPW.

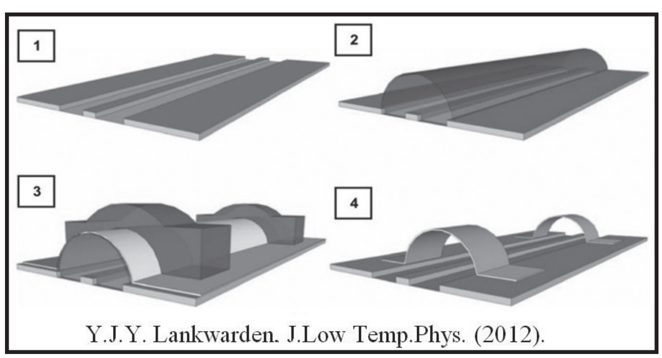

Figure 2: Air bridge fabrication process.

Heating the bar of resist above its glass transition temperature results in an arched shape, which serves as scaffolding for the air bridges. A thin layer of aluminum is deposited, followed by another layer of resist. A second lithography step covers the aluminum at the bridge locations. An etching step removes excess aluminum, and all of the remaining scaffolding resist is removed leaving behind freestanding air bridges.

This method could prove less lossy than the current crossover method, because it does not require a dielectric for support. The air bridge method also reduces the number of fabrication steps, which should improve device performance. Since the qubits used in these circuits are temperature sensitive devices, it is imperative that the resist have a low reflow temperature, and can be spun on at ~ 3 μm to set the height of the air bridges. SPR220-3.0 photoresist can be spun on at 3 μm, but its reflow temperatures are not known, so separate samples of SPR220-3.0 were baked at temperatures in the range 115°C-155°C for three minutes each. The reflowed resist was analyzed using profilometery and atomic force microscopy (AFM).

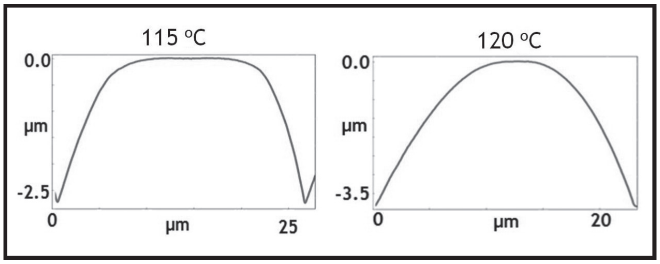

Figure 3: SPR220-3.0 photoresist baked at the indicated temperature for three minutes.

Results and Conclusions:

The results show edge rounding at all temperatures (Figure 3), however at 120°C, a clear semi cylindrical shape appeared. Temperature data was taken up to 155°C, but after 120°C, there was no significant change in the shape of the photoresist. Since the profilometer has a relatively large 12 μm tip radius, we verified the above results using AFM images (not shown) of before and after reflow.

We have discussed a method of suppressing the odd CPW mode that does not rely on a lossy dielectric for support. The reflow characteristics of SPR220-3.0 photoresist were characterized, and the reflow temperature of SPR220-3.0 was determined to be 120°C. This low reflow temperature should save our sensitive devices from thermal degradation.

After fabricating the air bridges, resonators will be used to compare the losses between air bridges and crossovers. This will improve the quality of our CPW circuit and add robustness to the architecture of superconducting quantum computers.

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References:

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