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Fabrication of Al air-bridge on coplanar waveguide

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Abstract

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Keyword:air-bridge;fabrication;superconducting coplanar waveguide

Show Figures

1. Introduction

As one of the most important platforms for realizing quantum information processing, superconducting quantum circuit has been actively investigated, both theoretically and experimentally.[1–3] In the context of quantum information processing (QIP) with superconducting quantum circuits,[4–6] microwave coplanar waveguide (CPW) resonator[7] proves to be extremely useful in maintaining quantum coherence,[4,6] controlling single qubit state,[4,6] performing qubit readout,[8] and mediating interactions between multiple distant qubits.[9] However, aside from the desired modes of CPW used for QIP, the ordinary CPW inevitably exhibits certain unwanted modes (i.e., parasitic slotline modes[10]) resulting from discontinuities and asymmetries in the ground planes.[11,12] These undesirable modes stand as a typical decoherence channel.[13,14] In addition, the discontinuities and asymmetries in the ground planes can also result in crosstalk between CPWs on the same chip, decreasing the fidelity of quantum state control and readout. Moreover, as quantum chips of tens of qubits with increasing circuit complexity become the norm, the focus of the field has now shifted towards suppressing crosstalk caused by parasitic slotline modes among CPW-based resonators and transmission lines, thereby achieving high fidelity in qubit manipulation.

In order to suppress the parasitic slotline modes, we introduce wirebonding technology into the standard procedure for CPW fabrication. However, in numerical simulation, the inductance of a 0.5-mm long slotline is 0.23 nH, which is smaller than the wirebond inductance but much larger than the inductance of an air-bridge.[15] So the signal will travel cross the slotline rather than propagate along the wire. In other words, air-bridge is a better method to suppress parasitic slotline modes.[15,16] Air bridge makes intersected lines possible, bringing greater freedom to the design of quantum circuits and improving the utilization ratio of chip area. Another benefit delivered by air-bridge is the reduced crosstalk between direct current and microwave which increases measurement fidelity. Generally, there are two ways to make bridge. One is using dielectric as insulating layer to separate crossed metal layers, but this way will affect the quantum coherence time because of two-level systems in dielectric. The other way is air bridge. In fact, several groups have already fabricated air bridges to avoid the parasitic mode and cross talk mentioned above, but the fabrication processes they use are more complex[17–19] and the bridges are not robust enough to withstand strong ultrasound.

Here, we propose a simpler procedure to prepare air bridge, which uses usual photoresist and standard lithography techniques. Using this process, we successfully prepared bridges of various widths and lengths. Compared with other methods, our air bridges are more robust: they can withstand strong ultrasound at power 120 W for 3 min and are compatible with the fabrication process of qubit.

2. Fabrication process

Figure 1 is the illustration of the cross section of a finished air-bridge: the height of the bridge is 3.0 μm and the bridge length ranges from 30 μm to 120 μm. Below is our procedure of fabrication in three steps.

Figure Option

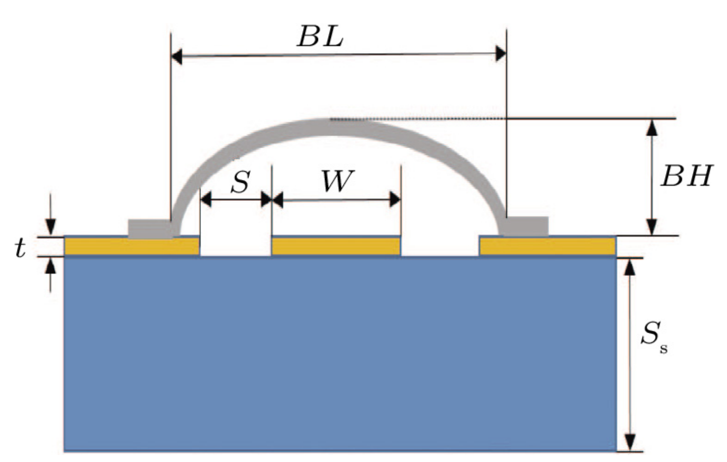

Fig. 1. (color online) Cross section view of an air-bridge crossing a CPW. Colored in blue, yellow, and grey are Si substrate, Nb film, and air-bridge.

First, a CPW transmission line is manufactured on a 500-μm thick Si substrate with standard photolithography and dry etching process. To be more specific, we sputter a 100-nm layer of Nb on Si substrate and perform lithography and etching with SF_6 by inductively coupled plasma (ICP etching). After that the transmission line is accomplished. The center trace width is 12 μm and the gap between ground and signal metal is 10 μm.

The second step is to set up the upholder of air-bridge. To make the experiment more general, we use S1813 from Shipley Microposit which is one of the most frequently used photoresists in laboratory. Its viscosity and surface tension ensure good reflowing which is essential for this experiment, because the thickness of photoresist is related to the bridge's height. First, 3.0-μm thick S1813 resist layer is spun on the Si wafer in 1000 rpm, on which is the CPW transmission line fabricated in step one. Then the wafer is baked on hot plate at 115 °C for 90 s. The photoresist is then exposed under UV light generated by DWL 66+ laser lithography system (Heidelberg Instruments), with exposure parameters set as follows — Dose: 200 mW/cm^2, Intensity: 80%, Focus: −60. With this equipment, it is easier to modify the pattern than with a mask aligner. By developing the photoresist in developer ZJX-238 for about 45 s, we obtain pattern with sharp-cut sidewalls. Nb film suffers no corrosion from developer while Al does, and such corrosion would in turn affect the properties of the transmission line. Therefore we use Nb instead of Al for the transmission line in step one. Next, we proceed to reflowing. This is done by baking the sample on hot plate at 140 °C for 4 min. During the baking, the tension of the resist causes the sharp-cut sidewall to deform into an arc shape, which serves as the upholder of the bridge and is related to the bridge's height and length. Generally, there are some photoresist remained after developing process. To clean the remains, we put the sample into an oxygen plasma produced by asher IoN Wave 10E with parameters: 200 W, 100-sccm argon, 200-sccm oxygen, for 180 s. In the end, we obtain an upholder as is shown in Fig. 2(a).

Figure Option

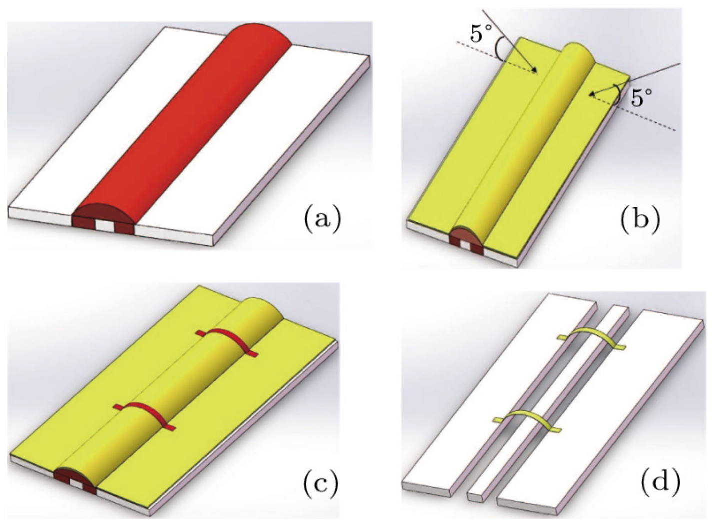

Fig. 2. (color online) (a)–(d) Procedure for superconducting airbridge fabrication. Colored in yellow, red, and white in the illustrations are aluminum, resist, and Nb, respectively. The preparing for CPW transmission line is omitted. (a) Pattern and reflow to make the upholder. (b) Deposition of aluminum. (c) Introducing bridge-like resist to define the bridge length and width. (d) Finished air-bridges over a CPW transmission line after wet etching and oxygen plasma.

The last step, which could be divided into four substeps, is the making of the bridge. First, we use ion beam milling to clean oxide layer of Nb surface and deposit a 500-nm layer of aluminum at ±5° as is shown in Fig. 2(b). The evaporation angle is to ensure a good contact at the corner of bridge and ground. As corner is also the easiest place to break, the angle, together with the thickness, can enhance the durability of the bridge. The second substep is to protect the area where we are going to build the bridge which is shown in Fig. 2(c). To this end, a 4.4-μm S1813 photoresist layer which consists of a 3.0-μm layer and a 1.4-μm layer, is spun to cover the aluminum layer. Then, the sample is baked on the hot plate at 115 °C for 90 s. After that, the sample is exposed under UV light again at the same exposure parameters as is mentioned above. Finally, the bridge-shaped resist is obtained by developing the sample in developer ZJX-238 for about 45 s. It should be noted that this resist which is used to protect the area we want must be thicker than 3.0 μm, otherwise the top of the bridge will be exposed in air and etched by aluminum etchant. Because of the reflowing, the top of the bridge is a little higher than 3.0 μm. Moreover, the photoresist will flow down the arching upholder because of the gravity and centrifugal force. In consideration of these facts, two layers of S1813 are necessary. Third, aluminum etchant (type A) is used at 20 °C for about 9 min with ultrasonic to remove the disposable aluminum layer. Forth, we remove the upholder and protection layer by putting the sample into oxygen plasma for 2 min with parameters: 200 W, 200-sccm oxygen. The sample is then immersed in an acetone heat bath at 60 °C for 15 min. This heat bath concludes the final step of our air-bridge fabrication procedure. The final image is shown in Fig. 2(d).

3. Result and discussion

The SEM images of completed air bridge after 3 min's ultrasound at power 120 W in acetone are shown in Fig. 3. The bridge in panel (a) measures 20-μm wide and 35-μm long. And the one in panel (b) is 40-μm wide, 30-μm long. In this experiment, we fabricated air-bridges of 7 different sizes, corresponding to the 7 colored cells in Table 1. We made 5 chips in total, and on every chip, all 7 sizes of bridges were fabricated, with 5 identical bridges in each size. See Table 1, in which the length of air-bridges varies along each column, and width varies along each row. The data in Table 1 show the quantity of air-bridges fabricated in every of the 7 sizes. If all bridges from a specific size are intact after 3-min's ultrasound at power 120 W, their corresponding cell is colored blue, otherwise in red. All bridges survive except one size: the 120-μm long and 20-μm wide one which breaks in middle. In Fig. 3(a), we can find that the middle of bridge is plane. The higher the proportion of plane, the easier it is to break in middle. It may need to chose photoresist with better reflowing property or to make higher upholder if the bridges should be made that long.

Figure Option

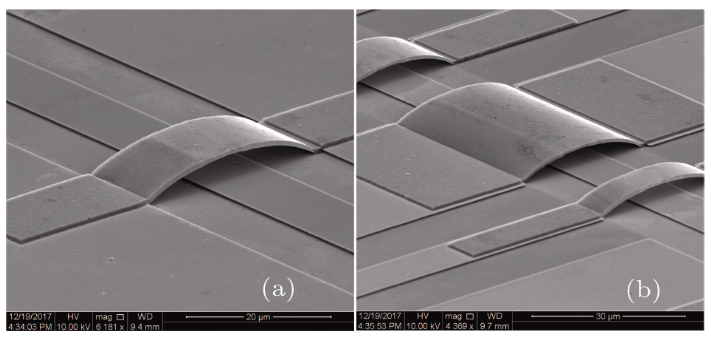

Fig. 3. (color online) Different types of air-bridges fabricated in experiment.

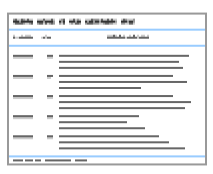

Table 1.
The comparison after ultrasound.
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What is also worth noting is the choice of concentration of the developer for resist removal after exposure in the last step, if it is needed to remove the resist and needless Al together, which means, using the developer as aluminum etchant. In this case higher concentration is recommended, or else it would take more time(about half an hour) to etch the aluminum with ZJX-238 and the sidewall undercutting would affect the pattern.

4. Conclusion

By using a simple fabrication process, we successfully fabricated bridges of lengths 30 μm, 35 μm, 40 μm, 45 μm and widths 10 μm, 15 μm, 20 μm, 40 μm, which can withstand ultrasound so that we can make qubit on this chip next. The success of this technique indicates that our technique is promising for various applications in superconducting quantum computation.

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