Development of NbTiN-Al Direct Antenna Coupled Kinetic Inductance Detectors

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Abstract We have developed a coplanar waveguide (CPW) Kinetic Inductance Detector consisting of Al and NbTiN, coupled at its shorted end to a planar antenna. To suppress the odd mode due to direct coupling to sky radiation by the KID we have also developed freestanding metal air bridges.

Keywords Low temperature detectors · Kinetic inductance detectors · Process development · Air bridges

1 Introduction

Kinetic Inductance Detectors (KIDs) are a very promising technology for use in sub-mm astronomy (100...5000 GHz). They are capable of detecting distant astronomical objects and their design and fabrication process allow for relatively easy up scaling to several kilopixel arrays.

In this article we present a fabrication process of hybrid NbTiN-Al direct antenna coupled KIDs including Al air bridges as used by Yates et al. [1, 2]. The Al part of the KID resonator is used for detection of radiation at frequencies above the gap frequency of 80 GHz. NbTiN acts as a superconducting ground plane for the antenna and KID and it is lossless below its gap frequency of 1.2 THz.

The geometry of the device is such that the antenna that couples to the sky radiation is located at the end of the KID itself. The coplanar waveguide (CPW) that

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Fig. 1 (Color online) Schematic overview of the process. Step 1. KID pattern in NbTiN (white); Step 2. Al part (blue); Step 3. Air bridges (red)

forms the resonator is also the port of the antenna. Any CPW can couple directly to sky radiation [3] by the so called odd-mode. This can result in radiation absorption in the KID not by the antenna but by the KID CPW itself. This will modify the beam patterns of the antenna detector and can also lead to performance deterioration for some antenna geometries [3]. To suppress the odd mode we have also developed freestanding metal air bridges. This is interesting not only for KIDs but for any high frequency circuit based on CPW technology.

2 Fabrication

In Fig. 1a schematic overview is shown of the process. First the KID pattern is defined in the NbTiN, followed by the Al part of the KID. As a final step the bridges are fabricated. The result is shown in Fig. 2, an artificially colored SEM image of a NbTiN-Al hybrid KID with an Al air bridge in the inset at the bottom. A laser machined Si lens array is mounted on the back of the wafer after dicing.

All devices are made on intrinsic (undoped) FZ Si wafers, 100 mm in diameter, 350 μm thick and with a resistivity of $>10\text{ k}\Omega\text{cm}$. Before deposition of the first layer, the substrate's native oxide is removed and passivated by a 1 minute dip in buffered-HF to prevent the occurrence of frequency noise [4].

A 300 nm thick NbTiN layer is deposited using reactive DC magnetron sputtering in a Nordiko 2000 system. With UV contact lithography the first pattern is exposed and developed in an AZ 5214 image reversal photoresist layer used in positive mode, defining the through-line, ground planes and KID resonators. The photoresist pattern

Fig. 2 (Color online) Artificially colored SEM image of a unit cell of the fabricated KID array. NbTiN is colored gold, Si blue and Al grey. The *bottom inset* shows an air bridge and Al part of the KID in more detail. The *upper right inset* shows a SEM image of a Si lens array located at the back of the wafer

Fig. 3 Continuous step coverage of Al due to the etched sloped edges of NbTiN

is transferred into the NbTiN layer by dry etching in a Leybold Reactive Ion Etcher. By using a gas mixture of SF_6 (13.5 sccm) and O_2 (20 sccm) the edges of the NbTiN become slightly sloped ($\sim 65^\circ$). This ensures the next deposited layer to have a continuous step coverage shown in Fig. 3.

We immerse the entire wafer without any photoresist pattern for 10 seconds in a 5% HF solution to remove the newly formed native oxide on the Si. This is done to reduce frequency noise in the resonators. The HF dip time is kept short to minimize possible attack of NbTiN. A 50 nm Al layer is deposited over the whole wafer by DC magnetron sputtering in a cryopumped loadlock equipped Evatec LLS801 system. Again UV contact lithography is used to define (a part of) the central line of the KID in AZ 6612 positive photoresist. This time the metal layer is patterned by wet etching using a diluted mixture of phosphoric-, acetic- and nitric acid (PAWN etch).

The now created NbTiN-Al hybrid KIDs are functional, but the antenna pattern can be improved by adding potential equalizing structures, which we call air bridges, see Fig. 4.

In Fig. 5a schematic overview is shown of the fabrication process of the air bridges. First a sacrificial layer of AZ ECI 3027 positive photoresist is applied and patterned leaving the KIDs covered. The thickness of the photoresist, 3 μm in this case, sets the height of the air bridges. A 30 seconds reflow bake at 130°C turns

Fig. 4 Free standing metal air bridges shorting the ground planes

Fig. 5 (Color online) Schematic overview of the fabrication process of air bridges. Step 1. KID pattern in NbTiN (*brown*); Step 2. Photoresist support structure (*red*); Step 3. Metal layer (*gray*) covering support structure and photoresist (*red*) defining the bridges on top of the metal layer; Step 4. Air bridges etched and both photoresist layers removed

the photoresist bar into a smooth arched shape. The 200 nm thick Al bridge layer is carefully deposited with minimum heat load in a Balzers BAS450 DC magnetron sputtering system by splitting the deposition run into several short steps with pauses and by using a thick copper heat absorbing substrate holder. This prevents the formation of gas bubbles in the photoresist. A second layer of AZ ECI 3027 positive photoresist is applied on top of the Al layer and the bridge areas are defined. PAWN etch is used again to transfer the pattern in the Al bridge layer. The most critical step is the removal of both photoresist layers, leaving the bridges unsupported. This is done by using two baths of undiluted AZ 100 Remover heated to 60–70°C, followed by rinsing first in ethanol then in IPA. An O₂ plasma cleaning step is added to remove any remaining residue.

Fig. 6 Resulting air bridge before including the reflow bake in the process

3 Results and Discussion

We have fabricated KID arrays of 8×9 pixels. An artificially colored SEM image is shown in Fig. 2 of one of the pixels. The results, showing high optical efficiency and photon noise limited radiation detection, are presented elsewhere [1].

The Al parts of the KID array are patterned using a wet etching recipe. At first the Al definition was done with a lift-off process. This had the advantage of not covering the entire surface with metal to be etched afterwards. The disadvantage of using lift off is the presence of small walls at the Al pattern edges, a well-known problem, even when using a photoresist undercut of a few micron. These walls turned out to cause (non-reproducible) excess phase noise. Another reason to switch was the need for passivating the Si surface. The lift off resist did not hold the 10 seconds needed and started peeling off in HF.

In Fig. 4a nice arched shape of the bridge, using reflowed photoresist is clearly visible. In early tests the reflow bake was not incorporated which resulted in an irregular shape as shown in Fig. 6. Introducing the reflow bake greatly improved the sturdiness of the bridges: they now can withstand rinsing, spinning, blow-drying and to some degree ultrasonic cleaning.

We have investigated the use of other metals as the bridge layer, such as Nb-Ta. The span limit of the Nb-Ta bridges (200 micron width) was considerably larger than the limit for Al bridges. The main disadvantage of using Nb-Ta is the need for dry etching. Despite the use of a proper endpoint detector and partly dry removal of the plasma-exposed photoresist, there remained some residue that decreased the performance of the detector. We are currently developing a lift-off process to enable air bridges of metals that normally need dry etching.

4 Conclusion

We have successfully developed a fabrication process for hybrid NbTiN-Al direct antenna coupled KID arrays. The detectors show high optical efficiency and photon noise limited performance.

The process includes fabrication of freestanding metal air bridges, which can be beneficial for other high frequency CPW containing circuits.

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