Growing Extra-Long Superconductors

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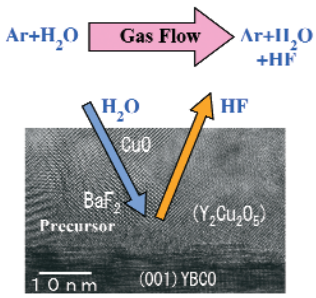
THE INTERNATIONAL SUPERCONDUCTIVITY TECHNOLOGY CENTER (ISTEC) was established as a nonprofit foundation in January 1988, with the approval of the Minister of Economy, Trade and Industry, Japan. The objectives of ISTEC are to contribute to the consistent advancement of superconductivity studies and the sound development of superconductivity-related industries. In October 1988, the Superconductivity Research Laboratory (SRL) was opened in Tokyo as the research laboratory of the ISTEC. Since then, the technology has matured to a point where superconducting materials are routinely being turned into products. Efforts are now being focused on developing longer coated superconductors, high-speed superconductors and low energy consuming superconductor devices, and on the continued search for new applications of bulk superconducting materials.

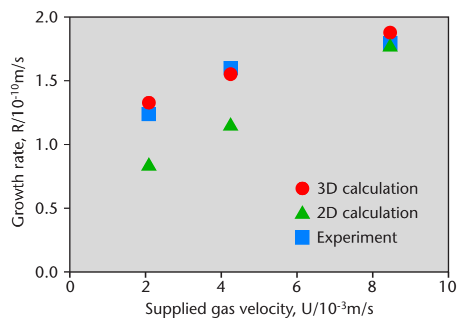
The Division of Superconducting Tapes and Wires at the SRL aims to develop a chemical solution process for creating long lengths – over 500m – of superconducting material. The superconductors are planned to carry a critical current of 200Amps at 77K. To keep the production costs low, a coating process called Metal Organic Deposition (MOD) will be used in a reel-to-reel continuous system. In this process, a thin film of the polycrystalline conductor yitrium barium copper oxide, or YBCO is created on a substrate. The substrate contains precursors consisting of metal trifluoroacetates (TFA). Water vapor (H_2O) is consumed in the process, and hydrofluoric gas (HF) is released. To be able to manufacture long and wide YBCO coated conductors with fast and constant growth rates, the gas flow system must be designed for surface reaction efficiency.

In experimental measurements of the YBCO growth rate, it was revealed (fortunately) that the growth rate is proportional to the square root of the molar fraction of H_2O in the supply gas, and that it is independent of the precursor thickness. This finding suggests that YBCO growth is limited by the H_2O and HF diffusion in the gas region, and that local equilibrium at the YBCO/precursor/gas interfaces is maintained during the process. Confirmation of the equilibrium condition is very important for treating the surface reaction problem precisely, because it is difficult to construct a precise non-equilibrium reaction model. To test the equilibrium hypothesis, a simple numerical YBCO growth and reaction model was developed as a special boundary condition for the gas flow region using user-defined functions (UDFs) in FLUENT.

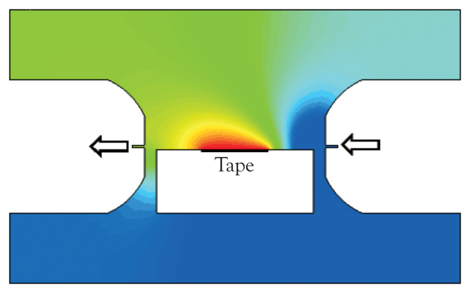
Two- and three-dimensional models were created, and used to predict the YBCO growth rate as a function of supply gas velocity. The results were compared to measurements made at the center of a 10mm square film in a basic reaction furnace. The 3D results were found to be in quantitatively good agreement with the experimentally measured values at all flow rates considered. The numerical model provided a precise calculation for the prediction of the YBCO growth rate in the MOD process. The computed HF molar fraction distribution on a transverse cross-sectional plane of the long-tape reaction furnace showed that a rapid and constant growth rate can be achieved using a suitable supply gas velocity. The results suggest that the numerical method using FLUENT can be used effectively to design a suitable gas flow configuration in the reaction tube for higher production rates for long YBCO coated conductors. ■



A cross-sectional picture of polycrystalline growth of the superconducting material YBCO in the precursor



A comparison of 2D and 3D FLUENT predictions and experimental measurements for YBCO growth rate as a function of supply gas velocity



Contours of HF mole fraction, released during the process, on a cross-section through the device, with supply gas passing over the substrate from right to left

Extra long superconductors are used for magnet coils for maglev trains; the coils are cooled in units such as these