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Metal buffer layers and Y-Ba-Cu-O thin films on Pt and stainless steel using pulsed laser deposition

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A versatile pulsed laser deposition chamber was employed for fabricating metal buffer layers and superconducting YBaCuO thin films on metallic substrates. Ag buffer layers were found to improve the resistive transition behavior for superconducting films on Pt and stainless steel. As-deposited YBaCuO films with T_c ($R = 0$) at 84 K were produced on stainless steel using *in situ* laser-deposited Ag buffer layers. The critical current density was measured to be approximately 10^3 A/cm^2 at 67 K.

Pulsed laser deposition is a demonstrated technique for fabricating high-temperature superconducting thin films with excellent resistive transitions (T_c) and high critical current densities.[1–4] This technique offers several desirable characteristics for film fabrication, including rapid deposition rates, congruent material transfer, and simple target requirements. In addition, because photons induce material removal, a variety of films can be deposited without the need for a specialized atmosphere. Therefore, multilayers requiring diverse operating conditions can be readily fabricated.

Most high-temperature superconducting thin films have been deposited on single-crystal substrates, especially $SrTiO_3$. Although single crystal substrates promote the growth of oriented epitaxial films and are suitable for electronic applications, these substrate materials are not suitable for conductor applications, such as electric power transmission and energy storage using magnetic tapes. Metal substrates and metal buffer layers may be required for these applications. We have studied the pulsed laser deposition of YBaCuO (YBCO) thin films on stainless steel and platinum. Our results show that YBCO superconducting films on these substrates can be improved by the use of *in situ* laser deposited metal buffer layers. Among the metals investigated, Ag was found to act as the best buffer layer for improving the resistive transition, consistent with numerous reports on the compatibility of Ag with YBCO.[5–12]

A diagram of the deposition chamber used in this work is shown in Fig. 1. The chamber is equipped with two quick-access doors that allow rapid replacement of the substrates and targets. The target holder can accommodate four separate materials simultaneously with the ability to rotate each material into the laser beam. The individual targets are not rotated during the deposition process and shallow craters are formed in the YBCO targets. We verified that this procedure is satisfactory by our ability to fabricate as-deposited superconducting YBCO films on $SrTiO_3$ with T_c ($R = 0$) at 91.6 K. The rotary push/pulls provide flexibility in adjusting the spacing between the target and substrate. This system can be expanded to incorporate additional heater/substrate assemblies with the capability of depositing several films sequentially.

A Lumonics XeCl (308 nm) excimer laser with 1 J/pulse and a repetition rate of 1 Hz, and a Questek KrF (248 nm) excimer laser with 650 mJ/pulse operated at 5 Hz were compared to deposit the buffer layers and YBCO films; both provided similar thin film properties. The Questek laser produced a sharp-edged beam intensity profile and did not require an aperture. The Lumonics produced a diffuse profile, especially at the edges of the beam. Improved superconductive transitions were obtained when this beam was apertured. In all cases, the energy density on the targets was adjusted to approximately 3 J/cm^2 for YBCO deposition and 1–3 J/cm^2 for the metal buffer layers. Pulse duration was approximately 25–30 ns from each laser. The difference in pulse repetition rate of 1 or 5 Hz and the resultant increased deposition rate per second showed no apparent influence on superconductive properties of the YBCO films, in agreement with recent reports.[13,14]

We deposited silver and platinum buffer layers on stainless steel, platinum, and several single-crystal substrates (MgO, $SrTiO_3$). On the metal substrates, improved super-

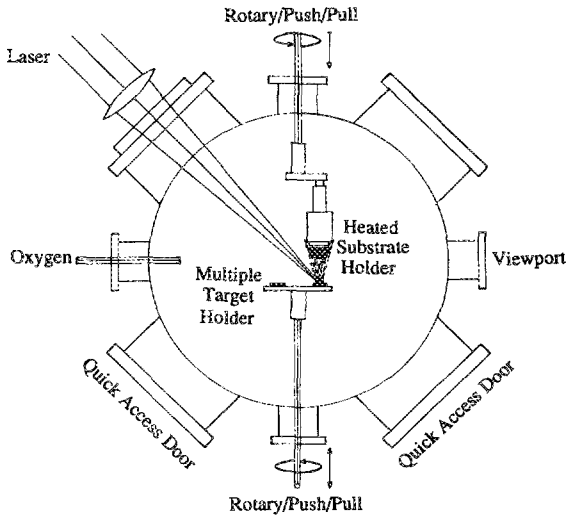

FIG. 1. Top view of the vacuum chamber with multiple target holder for laser deposition of buffer layers and superconducting thin films.

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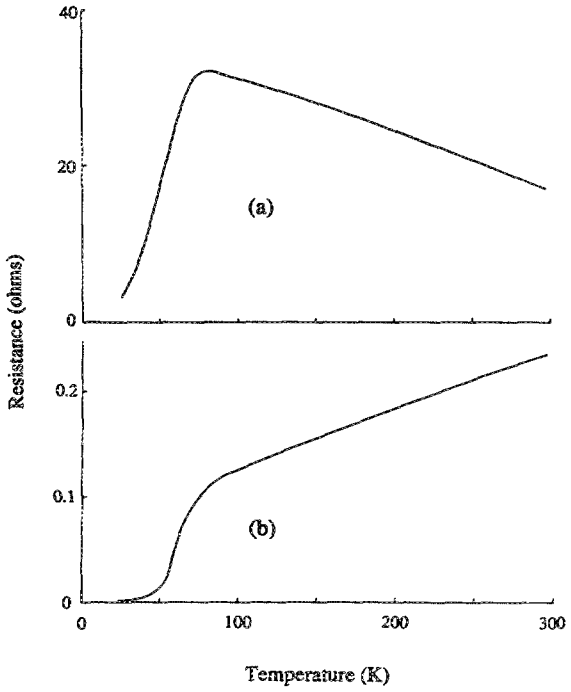

FIG. 2. YBCO thin films laser deposited on (a) platinum, and (b) platinum with a 3000-Å silver buffer layer. Each film was annealed for one hour at 850 °C in oxygen.

conducting transitions were always obtained for YBCO films using a Ag buffer layer. YBCO films on Pt buffer layers were usually insulating or exhibited semiconductorlike transitions that never reached zero resistance, even after post annealing in oxygen. These poor results may be due to the quality of the Pt buffer layers, although x-ray diffraction of Pt on MgO indicated an oriented polycrystalline film. A Pt buffer layer was reported to increase the critical current density for ErBaCuO films deposited on sapphire.[15]

We obtained the best Ag buffer layers for those deposited at 200 C in a vacuum of 10^{-6}–10^{-5} Torr, conditions similar to those reported for Ag films on Si.[16] At higher temperature and pressure, the Ag layers were porous and milky. At the lower temperature and pressure, a reflective silver layer uniformly covered the substrate surface. After depositing the silver layer, the pressure and temperature were increased to the conditions for the individual YBCO films.

Although we were not able to produce superconducting YBCO films on Pt buffer layers, we were able to do so on Pt substrates. Figure 2 shows the resistive transitions for 1-μm-thick YBCO films on Pt and on Pt with a 3000-Å Ag buffer layer. The substrate temperature was 450 °C and pressure 10^{-4} Torr oxygen for the deposition of the YBCO films. Both films were annealed at 850 °C for 1 h in oxygen. Superconducting transitions were only obtained by depositing the YBCO at this low temperature and pressure, and post annealing the films. Films made on Pt and on Pt with the Ag buffer layer near 700 °C and 200 mTorr pressure were porous and insulating; they could not be improved by annealing. The YBCO films deposited at the lower temperature were uniform and smooth with low normal-state resistance. It is interesting to note that these films exhibited superconducting transitions despite the use of an annealing temperature higher than the deposition temperature at which the films were demonstrated to be insulating.

In most cases, YBCO films did not exhibit a superconducting transition when deposited directly onto Pt. However, the few that did have a transition [for example, film 2(a)] exhibited higher normal state resistance with more semiconductorlike behavior than those using a Ag buffer layer. The normal state resistance for film 2(a) is 100 times greater than that of film 2(b) which was deposited and annealed under the same conditions, but contained the Ag buffer layer. The resistive transitions were always more metallic and narrower for the YBCO films using a Ag buffer layer. For film 2(b), the shape of the transition may be due to low oxygen or to residual interaction of the YBCO material with the Pt substrate. Research is underway to examine the interfaces of these multilayers using transmission electron microscopy.

Figure 3 shows resistive transitions for 1-μm-thick YBCO films deposited on stainless steel and stainless steel with a 500-Å Ag buffer layer. For these YBCO films, the pressure was 300 mTorr (oxygen) and the substrate temperature 700 °C. In contrast to the Pt, good superconducting transitions were obtained for these films as-deposited and without post annealing. As observed with Pt, the transition for YBCO on stainless steel was always better when a Ag buffer layer was used. The normal state resistance was a factor of 10 greater without the Ag buffer layer and the transition exhibited a long tail before reaching zero resistance at about 65 K [film 3(a)]. With the Ag buffer layer the T_c ($R = 0$) was 84 K, an improvement of twenty degrees [film 3(b)]. The flat shape of the resistance versus temperature curve may be due to incorporation of Fe or other metals from the stainless steel into the YBCO film; metals such as Fe, Ni, and Zn can be substituted for Cu and influence the normal-state behavior.[17] The critical current density J_c for the YBCO/Ag/stainless-steel configuration was measured to be approximately 10^3 A/cm^2 at 67 K. In magnetic fields of a

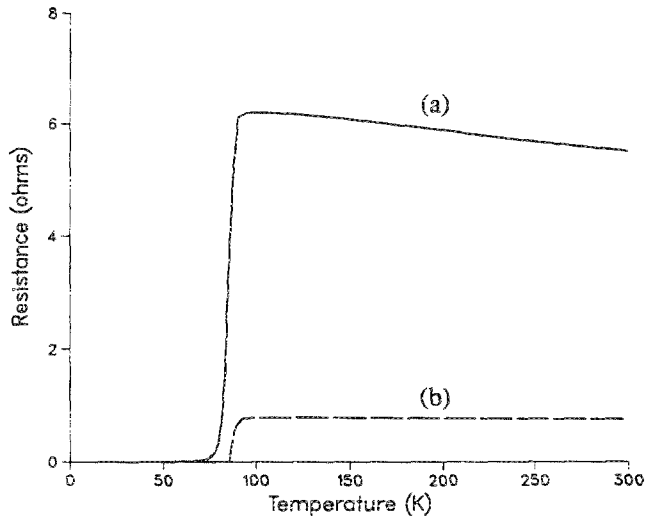

FIG. 3. As-deposited YBCO films on (a) stainless steel, and (b) stainless steel with a 500-Å silver buffer layer. The deposition temperature was 700 °C and oxygen pressure 300 mTorr.

few thousand gauss, J_c declined by three orders of magnitude. Thus, the critical current behavior was similar to that for good quality unoriented bulk YBCO. In agreement, x-ray diffraction analysis indicated that the film contained primarily the 123 phase with random orientation. Improvement in the quality of the buffer layer may enhance the superconductive properties of the films as has been demonstrated for YBCO on sapphire, Si, and other substrates.[12,15,18,19]

In summary, *in situ* laser deposited Ag buffer layers were found to improve the superconducting behavior of YBCO thin films on metal substrates. Pt buffer layers could not be used for fabricting superconducting YBCO films although these films could be deposited on Pt when a Ag buffer layer was used. Ag buffer layers were found to improve the superconducting transition of YBCO on stainless steel with T_c ($R = 0$) at 84 K.

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Efficient time integration of a viscoplastic model for shock waves

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An unconditionally stable numerical procedure is developed to integrate the stiff differential equation associated with the flow rule for viscoplasticity used by Swegle and Grady [J. Appl. Phys. **58**, 692 (1985)] to predict shock structure. Following the work of Rubin [J. Appl. Math. Phys. ZAMP **40**, 846 (1989)] the flow rule is integrated implicitly and is converted into a scalar equation. It is shown that for the Swegle–Grady model this scalar equation reduces to a quadratic equation that can be solved without iteration.

Recently Swegle and Grady[1,2] introduced a specific model for viscoplasticity which successfully predicts the shock structure observed in the particle velocity time histories measured in plate impact experiments on a number of materials. As is typical, the specific model for viscoplasticity causes the constitutive equations to become a stiff system which must be solved with special methods. Swegle and Grady[1] used the standard method of subincrementing to overcome this problem. However, this approach can be relatively inefficient and the conditions for stability of the integration procedure are somewhat arbitrary. The objective of this communication is to describe a method for efficiently integrating the stiff differential equations associated with the model of viscoplasticity used by Swegle and Grady[1,2] to predict shock structure.

Rubin[3] has developed a numerical procedure for efficiently integrating the differential equation for plastic defor-

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