Fabrication of High-T_c Hot-Electron Bolometric Mixers for Terahertz Applications

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Abstract **Superconducting hot-electron bolometers (HEB) represent the most promising candidate for heterodyne mixing at frequencies exceeding 1 THz. Nb HEB mixers offer performance competitive with tunnel junctions without the frequency limit imposed by the superconducting energy gap. Although the performance of $YBa_2Cu_3O_{7-\delta}$ HEB mixers is not projected to be superior to that of Nb devices at low operating temperatures, they introduce the possibility of sensitive, low power heterodyne detectors operating at temperatures approaching 90 K for applications requiring portability and closed refrigeration. We report on the fabrication process, and the *dc* and optical characterization, of high-T_c mixers based on ultra-thin (≤20 nm) $YBa_2Cu_3O_{7-\delta}$ patterned to micrometer dimensions and incorporated into 2.5 THz receiver structures.**

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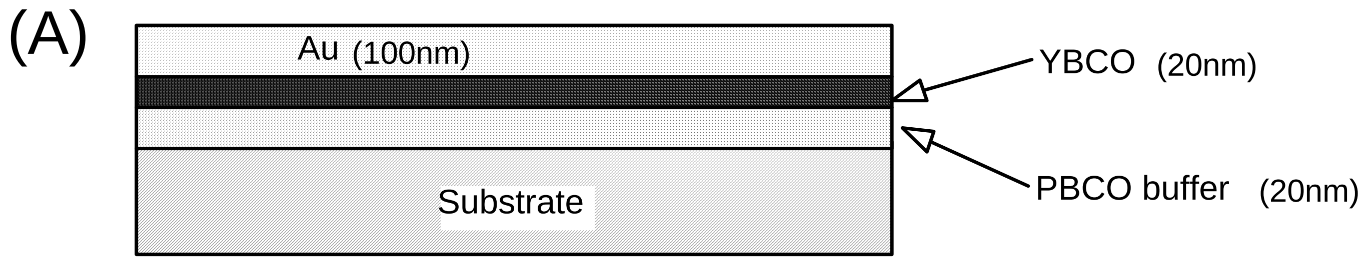
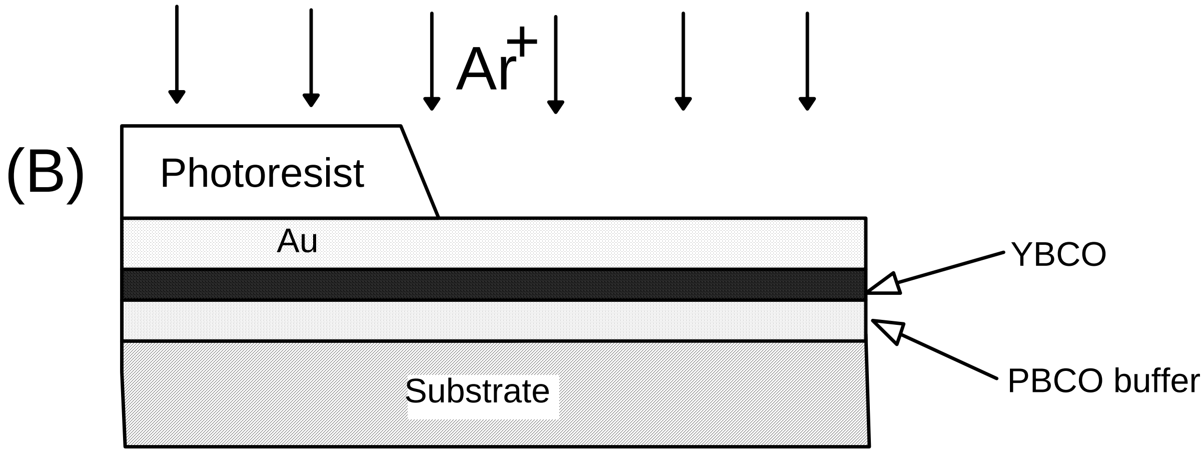
Requirements

(1) The substrate must have a high thermal conductivity and be compatible with epitaxial $YBa_2Cu_2O_{7-\delta}$ growth.
(2) The thermal boundary resistance between the HTS film and the substrate should be as small as possible.
(3) Substrates need to have a small loss-tangent at both 2.5 THz and at the IF frequency.
(4) Substrates need to have a convenient dielectric constant at both 2.5THz and at the IF frequency.
(5) The HTS mixer film volume must be small enough to allow device operation at microwatt LO power levels.

In this work, ~20 nm YBCO thick films on $YAlO_3$ substrates were used to fabricate HEB mixers.

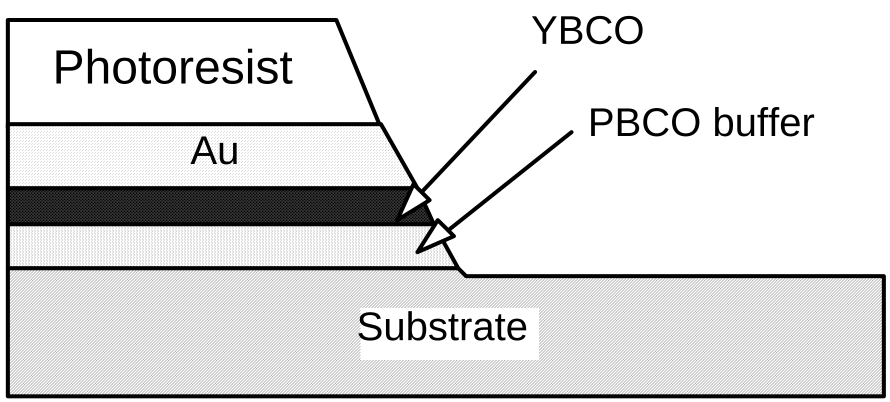


Growth of the superconductor and gold (Au) contact layers are performed completely *in situ* without exposure of interfaces to the ambient environment. The devices are grown on 250 μm thick, $1x1cm^2$ (001) $YAlO_3$ substrates polished on both sides. PLD of 20nm PBCO, 20nm YBCO, 100nm sputtered Au. Typical T_c for these trilayers, as determined by AC susceptibility, is 83-86 K with a transition width of less than 2 K.

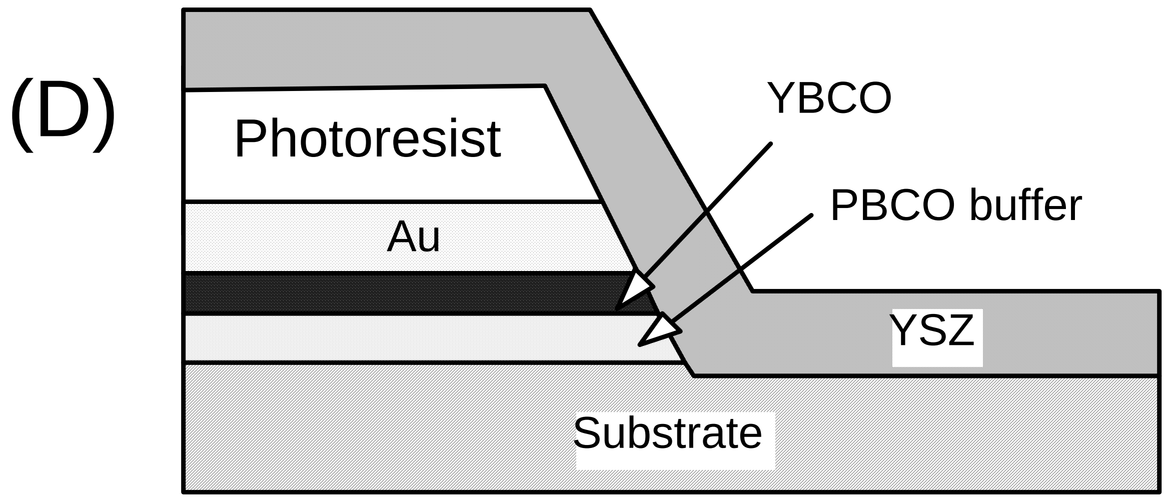


Next, the devices are placed into the load-lock of the deposition system in which an ion mill is located. The etching process uses normally incident 500 eV Ar+ ions at 1 mA/cm2 for 5 minutes.

(C)

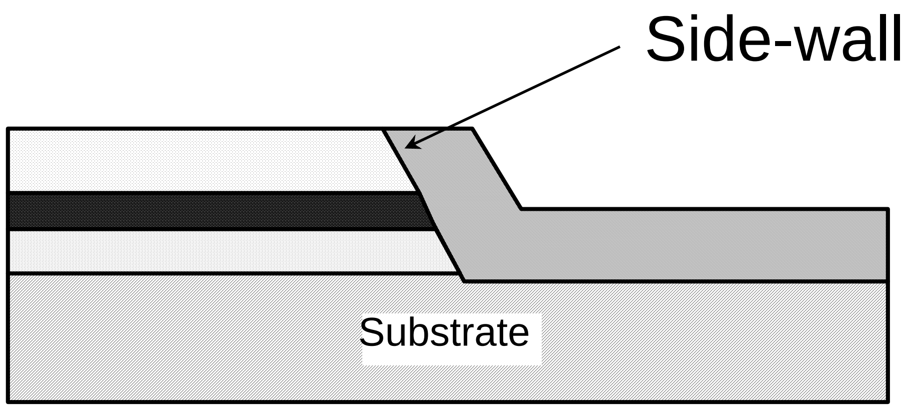


Cross section after ion milling.



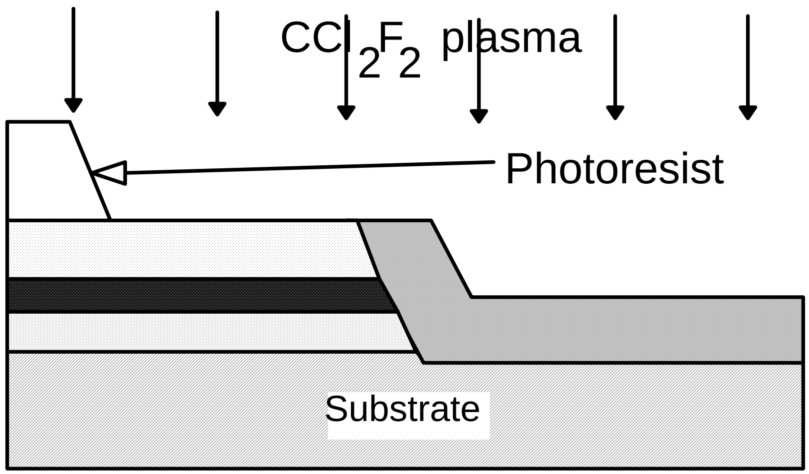
After milling, the devices are transferred from the load-lock directly into the deposition system where 60 nm of YSZ is deposited at room temperature by PLD.

(E)



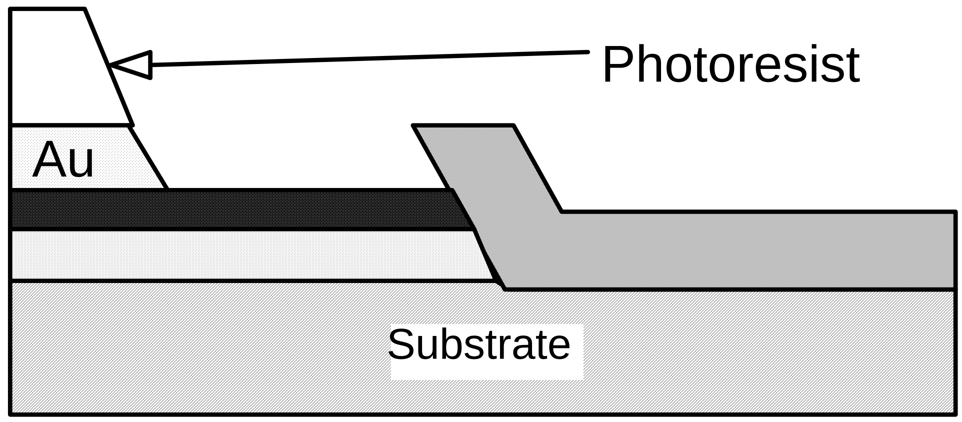
The photoresist is then removed by ultrasonically cleaning the devices in acetone for 1-2 minutes. The devices are rinsed in 100% ethanol and blow dried with dry N2. This YSZ deposition and lift-off process leaves the side-walls of the device coated with a protective layer of YSZ.

(F)



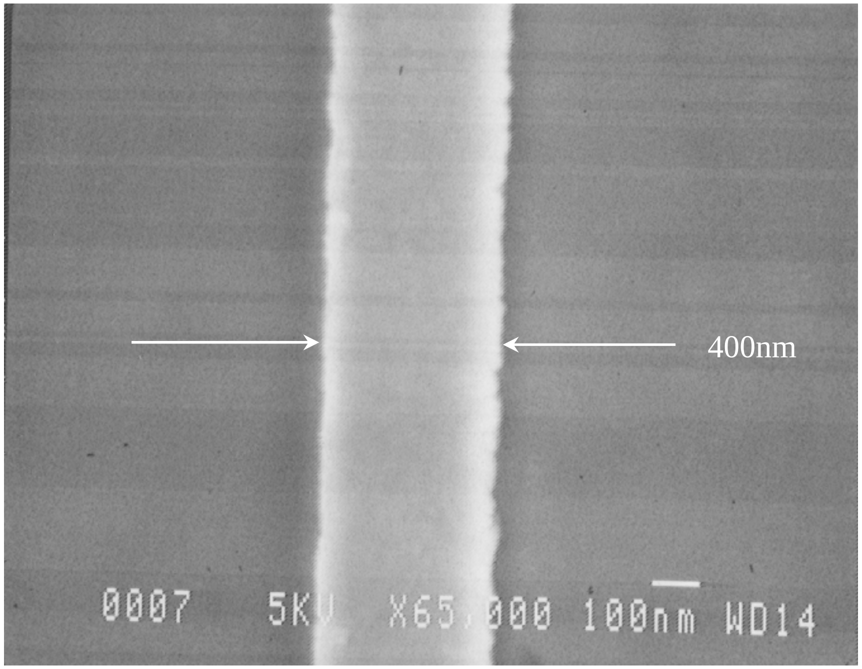
(1) Oxygen ashing for 5 minutes in a 200 mTorr oxygen plasma at 60 watts with approximately -80 self bias. (2) Etching for 50 minutes in a 200 mTorr 1:10 O_2:CCl_2F_2 plasma at 60 watts with approximately -20 volts self bias. The approximate Au removal rate is 2.5 nm/minute. We have found that over etching does not damage *c*-axis-oriented YBCO. (3) Oxygen ashed for 2 minutes in a 200 mTorr oxygen plasma at 30 watts with approximately -40 volts self bias.

(G)



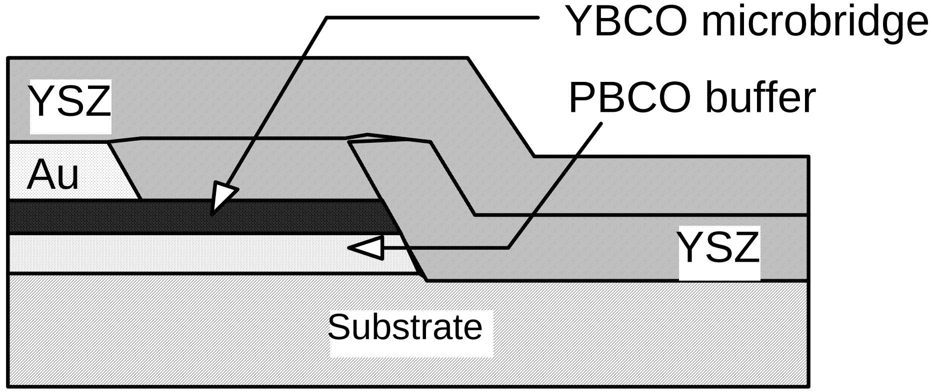
This is the resulting structure from this Au removal process. It should be noted that without the YSZ side-wall coating covering the *a*-*b* plane edges of the YBCO layer, lines as wide as 50 μm are no longer superconducting after the Au RIE process, presumably due to chlorine being driven into the film along the *a*-*b* planes.

With the YSZ side-wall coating, we have successfully used this 3-step Au removal process on 20 nm thick YBCO lines as narrow as 400 nm and maintained T_c above 80 K.

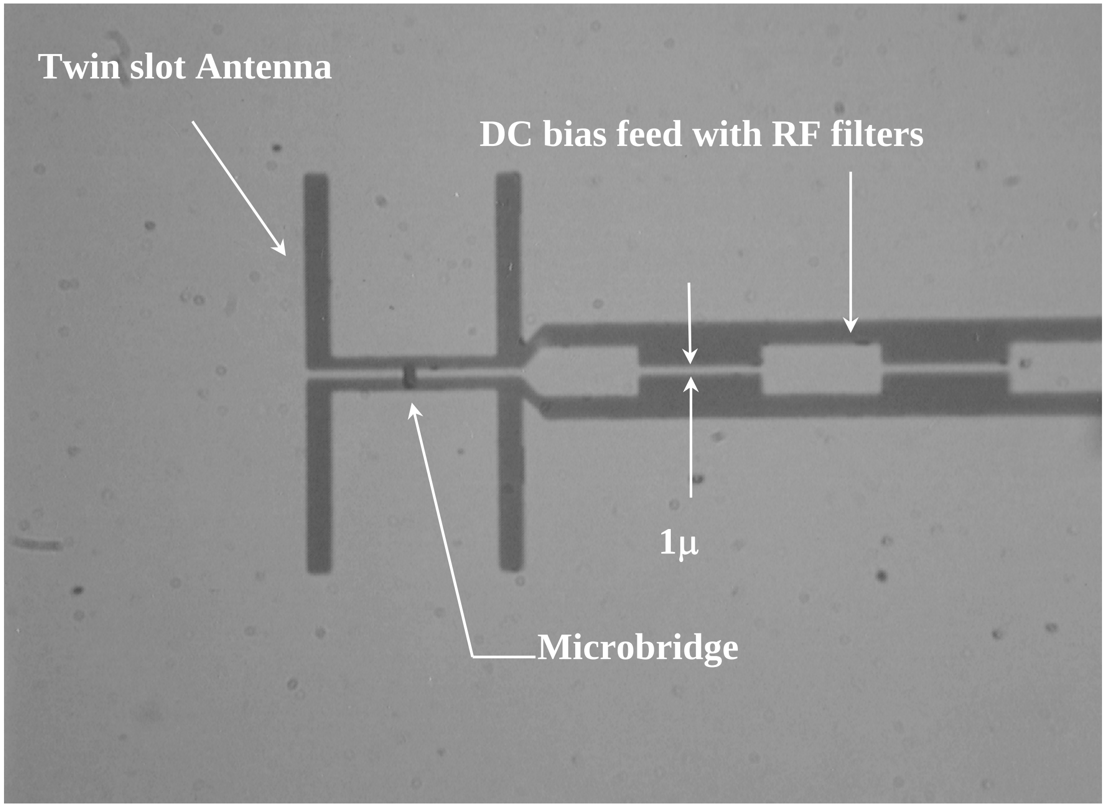


Requires:
1. Sidewall protection during RIE Au removal.
2. High-temperature reoxygenation.

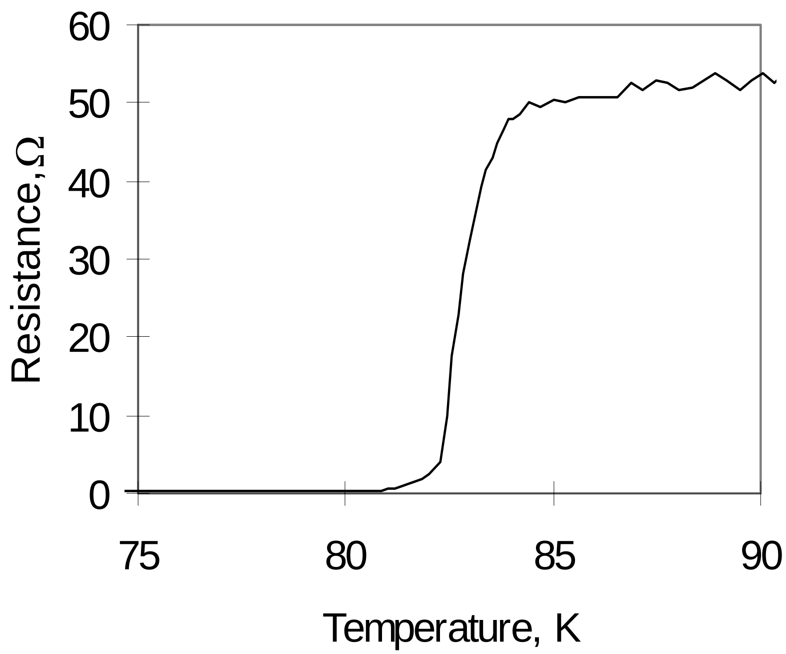
(H)



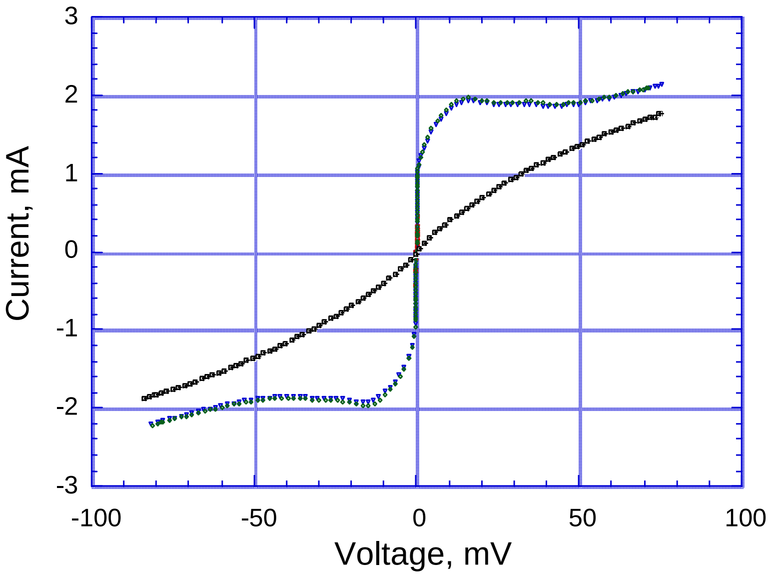
Next,100 nm of YSZ is deposited by PLD, filling in the area where the Au was just removed. The photoresist is then removed. The devices are next placed back into the deposition system where 100 nm of YSZ is deposited by PLD onto the entire substrate at room temperature, thus encapsulating the device.



Finished HTS bolometric mixer showing the microbridge, twin slot antenna, and RF filter structure for feeding the DC bias in and extracting the intermediate frequency (IF) out.



R vs. T for a 1x1x0.02 μm^3 microbridge HEB mixer.



I-V @ 77 K with and without the application of 2.5 THz local oscillator power, for a 1x1x0.02 μm^3 microbridge HEB mixer.

I-V data provided by B.S Karasik, M.C Gaidis and W.R. McGrath

CONCLUSION

We have designed and fabricated superconducting hot-electron bolometers based on a previously developed model. The devices utilize ultra-thin YBCO ($\leq$20 nm) films patterned into 1μm by 1μm microbridges and passivated with YSZ.