Josephine

Deliverable 4.1:

YBCO/graphene (TMDC)

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Disclaimer:

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1 Aim of the project

The JOSEPHINE project aims to create a novel class of high-temperature Josephson junctions (JJs) with electrical characteristics that can be tuned in-operando. These would enable many new applications in superconducting electronics (computing, communications and sensing) but most notably in the field of neuromorphic computing. These tuneable junctions can behave as artificial neurons and synapses up to 100x faster, 10x more compact and orders-of-magnitude more energy-efficient than what is currently available.

2 Introduction

This document constitutes deliverable 4.1 of the JOSEPHINE project, entitled "YBCO/graphene (TMDC)" and due at M12. It is a result of WP4 "Dirac & 2D semiconductors JJs".

The present document is classified as Public. It contains information that demonstrates we have succeeded in fabricating junctions coupling Graphene and Transitions Metal Dichalcogenides with YBCO (YBCO/graphene and YBCO/TMDC junctions), based on transferred 2D material flakes. Both single (one interface) and multiple-interface junctions have been fabricated using an advanced (ion irradiation) lithography developed by CNRS to combine cuprate superconductors and flakes of 2D materials (such as graphene or TMDCs) in planar, gate-tuneable devices. We have investigated in situ capping of YBCO with different noble metals (Au, Pt), before choosing Au for transferring the 2D crystals.

We will not describe here the devices' fabrication steps, in order to protect intellectual property until the experimental results on the devices are published in peer-reviewed journals. Thus, we will only provide microscopy images of the "demonstrators", that is, YBCO/2D material junctions in which electrical measurement of the conductance across their interface can be performed. These microscopy images are accompanied by a description. In addition, we include a few electrical measurements that show that the demonstrators are functional. Notice that larger data sets are the object of different deliverables that will be provided at a later stage of the project.

3 Microscopy images of the devices

3.1 Devices used to characterize the metal overlayer

These devices are used to characterize the transparency of the YBCO/metal interface and the propagation of d-wave superconducting correlation in the metal. Optical microscopy images of one of the fabricated devices are shown in the figure below.

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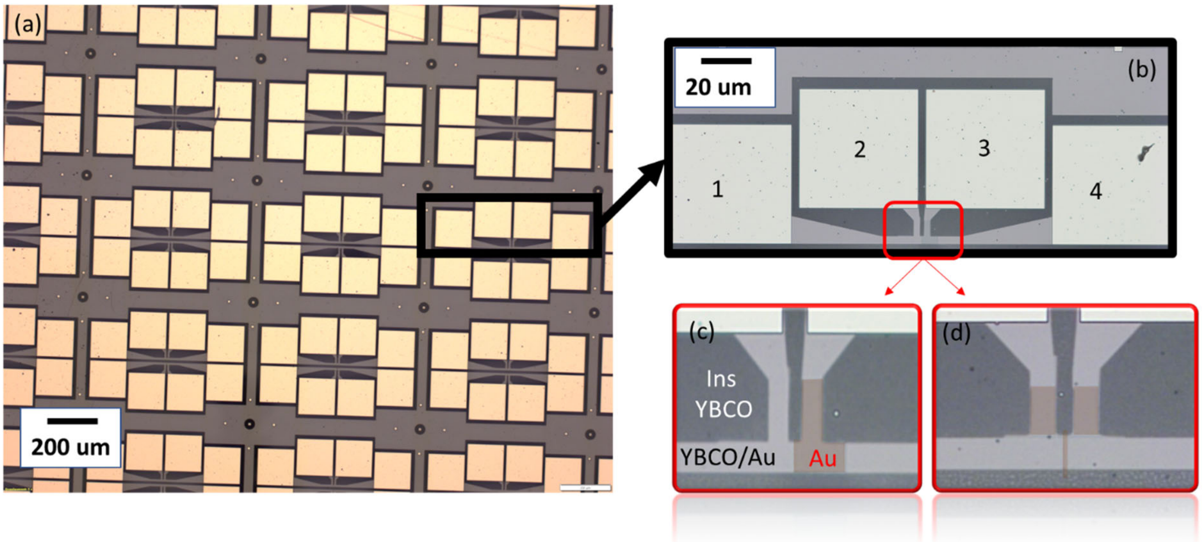

(a) shows a top-view picture of one of the fabricated chips (partial view). Each chip can contain up to ~100 devices. (b) shows a close view of one of these devices. It presents four Au (200 nm thick) square pads (numbered 1-4) that allow wire bonding the device for electrical measurements. Each of those pads is connected to the central part of the device by superconducting leads made of YBCO covered with a thin (4 nm) Au overlayer (light grey labelled YBCO/Au). The dark grey areas surrounding those leads are made of YBCO irradiated with O^+ ions to make it strongly insulating (labelled "Ins YBCO"). In the central part of the device, which is highlighted by the red rectangle, one finds the actual "junction". Examples of the studied junctions are shown in (c) and (d). In reddish colour areas, the YBCO has been irradiated (and so it is insulating), but it is still covered by the thin Au overlayer. Thus, these areas are just an ultrathin Au film lying on insulating YBCO (labelled Au). By using different irradiation masks, junctions with different geometries are obtained. (c) shows a typical device used to measure the conductance across the interface between Au proximitized by superconducting YBCO (YBCO/Au) and Au lying on insulating YBCO (Au). It is thus an Superconducting/Normal (or S/N) junction. For this measurement, the current is injected between pars 1 and 4, and the voltage is measured between 2 and 3. The same current/voltage probe configuration in (d) allows access to an Superconducting/Normal/Superconducting (or S/N/S) device.

3.2 YBCO/2D material junctions

Using similar lithography approaches and geometries as above, we have fabricated devices in which the current flows between two superconducting YBCO/Au electrodes across a graphene or TMDC flake that is transferred onto the lithographed chips. See some microscopy pictures below.

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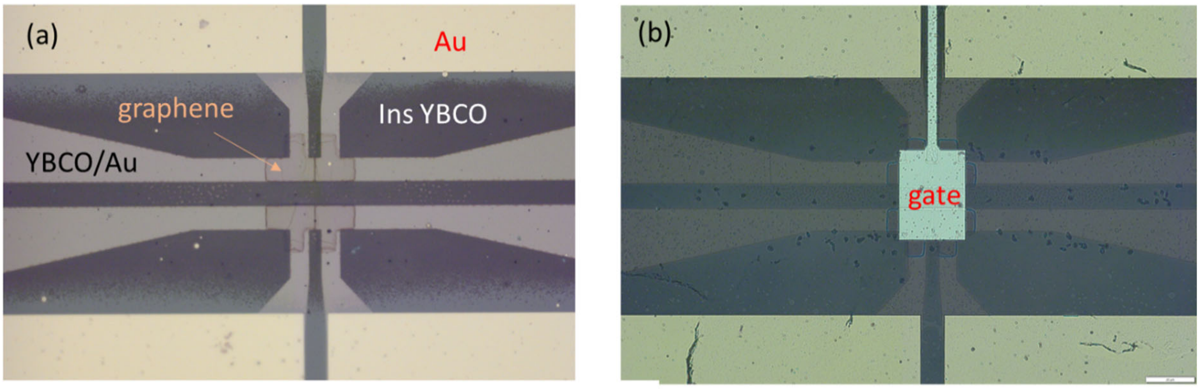

This first example (a) uses the same geometry as in the YBCO/metal junctions. The key difference is that here the YBCO/Au leads are separated in the central part by a narrow gap of insulating (irradiated) YBCO. The gap is between 50nm and 800 nm wide, depending on the device. Then, a graphene (or TMDC) flake is transferred on the chip and lithographed [orange in (a)] to create a conducting bridge that connects the two YBCO/Au leads (these are otherwise electrically disconnected by the narrow Ins YBCO gap, whose resistance is in the Mega Ohms range). By using different combinations of current injection/voltage measurement probes of the four available, we can study the conductance across a single {YBCO/Au}/Graphene interface (S/N junction), are two of them in series {YBCO/Au}/Graphene/{YBCO/Au} (S/N/S junction).

The above layout can be covered with a gate material (we used either AlO_x or HfO_2) and completed with a top gate electrode as shown in (b). This allows measuring the conductance of the devices upon varying the doping of the graphene or TMDC flake.

The above layout is well adapted for large flakes of 2D materials, generally grown by CVD, which provides large coverage (mm^2). For exfoliated flakes, which are smaller, we have designed another layout that allows contacting flakes whose typical area is 10 μm^2. Pictures of this approach are not shown here for IP protection reasons.

4 Functionality of the demonstrator

4.1 Transport measurements

We show below for demonstration purposes conductance *vs.* voltage measurements obtained in the devices as those shown above.

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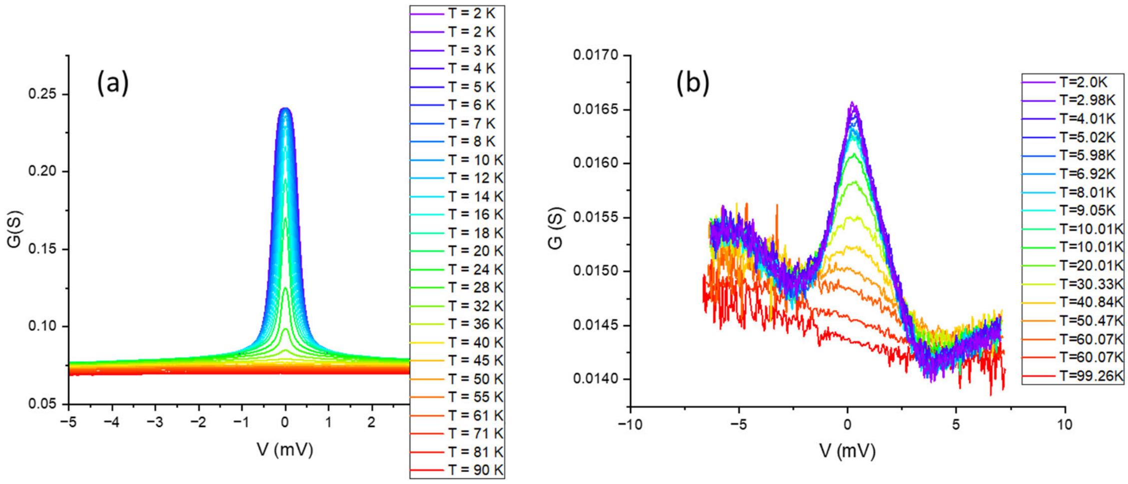

(a) Shows the conductance of an YBCO/Au/YBCO junction, showing a large conductance enhancement at zero bias below the superconducting transition. (b) shows the conductance of a {YBCO/Au}/graphene interface, which also shows spectroscopic features indicating proximity effects.

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