Formation of Artificially-Layered High-Temperature Superconductors Using Pulsed-Laser Deposition

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Summary

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Pulsed-laser deposition has been used to synthesize artificially-layered high-temperature superconductors. Novel thin-film $\text{SrCuO}_2/\text{BaCuO}_2$ superlattices have been synthesized which superconduct at temperatures as high as 70 K. These results demonstrate that pulsed-laser deposition and epitaxial stabilization can be effectively used to engineer artificially-layered thin-film materials.

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The layered structure of the copper oxide superconductors opens the possibility of forming novel materials by carefully controlling the epitaxial growth of sub-units of the crystal structures. Thin-film growth methods, such as pulsed-laser deposition (PLD), offer unique opportunities for the atomic engineering of new high-temperature superconducting (HTSc) materials through the ability to form artificially layered crystal structures. Moreover, the surfaces of single-crystal substrates provide an "atomic template" that can be used to stabilize epitaxial films in metastable crystal structures. A necessary milestone in the effort to form new artificially-layered HTSc structures is to control the growth of "infinite layer" $(\text{Ca,Sr})\text{CuO}_2$ films at the unit-cell level (~ 3.4 Å). The infinite-layer structure can be viewed as a fundamental building unit of all of the HTSc cuprates.

We have recently demonstrated that unit-cell control of $(\text{Sr,Ca})\text{CuO}_2$ growth can be achieved using pulsed-laser deposition over an oxygen pressure regime in which in situ surface analysis techniques, such as reflection high-energy electron diffraction, are not possible.¹ We have successfully grown $\text{SrCuO}_2/(\text{Sr,Ca})\text{CuO}_2$ superlattice structures utilizing a conventional PLD multi-target system operating at an oxygen pressure of 200 mTorr. X-ray diffraction peaks attributed to the superlattice structures are observed, even for $\text{SrCuO}_2/(\text{Sr,Ca})\text{CuO}_2$ superlattice structures with SrCuO_2 and $(\text{Sr,Ca})\text{CuO}_2$ layer thicknesses of a single unit cell (~ 3.4 Å). The x-ray diffraction data also reveal finite-thickness oscillations in the x-ray intensity, which is indicative of films with extremely flat surfaces. The growth of superlattice structures by PLD is made possible, in large part, by this surface flatness.

Utilizing this capability, we have also synthesized a new series of artificially-layered HTSc compounds, grown as $\text{SrCuO}_2/\text{BaCuO}_2$ crystalline

superlattice structures.² While previous efforts to grow artificially-layered cuprate structures have been restricted to sophisticated MBE-like apparatus using in situ surface analysis techniques, we have formed these materials simply using pulsed-laser deposition. By sequentially depositing from BaCuO₂ and SrCuO₂ ablation targets in a PLD system, artificially-layered crystalline materials were constructed in which the layering sequence was controlled on nearly the atomic-layer scale. The SrCuO₂ and BaCuO₂ layers are epitaxially stabilized in the infinite layer structure, and form the building blocks for the compounds. Note that SrCuO₂ in the infinite layer structure is an insulator, while BaCuO₂ normally does not form the infinite layer structure, even by high-pressure synthesis techniques. Utilizing this approach, we have synthesized a new HTSc series, Ba_mSr_{n-1}Cu_{n+1}O_{2n+m+8} with $T_c(\text{onset})$ and $T_c(\text{resistance, } R=0)$ as high as 70 K and 50 K, respectively. These results represent not only the synthesis of new structural families of superconductors, but also demonstrate that pulsed-laser deposition and epitaxial stabilization can be effectively used to engineer artificially-layered thin-film materials.

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