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Ambature Develops a-axis YBCO Film

The intellectual property licensing company Ambature, Inc. has announced the development of a-axis YBCO wafers with extremely thin and smooth layers and interfaces. Testing results with this high-temperature superconducting material have demonstrated that, when designed into trilayer Josephson junction devices, a-axis YBCO offers advantages over the more common c-ax is YBCO, such as simpler foundry fabrication, quantum device design, and high-performance analog and digital circuit solutions. The company plans to scale its technology into standalone Josephson junction applications using traditional silicon foundries.

"We hope to remain fabless," commented Ambature CEO Ron Kelly. "We intend to take the design of our materials and devices to at least the prototype stage so we can show the relevant performance and cost improvements to potential licensees. In this way, we will do our own R&D, we will do cooperative R&D with licensees, and they and other licensees down the road will create their own intellectual property and devices building on our a-axis foundation as a-axis superconducting technology proliferates."

Current Moves Both Horizontally and Vertically in a-axis YBCO

Josephson junctions in $YBa_2Cu_3O_{7-x}$ are commonly made using epitaxial $YBa_2Cu_3O_{7-x}$ films oriented with the c-axis perpendicular to the film surface. Theorists had hypothesized that growing $YBa_2Cu_3O_{7-x}$ films oriented with the a-axis perpendicular to the film surface could be an effective means of fabricating high quality Josephson junctions.

In both a-axis and c-axis YBCO, current moves along the individual layers but not from one layer to the next. This means that a-axis YBCO can have easy current flow in both the horizontal and vertical directions, while c-axis flow is limited to the horizontal direction. This characteristic of a-axis YBCO allows for improved device geometries and superconducting properties, along with simplified fabrication steps.

For optimal conductor performance, tunnelling should occur in-line with the YBCO planes. Since the c-axis YBCO planes are horizontal, the current must flow through horizontal Josephson junctions, along the stacked sheets but not through the vertically stacked superconducting layers. With vertical a-axis film, the current flows across the Josephson junction from one superconducting layer to the next.

Fabrication Focused on Surface Smoothness

Regarding superconducting properties, an a-axis stacked Josephson junction has perfectly aligned trilayers and therefore ideal coherence length and critical current. While the trilayers in c-axis ramp junctions can be aligned, growth, fabrication, and reproducibility challenges make this more difficult.

Fabricating stacked a-axis Josephson junctions is a more straightforward process. All the layers are grown at once, and then the contact fabrication is completed, eliminating the need to take samples in and out of high vacuum environments, speeding up development times, and reducing processing errors. "Fabricating devices can be done with typical semiconductor tools (Reactive Ion Etching, ion mill, metalization)," Kelly noted. "Growth of the material itself is currently in molecular-beam epitaxy, and we think it will be possible to move to a high-throughput tool such as chemical vapour deposition."

However, despite this process simplification, experimentalists have had difficulty producing quality a-axis $YBa_2Cu_3O_{7-x}$ films. The fabricated Josephson junctions were neither controlled nor reproducible due to surface roughness.

The characterization of Ambature's a-axis YBCO film was conducted at Cornell University. The researchers fabricated $YBa_2Cu_3O_{7-x}/PrBa_2Cu_3O_{7-x}/YBa_2Cu_3O_{7-x}$ trilayers grown on (100) $LaAlO_3$ by ozone-assisted molecular-beam epitaxy (doi.org/10.1063/5.0034648). They paid special attention to growth conditions that yield smooth surfaces and separately calibrating the flux of each element. Measurements indicated that the superconducting proximity length along the a-axis of $YBa_2Cu_3O_{7-x}$ was nearly an order of magnitude longer than along the c-axis, making the a-axis direction relevant for forming controlled and reproducible $YBa_2Cu_3O_{7-x}$ based Josephson junctions.

"A precisely controlled temperature ramp ensured that the YBCO films were smooth and high-quality," Kelly said. "The growth begins at a low temperature

‣ to seed a-axis YBCO layers and then ramps to a high temperature to improve the quality and smoothness of the film."

Technology Addresses Parasitic Heat and Quantum Decoherence

The researchers investigated the films using atomic-resolution scanning transmission electron microscopy (STEM). They assessed the structural quality of the material by X-ray diffraction (XRD) measurements. The findings suggested that high-performance Josephson junctions and other oxide electronics would be possible with precise control of growth conditions to create the required sharp interfaces and smooth surfaces.

Ambature notes that this technology addresses two basic problems: parasitic heat and short-lived quantum coherence. Parasitic heat caused by electrical resistance is the major obstacle to advances in semiconductor power, speed, efficiency, density, and reliability. Short-lived quantum coherence hinders progress in developing a number of quantum applications exploiting quantum effects, especially quantum computing.

"In general, there cannot be parasitic heat because superconductors do not have resistance," Kelly said. "More specifically, our films enable stacked three-dimensional circuit design because of the multi-directional current flow.

"The orientation of our a-axis films helps to increase the coherence length of Cooper pairs as they tunnel in a Josephson device. C-axis materials need to be fabricated into complex devices (ramp junctions) to align the optimal coherence length to the correct junction orientation. A-axis materials on the other hand are grown in the optimal orientation and can be simply fabricated into layered devices."

Based in Waterloo, Ontario and Scottsdale, Arizona, Ambature, Inc. is currently focused on designing superconducting quantum materials and devices to power an innovative and sustainable future. The company owns and offers licenses for over 200 patents, with over 3700 unique patent claims, worldwide. ■