# Supplemental Material to the article
# "Planar architecture for studying fluxonium qubit"

**1. Fabrication and processing.** The fluxonium qubit samples were fabricated using the common Dolan bridge [1] shadow evaporation technique (Fig. S1). We first cleaned 525 $\mu$m thick high resistance silicon ($>10000$ ohms) samples ($25 \times 25$ mm) in a Piranha solution (1 : 4) followed by native oxide removal in hydrogen fluoride (HF) solution (1 : 50) for 120 sec. Than a standard two-layer e-beam resists stack (100 nm thick AR-P.6200 resist on top of a 700 nm thick copolymer MMA) was spin coated and fluxonium qubits topology was patterned by means of e-beam writer operating at 50 kV (Raith Voyager, Germany). The first resist layer was developed in the AR600-546 solvent for 1 minute, followed by second development in the isopropyl alcohol (IPA): deionized water (DIW) solution for 4 min.

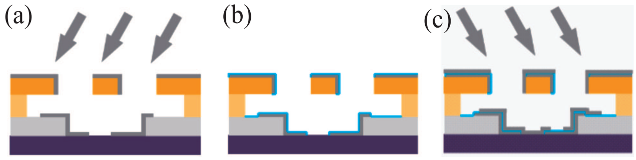


Fig. S1. Shadow evaporation of Josephson Al-AlOx-Al through a two-layer mask: (a) – Deposition of the bottom aluminum electrode at plus 11° angle. (b) – Bottom aluminum electrode oxidation. (c) – Deposition of the top aluminum electrode at minus 11° angle

The next step consists of the two angle evaporations of bottom and top electrodes of, respectively, $+11°$ and $-11°$, separated by an in situ oxidation. The barrier of the Josephson junction was formed in pure oxygen at 0.01 mbar pressure using a static oxidation technique. Al-AlOx-Al Josephson junctions were deposited in ultrahigh vacuum ($\sim 10^{-10}$ mbar) and deposition rate about 1 Å/s using an UHV electron-beam physical vapor-deposition system Plassys MEB 550 SL3 to ensure low line edge roughness of the electrodes ($< 2$ nm).

The final process step of the fluxonium qubit fabrication was the resistive mask removal in standard NMP-based solvent for 3 h.

The scanning electron microscopy (SEM) images of Josephson junctions, Josephson junctions chains, and fluxonium qubits are shown in Fig. S2.

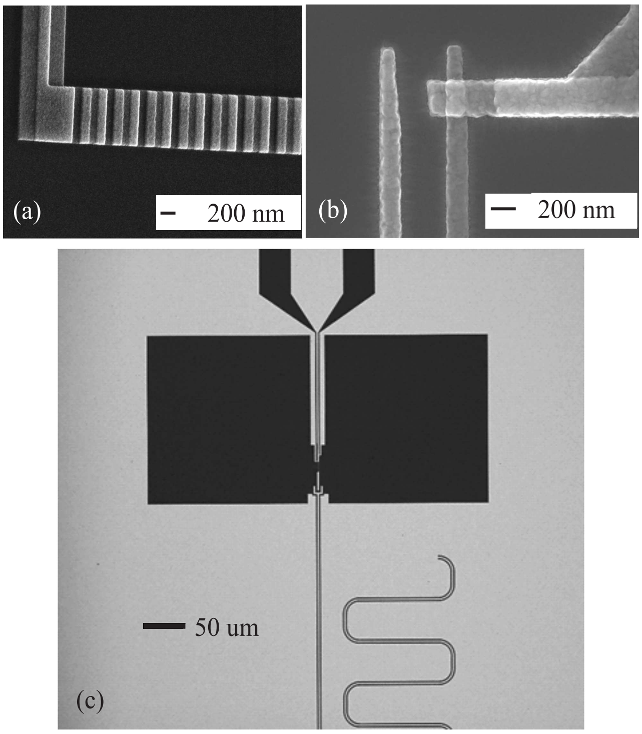


Fig. S2. (a) – SEM image of the Josephson junctions chain. (b) – SEM image of the Josephson junction. (c) – Optical microscope image of fluxonium qubit

**2. Sample mount.** Special microwave handmade sample copper holder is used for mounting chips for experiments (Fig. S3). The test chip is mounted in the cutout of the copper substrate and glued using BF-6 glue. Microwave lines on chip are wirebonded to the board contacts. Copper holder together with the sample is placed into a Cryoperm shield to protect it from stray quasistatic magnetic fields.

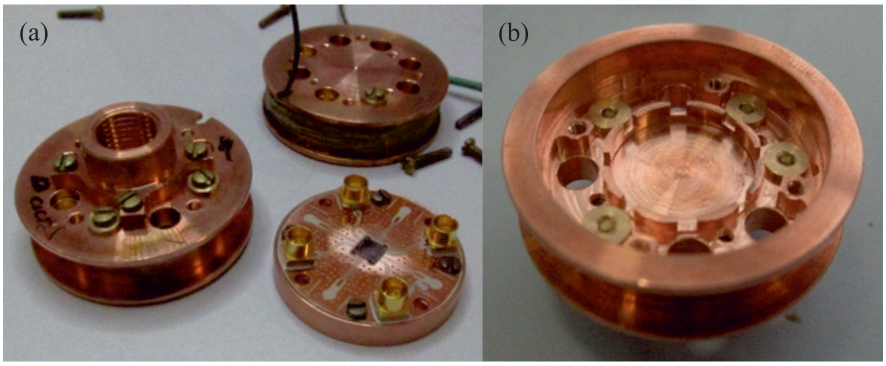


Fig. S3. (a) – Photo of the universal holder for chips mounting. (b) – Reverse side of the universal holder cover

**3. Cryogenic setup.** The experiment is performed in a dilution refrigerator Oxford Instruments Triton DR-200 with a temperature 20–30 mK. Microwave cryogenic measurement set-up is performed on Fig. S4. The incoming signal line is attenuated using 20 dB microwave attenuators at different temperature plates with total attenuation of 60 dB for sample isolation from spurious radiation from microwave equipment transmitted via cables. The cryogenic isolator Quinstar is placed between the sample and a low-noise HEMT amplifier (LNF-LNC0.3_14A) mounted at the 3 K stage. Connection to the DC-lines at 20 mK stage is made using additional low frequency Fe-based powder filters with an exponential frequency response (exponent 5 dB/GHz).

**4. Microwave signals.** Sample single tone and two-tone spectroscopy are provided with vector network analyser Agilent PNA-X (VNA) and sinusoidal signal generator Agilent PSG E8257D (GSS). Both microwave signals from VNA and GSS are combined at room temperature and sent into the P2 line of the refrigerator (Fig. S4).

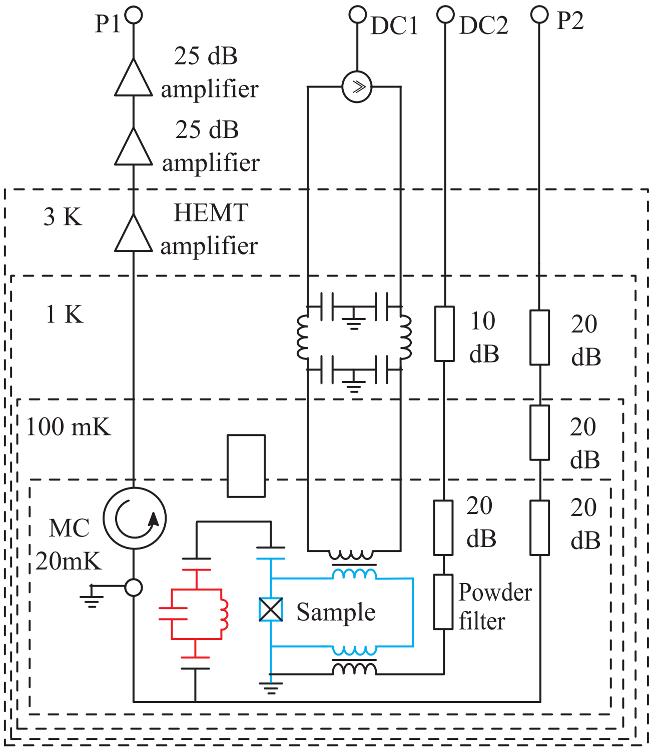


Fig. S4. Cryogenic part of the microwave measurement set-up connection scheme

VNA is used for measuring microwave signal transmission coefficient near the resonator frequency, it is also used like a reference frequency source for readout signal in heterodyne pulse measurement circuit. GSS is a second tone frequency source for qubit excitation, it is also used like a reference excitation frequency source for excitation microwave signal in a heterodyne circuit. Fluxonium magnetic flux is biased with multichannel voltage source connected to the DC1 and DC2 line of the refrigerator with RC-filter and 2kOm resistor at room temperature. Pulse measurements are provided with IQ mixers (IQ-0318 and IQ-4509), arbitrary waveform generator Tektronix AWG5014C (AWG) and two channel digitizer Spectrum M2i-2321.

# References


[1] G. J. Dolan, Appl. Phys. Lett. **31**(5), 337 (1977).