Au/$YBa_2Cu_3O_{7-x}$ heterostructures for microwave applications

I. Gundareva[1,2*], J. Martinez-Castro[2,3,4], F. Stefan Tautz[2,3,5], D. Grützmacher[1], T. Schäpers[1,2], M. Lyatti[1,2]

[1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany

[2]Jülich Aachen Research Alliance, Fundamentals of Future Information Technology, 52425 Jülich, Germany

[3]Peter Grünberg Institute (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany

[4]Institute of Experimental Physics II B, RWTH Aachen, 52074 Aachen, Germany

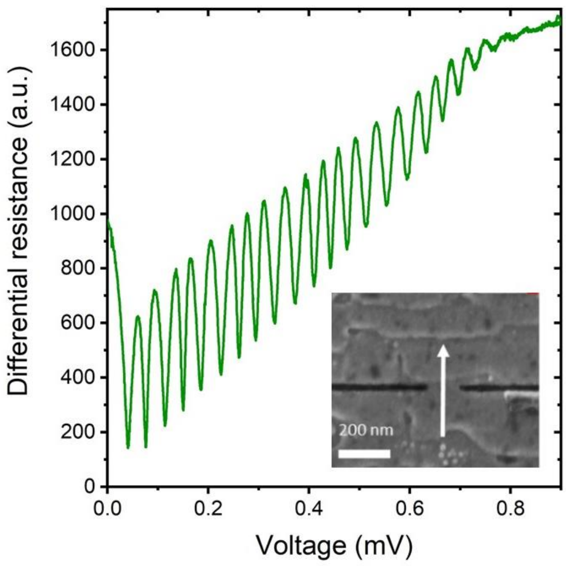

Figure 1 - Response of a nanoconstriction with a width of 60 nm to the radiation with the frequency of 17.6 GHz. Inset shows a nanoconstriction.

Hybrid devices based on a superconductor and 1D or 2D emerging materials are highly relevant both for many applications including quantum technologies and fundamental research [1,2]. Superconductor electrodes are an integral part of these devices and allow the proximity effect to be possible. Usually, these electrodes have been fabricated using low-temperature superconductors but an induced superconducting gap for these structures is rather small and typically has μeV scale. An alternative approach using high-temperature (high-T_c) superconductors is very promising because they possess much larger energy gaps and can be much more stable to external interferences [3]. Until recent times, only several attempts to use high-T_c superconducting electrodes for hybrid devices were made. The use of high-T_c superconductors as electrodes for topological insulators shows conflicting results. Graphene/$YBa_2Cu_3O_{7-x}$ (YBCO) hybrid structures showed only hints of induced superconductivity. Conventional high-T_c superconducting electrodes are based on films where the c-axis is normal and the CuO_2 planes are parallel to the film surface, providing a relatively low induced energy gap [4].

In our work, we employed vicinal substrates to produce the (YBCO) electrodes, where the CuO_2 planes have direct access to the film surface. For better compatibility with proximitized materials, we capped YBCO film with a gold layer deposited *in situ*. Having fabricated Au/YBCO heterostructures, we investigated their properties with scanning tunneling microscopy and observed a large energy gap of around 20 meV at the surface of the gold film. The experimental results are in good agreement with the theoretical estimates based on the calculated value of the coherence length in gold.

To study the microwave properties of the Au/YBCO electrodes, we fabricated nanoconstrictions with widths from 30 to 500 nm and measured their response to the external monochromatic radiation with a frequency of 15-94 GHz in the 60-77.4 K temperature range. The critical current of the nanoconstriction oscillates with the increasing power of the external radiation. The differential resistance of the representative nanoconstriction at a temperature T = 77.4 K with a critical current completely suppressed by 17.6 GHz monochromatic radiation is shown in Figure 1. The Shapiro-like steps are clearly visible up to a voltage bias of 0.8 mV giving evidence of the frequency synchronization of the internal nanoconstriction dynamics by external radiation at frequencies up to 390 GHz. The upper frequency of the synchronization increases up to 650 GHz with the decrease of the temperature down to 60 K. The observation of Shapiro steps induced by 94 GHz monochromatic radiation can be evidence of Josephson dynamics in Au/YBCO nanoconstrictions but not the synchronization of Abrikosov vortices motion.

We consider the Au/YBCO electrodes on vicinal substrates to be promising for the hybrid Josephson junctions due to the large induced energy gap at the gold surface and low surface roughness. The microwave response of the Au/YBCO nanoconstriction at frequencies up to 94 GHz confirms that these electrodes can be used for microwave applications.

[1] D. Perconte, D. Bercioux, B. Dlubak, P. Seneor, F. S.Bergeret, J. E.Villegas, "Superconducting Proximity Effect in d-Wave Cuprate/Graphene Heterostructures," Ann Phys-Berlin, vol. 534, 2100559, 2022.

[2] E. Prada, P. San-Jose, M. W. A. de Moor, A. Geresdi, E. J. H. Lee, J. Klinovaja, D. Loss, J. Nygard, R. Aguado, L.P. Kouwenhoven "From Andreev to Majorana bound states in hybrid superconductor-semiconductor nanowires," *Nat Rev Phys*, vol. 2, pp. 575-594, 2020.

[3] J. T. Kao, S.M. Huang, C.Y. Mou, C.C Tsuei, "Tunneling spectroscopy and Majorana modes emergent from topological gapless phases in high-T_c cuprate superconductors," *Phys Rev B*, vol. *91*, p. 134501, 2015.

[4] R. Baghdadi, R.Arpaia,S. Charpentier, D. Golubev, T. Bauch, F. Lombardi, "Fabricating Nanogaps in YBa2Cu3O7-d for Hybrid Proximity-Based Josephson Junctions," Phys Rev Appl,vol 4, p. 014022,2015.