INTEGRATED NIOBIUM THIN FILM AIR BRIDGES AS VARIABLE CAPACITORS FOR SUPERCONDUCTING GHZ ELECTRONIC CIRCUITS

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Abstract. Superconducting GHz electronics can be improved by variable tuning circuits. We present a low temperature (< 150°C) process for the fabrication of niobium (Nb) thin film air bridges as variable capacitors, which can be integrated in Nb superconducting electronics. These elements can be applied for on-chip adjustment of filters, resonators and tuning circuits. Measurements and calculations of the electrostatic actuation of the bridges will be compared.

1. INTRODUCTION

Variable tuning elements are of high interest for all high frequency applications. Waveguide backshorts are not integrable with planar filter structures, resonators and other superconducting electronic circuits. Electrostatically actuable air bridges can be fabricated on the same substrate as the circuits to be tuned. The bridges are actuated by applying a suitable voltage between the bridge and the ground electrode underneath it as shown in Fig. 1. Some recent developments on this type of elements, using normal conductors or silicon, has been presented by Rebeiz and Muldavin [1].

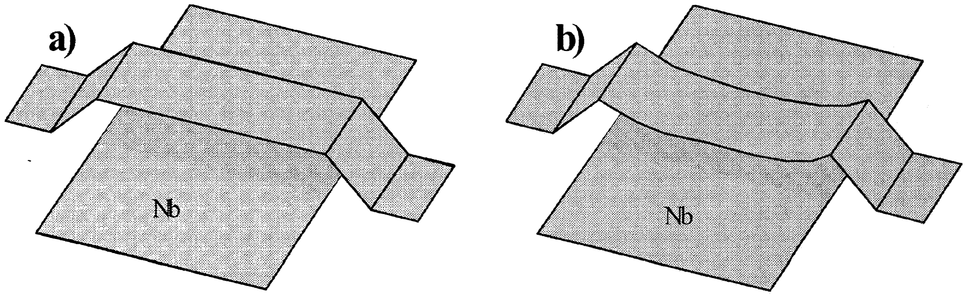


Figure 1. Schematic picture of an air bridge with electrode underneath for electrostatic actuation, a) without and b) with applied voltage.

In superconducting GHz electronic circuits the air bridges can be used for impedance matching, e.g. between the intrinsic capacitances of tunneling diodes and other parts of the circuit. In microstrip technology the air bridges can be implemented as tunable inductors, which broadens the range of application.

2. FABRICATION PROCEDURE

Most of the superconducting electronic circuits are based on superconducting Nb. Compared with galvanically grown bridge layers sputtered Nb air bridges have the advantage, that the same techniques can be used as for the other parts of the superconducting circuitry. As is depicted in Fig. 2a, in the first step the sacrificial layer, which defines the vertical shape of the bridge, is prepared. Here, the photoresist AR-4000/8 (ALLRESIST GmbH) was used, giving a resist thickness of 5 µm. Smooth rims of the sacrificial resist structures are necessary to avoid breaking of the Nb film at the edges of the structures. To obtain sufficiently smooth edges, the resist was baked in a convection oven before exposure and after development.

In the second step, the Nb layer was sputtered by DC-magnetron sputtering in steps of 9 s deposition and 5 min pause (Fig. 2b). The pauses are needed to reduce surface heating and thus deformation or polymerization of the resist layer.

The widths of the bridges are defined in the third step by a negative tone photoresist mask. For a good coverage of the structures, we used the same thick resist AR 4000/8 with a reversal process. Through this resist mask, which covers the surface of the Nb bridges, the non-covered parts of the Nb layer were etched by RIE (Reactive Ion Etching) as shown in Fig. 2c.

In the final step, the resist was washed away in 70°C hot acetone (Fig 2d).

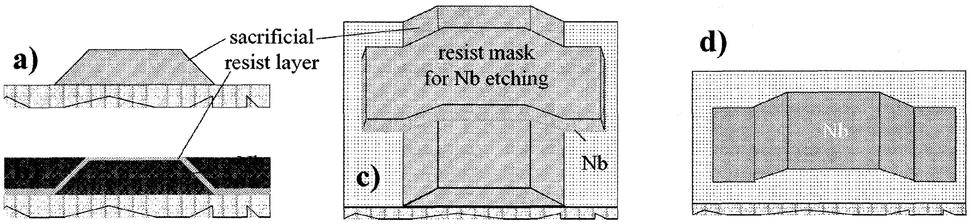


Figure 2. Fabrication process for sputtered Nb air bridges.

Air bridges with 200-700 nm thick Nb layers were fabricated with a typical length of 100 µm and widths of 50-300 µm (Fig. 3). The sputtered Nb films show tensile stress of 10...30 MPa. We tentatively explain this phenomenon with the expansion and shrinking of the sacrificial resist layer during deposition and cooling time, respectively.

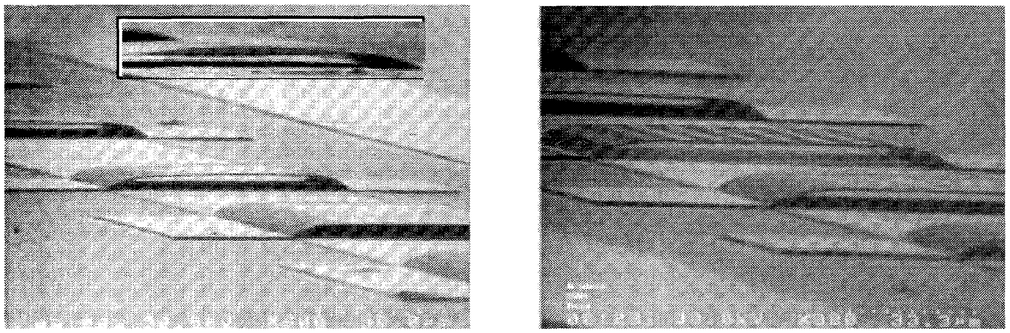
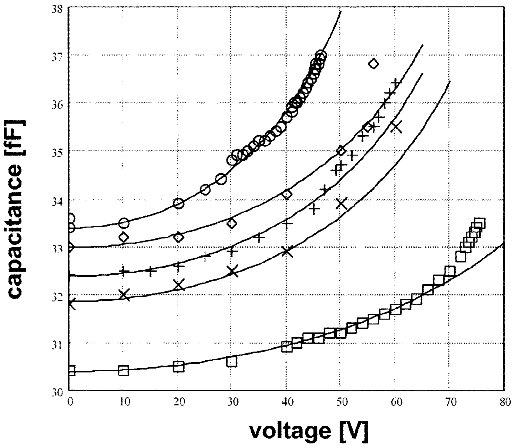


Figure 3. Nb air bridges, 5 µm high, 100 µm long, 100µm and 200 µm wide. The Nb film is 700 nm thick (240 nm in the inset). The inset shows the bending of the bridge layer and the reduced height due to stress in the Nb film.

Due to this stress, the released bridge shows a saddle structure (see inset of Fig. 3). This effect is more pronounced for thinner than for thicker Nb films and raises the zero-voltage capacitance of the device. Hence the zero-voltage capacitance can be adjusted by RIE of an initially too thick bridge layer. The Nb electrode underneath the bridge is produced with a standard lift-off process prior to the bridge fabrication.

3. PROPERTIES

Recent measurements on air bridges with 200-260 nm thick Nb bridge layers gave very promising results. These bridge layers were originally 330 nm thick before being thinned by RIE. The electrode underneath the bridge was covered by an AlN layer as a protection against RIE during the bridge layer etching. In the graph of Fig. 4 the measured voltage dependence of the capacitance is displayed for different bridges that are 100 µm long and 100 µm wide. Variations in the zero voltage capacitance can be explained by differences in the bridge height as described before. Standard formulas, found e.g. in [2], were used for the calculation of the mechanical behavior of air bridges with fixed ends. The deflection of the bridge was assumed to be parabolic and was iterated until the bending force was in equilibrium with the electrostatic force. In order to take into account the increased stiffness due to the saddle structure of the bridge layer, the calculations were done with an effective bridge layer thickness th_{eff}, being four to five times the Nb film thickness. Without applying a voltage, close to the posts the bridges were higher (h_p) than in the middle (h_m). Taking the Young modulus of bulk Nb (E = 105 GPa) and the mechanical parameters as indicated in the table, the theory confirms the measured values (Fig. 4). In the upper voltage region of some measurements the capacitance raised stronger than calculated with raising voltage. This effect can be explained with a flop-in effect of the saddle structure. An increase of more than 10% in capacitance was achieved applying 45 V. With improved geometries it seems possible to reduce this voltage to below 10 V.



sample	h_p	h_m	th_{eff}	w_{el}
	µm	µm	nm	µm
?	4.0	1.36	990	60
?	4.0	1.75	1350	60
?	5.0	1.80	935	90
+	5.0	1.84	910	90
x	5.0	1.53	920	90

Figure 4. Graph: Measured voltage dependence of the capacitance for different air bridges. The lines are calculated taking the parameters given in the table. The height at the posts and in the center of the bridge are given by h_p and h_m, respectively. The thickness of the AlN on top of the electrode layer is named th_{AlN}, whereas th_{eff} is the effective thickness of the bridge layer. The width of the electrode underneath the bridge is called w_{el}.

4. CONCLUSIONS

Variable capacitors in surface mounted air bridge technology were fabricated with sputtered Nb for integration with superconducting electronic circuits. The measured voltage dependence of the capacitance corresponds with calculations and shows a 10% variability of the capacitance at 45 V. With improved geometries it seems possible to reduce this voltage to below 10 V. For 50...300 µm wide and 100 µm long air bridges capacitance values of 15...100 fF can be achieved. Further developments will include reduction of stress in the bridge layers.

References

[1] G. M. Rebeiz and J. B. Muldavin, "RF MEMS switches and switch circuits", IEEE microwave magazine, December 2001, pp 59-71.

[2] R. J. Roark and W. C. Young, "Formulas for Stress and Strain", McGraw-Hill, 1984.