Synthesis of Y–Ba–Cu–O thin films by laser annealing

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Developing high-temperature superconducting films with superior critical properties is an extremely important problem. The synthesis of superconducting films of perovskite ceramics by a variety of methods has been reported in several papers.[1,2] Better results have been achieved for films of the Y−Ba−Cu−O system. The temperature at which the superconducting transition begins is $T_c \approx 94$ K, the width of this transition is $\Delta T_c \approx 10\text{-}30$ K, and the critical current density is $J_c \approx 10^3$ A/cm^2. The apparent reason for the large value of ΔT_c and the low values of j_c is that the compounds which have been synthesized are imperfect and contain other − nonsuperconducting − phases. In addition, the methods used to synthesize the superconducting films in Refs. 1 and 2 are of limited applicability because of two serious drawbacks: 1) The films must be subjected to high-temperature annealing at ~600-900°C after they are deposited. This requirement is incompatible with semiconductor technology in most cases. 2) The films having the critical properties specified above were synthesized primarily on $SrTiO_3$ substrates, although this material is not widely used.

In this paper we report the synthesis of thin (≤ 1 μm) superconducting films of the compound $Y_1Ba_2Cu_3O_7$ with $T_c \approx 96\text{-}102$ K and with a superconducting width $\Delta T_c \leq 3$ K. The superconducting films were synthesized by the laser annealing of the surface of a sample consisting of a finely disperse mixture of oxides of yttrium, barium, and copper. The finely disperse stock material was prepared by a chemical method.[3] The nitrates of barium, copper, and yttrium were dissolved in nitric acid in the required stoichiometric proportions of the components Y, Ba, and Cu. After evaporation of the solutions and deposition, the resulting mixture was annealed in air at ~900°C for several hours. The results of chemical, x-ray, and thermal analyses showed that the finely disperse mixture obtained as a result consists of the oxides of Y, Ba, and Cu in which these components are present in the gives stoichiometry. From this mixture we pressed tablets 5.0 mm in diameter and ~1 mm thick. The surfaces of the resulting tablets were subjected to laser annealing, which produced a thin (≤1 μm) superconducting layer of the compound $Y_1Ba_2Cu_3O_7$.

The laser annealing was carried out in an oxygen atmosphere by running a laser beam 200 μm in diameter (at the 1/e level) in a raster over the surface of the tablet at a scan step of 50 μm. The length of the laser pulse at half-maximum was 50 ns, and the wavelength of the light was λ = 1.06 μm. The radiant energy density was varied over the range 0.01–1.00 J/cm^2.

To obtain the required stoichiometry in the resulting film, we carried out the laser annealing in an oxygen atmosphere at pressures up to 100 atm.

The superconducting transition was detected from the change in the relative magnetic suscepti-

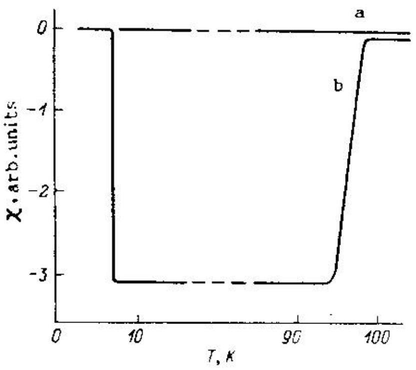

FIG. 1. Relative magnetic susceptibility versus the [illegible] a) Before; b) after laser annealing.

bility χ_{rel} as the temperature was varied. [illegible] frequency and amplitude of the modulating [illegible] field were 41 Hz and 30 Oe, respectively. [illegible] sample temperature was measured in the rang[illegible] 4.2-300 K by a TSU-1 carbon resistance the[illegible] to within 0.5 K. The diamagnetic response [illegible] the test sample was compared with that from [illegible] sample of known geometry, positioned in a co[illegible]pensating coil.

Fig. 1 shows the relative magnetic susc[illegible] versus the temperature for the films of the [illegible] Cu−O system which we synthesized. The ju[illegible] χ_{rel} at 7.2 K (Fig. 1) is a consequence of the [illegible] conducting transition of the lead, normalized [illegible] a thickness of 1 μm. The temperature at whic[illegible] superconducting transition begins for these Y-[illegible] Cu−O films was 98 K. The width of the sup[illegible]ducting transition between the levels 0.1 and [illegible] of χ_{max} was 3 K. Also shown in this figure is a plot of χ_{rel} versus the temperature for a ta[illegible] which was not subjected to laser annealing (li[illegible]

An estimate of the diffusion range ℓ_{diff} of the components of the stock material for these laser-annealing conditions yields $\ell_{diff} \approx 0.1$ μm. [illegible] figure is an order of magnitude greater than [illegible] dimensions of the CuO, BaO, and Y_2O_3 crystal[illegible] in the finely disperse stock material. Accordi[illegible] the comments above and a comparison of the a[illegible]plitudes of the diamagnetic response from lead [illegible] the Y−Ba−Cu--O film (Fig. 1) suggest that this Y−Ba−Cu−O film has a high concentration (~1[illegible] of the $Y_1Ba_2Cu_3O_7$ superconducting phase. In several cases we obtained samples in which the superconducting transition began at 102 K. The critical current density j_c measured at 77 K in zero magnetic field was not less than (5-8)·10[illegible] for the better samples. The values cited for j_c here are lower estimates, since we were not ab[illegible] to determine the thickness of the resulting sup[illegible]conducting film on the tablet very accurately, [illegible] we were not able to achieve a reliable ohmic co[illegible] with the test samples.

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this study has shwn that it is thesize high-temperature supercon- by the method of laser annealing a finely disperse stock material. this method will make it possible thin films of high-temperature super- various semiconducting and insulating the deposition of a finely disperse various substrates is a problem which solved.

We wish to thank S. V. Gaponov for a useful discussion of these results.

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spectroscopy of surface centers in silicon in metal–oxide–onductor structures

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Raman spectra of metal–oxide–semiconductor on a silicon surface reveal an emission electron–hole pairs which are bound with a charge layer (the S line[1,2]). At a high charge density n_S the surface pairs exist form of a two-dimensional (2D) plasma with separate electron and hole layers. The position of the S line is determined in this the depth of the Fermi level of the 2D the surface-charge layer and by the of the electron–hole correlation interac- 3) meV (Ref. 1). At low values of n_S pairs exist in the form of excitons a surface-charge layer.[3]

the present experiments on a number of on the (100) surface of phosphorus-doped we have observed a new line on the long- side of the S line in the spectrum. line comes from the radiative recombination electrons and holes which are localized at centers (the D line; Fig. 1). As the gate is increased, this new line arises after a is reached during the formation of an space-charge layer. This spectral position line is determined by the depth of the level of the 2D electrons in the quantum well the binding energy of a hole at a surface At a low density of two-dimensional the binding energy of a hole at a surface about 45 meV, and the spectral peak of lies 25 meV lower in energy than the line of an exciton bound to a neutral donor phorus). As n_S increases, this line shifts long-wavelength direction because of an in- the depth of the electron Fermi level in quantum potential well. At low values of n_S spectral width of the D line is determined by width of the band of hole energy levels in the band bending region near the surface and by fluctuations of the surface potential. The in this case is substantially greater than Fermi energy of the 2D electrons. At large of n_S, its spectral width becomes approxi- the same as the Fermi energy of the 2D electrons, and it increases with increasing n_S. of the spatial separation of the electrons and holes we observe a short-wavelength shift of the D line with increasing excitation level. This shift is approximately equal to $\Delta\mu_D \approx 4\pi e^2 \epsilon_0^{-1} \cdot n_p Z_d/2$, where n_p is the density of localized holes, $z_d/2$ is the average distance from the surface to the holes, ϵ_0 is the dielectric constant of the silicon, and e is the charge of an electron. By determining

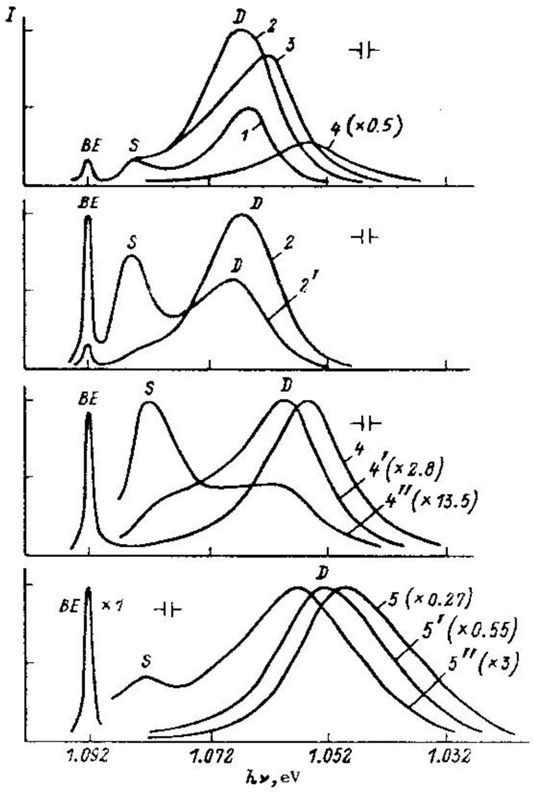

FIG. 1. Recombination radiation spectra of silicon at T = 1.9 K (MOS structure; Si:P with a donor density ~$3 \cdot 10^{15}$ cm^{-3}; TO–LO lines). The electron densities in the channel, n_S, are, in units of 10^{12} : 1) 0.07; 2, 2') 0.3; 3) 0.54; 4–4'') 1.47; 5–5'') 3.35. The excitation level, in units of W/cm^2, is: 1–5) 10^{-3}; 2'–5') 10^{-2}; 4'', 5'') 10^{-1}.

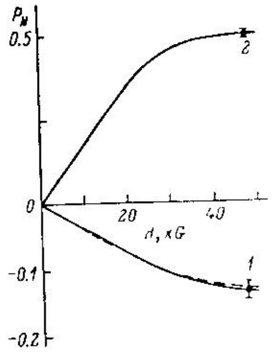

FIG. 2. Degree of circular polarization of the recombination radiation of silicon, P_N, versus the magnetic field H at T = 1.9 K. 1) TO—LO—D line, $h\nu \approx 1.071$ eV, $n_S = 5.4 \cdot 10^{11}$ cm^{-2}; 2) TO line of a bound exciton (BE), $h\nu \approx 1.092$ eV. The excitation level is $5 \cdot 10^{-3}$ W/cm^2.

the nonequilibrium hole density n_p from measurements of the short-wavelength shift of the S line in the case of a (100) hole layer,[4] and also using $\Delta\mu_D$, we find the average distance from the surface to the localized holes to be $Z_d/2 \sim (2\text{-}3) \cdot 10^{-6}$ cm. In this case the maximum short-wavelength shift corresponds to completely filled surface centers with a density $n_d = n_p \sim 10^{10}$ cm^{-2}. We suggest that these surface centers are boron acceptor atoms. An excess boron concentration ($\sim 10^{16}$ cm^{-3}) may arise near the surface during the deposition of the semitransparent metallic gate of boron-doped polycrystalline silicon on the oxide. When the emission is detected along the direction perpendicular to the surface, we observe in the Faraday geometry (Fig. 2) circular polarization of the LO—D emission line, due to the orientation of the heavy holes in the magnetic field. The energy level of the light holes is split off by the surface electric field and does not contribute to the emission. The TO—D emission line is unpolarized in a magnetic field because of the orbit-valley splitting of the states of the 2D electrons. The average degree of circular polarization of the resultant TO—LO—D emission line is

$$P_N = I_{LO}(I_{LO} + I_{TO})^{-1}\, th(3g_1\mu_0 H/2kT),$$

where $I_{LO}/I_{TO} \approx 0.14$, μ_0 is the Bohr magneton, H is the magnetic field, kT is the temperature, and $g_1 \approx 0.6$ is the g-factor of the holes. The degree of polarization of the emission is essenti independent of the excitation level and of n_S. I reaches a maximum at the short-wavelength edge of the line in the region of the maximum contribu tion of the LO emission line. The absence of quenching of the TO—D line in a magnetic field a large values of n_S is evidence of a pronounced mixing of the hole states with angular momenta ±3/2 and ±1/2. When the emission is detected al a direction parallel to the surface, the TO—D lin in the absence of a magnetic field is polarized al the surface with a degree of linear polarization $(I_\parallel - I_\perp)/(I_\parallel + I_\perp) \approx 0.30$, confirming the conc sion regarding the 2D nature of the electrons. decrease in the intensity of the D line with incr ing n_S (Fig. 1) may be a consequence of a decr in the overlap of the electron and hole wave fun tions as a result of a decrease in the radius of t wave function of the 2D electrons.

We wish to thank A. A. Rogachev for usef discussions.

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Breakup of an individual solid particle in a collision with the surf of a moving object

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The supersonic flow of a dust-containing gas around a blunt object was studied experimentally in Refs. 1 and 2. The investigators observed the formation of a zone of elevated concentration of the disperse phase near the shock layer. It has been suggested that this effect is a consequence of the breakup of solid particles in collisions with the surface. In an effort to refine the model which has been proposed for the formation of a zone of elevated concentration of the solid phase, we have now carried out experiments on the collision of individual particles with a plane surface.

According to our estimates, most of the fragments which result from the breakup are less than 10 μm in size. It follows that in order to m the velocities of the fragments we should pr their slowing in the gaseous medium. The of solid particles with surfaces were acceler means of a gas jet; the maximum collision v was ~100 m/s.

To carry out some similar studies we ballistic method, which make it possible to the gas from influencing the motion of the and to study the collision process at encou ities ~850 m/s. We studied the collision o falling solid particle with an object hurled atory accelerator. The samples were incan steel cylinders whose leading edge was c

