
Technical Memorandum

Ambature TM # 2020-04

To: Ron Kelly, CEO, Ambature Inc.

Cc: Davis Hartman, Michael Lebby

From: Mitchell Robson

Date: 04/06/2020

Re: **A-axis Advantages**

Ron,

There are many advantages of a-axis YBCO when compared to c-axis YBCO, mostly centered around material growth and device fabrication. In this report, “growth” will refer to YBCO or PBCO material deposition and “fabrication” will refer to a collection of steps that alter the grown YBCO/PBCO layers to produce a device. c-axis YBCO grows in stacks, layered like sheets of paper, while a-axis sheets grow vertically, like walls. The orientation of YBCO layers determines the direction of current flow (see Fig. 1.).

In both a-axis and c-axis YBCO current can move along the individual layers but not from one layer to the next. Therefore, a-axis YBCO can have easy current flow in both the horizontal and vertical directions, while c-axis can only have it in the horizontal direction. This anisotropic current flow leads to several advantages of a-axis YBCO over c-axis. Broadly, the main advantages are:

1. Ideal device geometries
2. Improved superconducting properties
3. Simplified fabrication steps

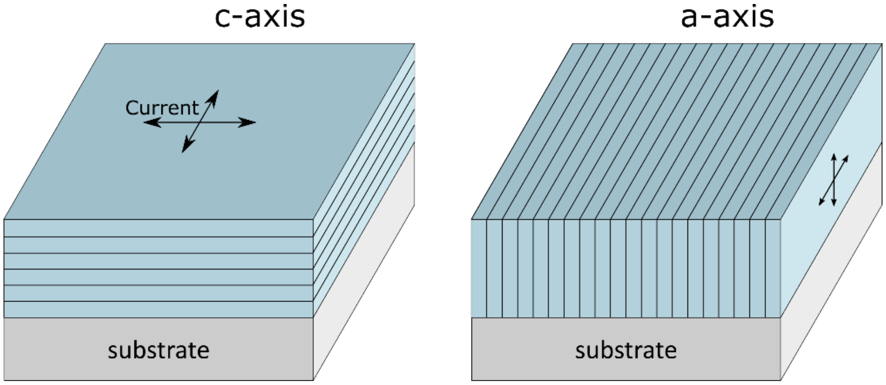

Fig. 1. c-axis and a-axis layers with indicated current flow

Device Geometry

The flow of current in YBCO determines the structure of its Josephson junctions (JJs). In general, a JJ is made up of two superconducting layers surrounding an insulating or non-superconducting layer. Current flows from the first superconductor, through the insulator via tunneling, into the second superconductor. For the best performance, tunneling should occur in-line with the YBCO planes. Since the c-axis YBCO planes are horizontal and current flows horizontally, the JJ must also be horizontal. This presents a huge problem during growth. By nature, layers grow in the vertical direction (ie growing films get thicker with time) but growth would need to occur in the horizontal direction to form a horizontal c-axis JJ. Fig. 2. shows two vertically stacked JJs, one made of c-axis materials and the other a-axis materials. The c-axis JJ can have current flow through the stacked sheets but not from one superconductor to the next., thereby making it a poor JJ device. On the other hand, the walls of the a-axis film direct current flow across the JJ from one superconductor to the next.

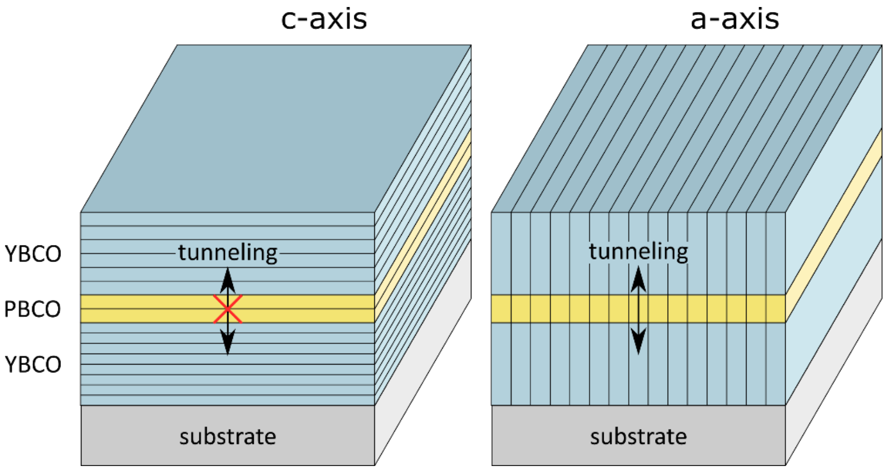

Fig. 2. Stacked c-axis and a-axis YBCO JJs. The orientations of the layers determine if tunneling is possible

Several device structures have been proposed to circumvent the c-axis growth orientation limitations, but none are ideal. Fig. 3. below shows the most popular solution, a ramp junction. A ramp junction allows for tunneling to occur along the c-axis planes, however, it is complex to form and lacks good parameter control. It requires a series of repeating growth and fabrication steps to form the ramped edge. This complexity leads to reproducibility issues and a decreased quality of the layers. It is particularly detrimental in the thin tunneling section of PBCO, since thickness, quality, and roughness all largely affect tunneling current. Horizontal c-axis JJs also tend to take up more surface area than stacked JJs, and device size is a key parameter for manufacturers. For all these reasons, the ramp junction has limited ability to scale up for real-world applications.

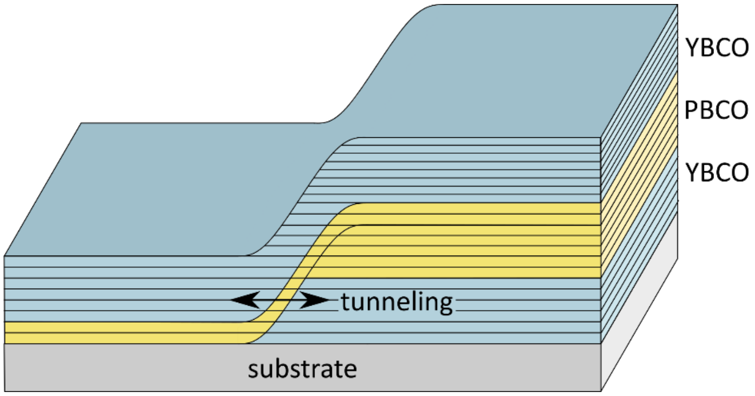

Fig. 3. c-axis ramp junction. Notice how it requires two PBCO layers, one as a thin tunnel layer and the other to isolate in the vertical direction

The a-axis equivalent of a ramp junction is simply a stacked trilayer junction like in Fig. 2. This stacked structure has better reproducibility, better uniformity, and better control over device parameters since the layering occurs in the same direction as growth. Any growth or fabrication engineer would prefer the stacked JJ due to its simplicity and familiarity, making it significantly easier to scale than the ramp junction. It also has a clearly defined junction area, which is the area across the junction where there is uniform current flow. Junction area is an important design parameter when creating functional devices such as SQUIDs. You can imagine it is difficult to determine where the current is uniform in a ramp junction when it has varying PBCO thickness and angled contact between the three layers.

Superconducting properties

a-axis device geometries improve the superconducting properties of the trilayer junction, most importantly, coherence length and critical current. Coherence length is the ability of the superconductor to remain superconducting if it has non-uniformities such as insulating layers and imperfections in the material. If a superconductor has a short coherence length, then it must have exceedingly high crystal quality and thin insulating layers to form a good JJ with a high critical current. Critical current is the maximum current a superconductor can support while remaining a superconductor. Beyond the critical current, a superconductor becomes a normal conductor, which can limit JJ detector capabilities in some applications. Both the coherence length and the critical current are larger in-plane along the YBCO layers. An a-axis stacked JJ has perfectly aligned trilayers and therefore ideal coherence length and critical current. YBCO and PBCO layers in c-axis ramp junctions can be aligned, as it is drawn in Fig. 3, however, the complex growth, fabrication, and low reproducibility all make it more difficult.

Fabrication

Electrical contacts must be formed to complete the JJ. Separate electrical contacts are made to the YBCO layers through a series of fabrication processes. As discussed above, the ramp junction requires a series of iterative growth and fabrication steps just to form the initial shape of the device. It then must go through another series of fabrication steps to form the electrical contacts. Stacked a-axis JJs have a more straightforward process. All the layers are grown at once, and then all the fabrication for contacts is completed. From a device manufacturing perspective, this eliminates the need to take samples in and out of high vacuum environments, speeding up development times, and reducing processing errors.

An example of the a-axis stacked JJ fabrication process is shown in Fig. 4. below. Starting with a fully grown trilayer stack, some material is removed to uncover the bottom YBCO layer. The upper YBCO and PBCO layers are removed by either dry physical etching (bombardment) or wet chemical etching (chemical reaction). Both are common in semiconductor labs. Next, electrical contacts are deposited on the top and bottom YBCO layers, again using standard semiconductor equipment, and the basic JJ is complete. Overall, if high quality a-axis material is grown, then the JJ can be fabricated using standard semiconductor equipment without the need for custom solutions.

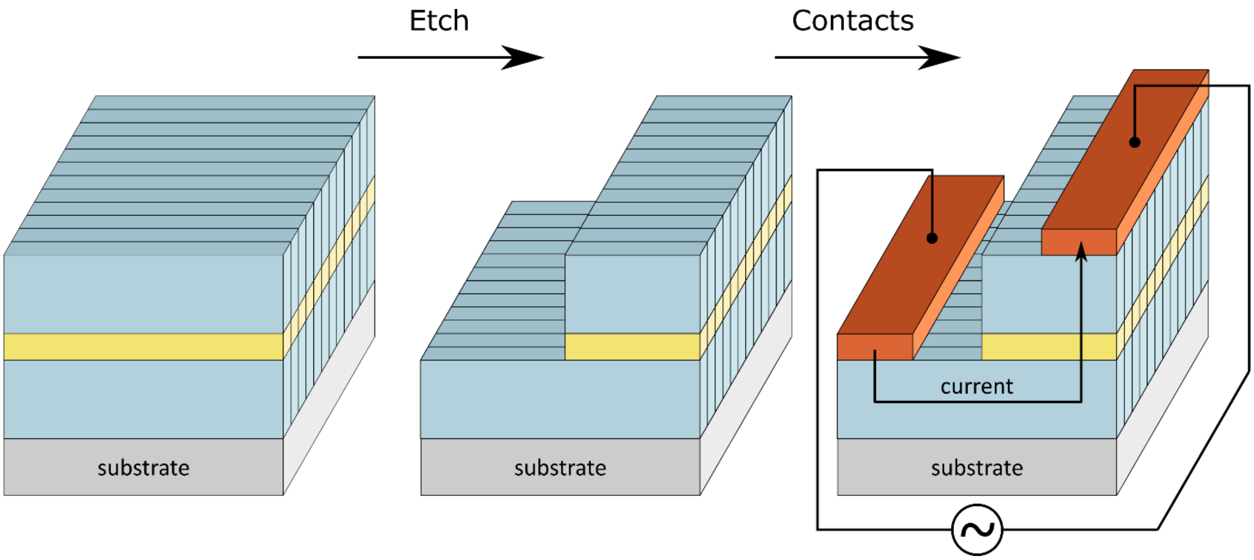

Fig. 4. Device fabrication process of a stacked a-axis Josephson junction with indicated current flow

Mitchell Robson