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# Measurement of laser ablation threshold on doped BiSrCaCuO high-temperature superconductors by the pulsed photothermal deflection technique

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Laser-induced damage and ablation thresholds of bulk superconducting samples of $Bi_2(SrCa)_xCu_3O_y$($x$=2, 2.2, 2.6, 2.8, 3) and $Bi_{1.6}(Pb)_xSr_2Ca_2Cu_3O_y$ ($x$=0, 0.1, 0.2, 0.3, 0.4) for irradiation with a 1.06 $\mu$m beam from a Nd-YAG laser have been determined as a function of $x$ by the pulsed photothermal deflection technique. The threshold values of power density for ablation as well as damage are found to increase with increasing values of $x$ in both systems while in the Pb-doped system the threshold values decrease above a specific value of $x$, coinciding with the point at which the $T_c$ also begins to fall.

## I. INTRODUCTION

Studies on pulsed-laser-induced ablation from solid targets have recently gained great importance because of its potentiality for use as an alternative tool for the deposition of high-temperature superconducting thin films.[1,2] There exists a number of parameters such as the nature of the target, wavelength of laser radiation, and laser power that control the ablation process. Accurate knowledge of ablation threshold is essential in controlling the laser power for a given target in order to get good quality thin films. Various techniques are used to characterize the ablation process thereby yielding precise information regarding the etching rate, the velocity of ablation products, the threshold of ablation, etc.[3,4] Thermo-optic deflection (mirage effect) has recently been shown to be one such technique to measure the laser-induced damage threshold of a variety of targets including optical materials and polymers.[5,6] The photothermal deflection technique essentially consists of measuring the deflection of an optical beam (probe) due to the refractive index gradient in the vicinity of a sample surface generated by a pulsed/modulated pump beam. In the present case the technique employed, viz. photothermal deflection, exploits the signal due to the deflection and/or distortion of the probe beam caused by the thermal wave which occurs near the ablated sample. This technique has been used by Sell *et al.*[7] to measure the ablation threshold of high-temperature superconducting bulk YBaCuO samples using pulsed UV excimer laser. In the present communication we report the results of laser-induced ablation threshold measurements carried out on high-temperature superconducting samples of $Bi_2(SrCa)_xCu_3O_y$($x$=2, 2.2, 2.6, 2.8, 3) and $Bi_{1.6}(Pb)_xSr_2Ca_2Cu_3O_y$ ($x$=0, 0.1, 0.2, 0.3, 0.4) by irradiating the target with a Nd-YAG laser beam at 1.06 $\mu$m wavelength.

## II. EXPERIMENT

Samples of superconducting materials with varying Sr, Ca, and Pb concentrations were prepared by the well-known solid-state reaction matrix method.[8,9] The specimens were made into pellets of 1 cm diameter and the $T_c$ values were measured using the four-probe technique under vacuum conditions. The experimental setup to determine the laser-induced damage and ablation threshold of the samples is shown in Fig. 1. The ablation beam is a focused output of the pulsed Nd-YAG laser (DCR-11, Quanta Ray) operating at 1.06 $\mu$m (pulse width=10 ns). The refractive index gradient (RIG) generated in the gas surrounding the sample following the irradiation is probed by a stabilized 5 mW He-Ne laser (Spectra Physics) beam. A converging lens ($f$=25 cm) focuses the probe beam so that in the interacting region the probe beam diameter is smaller than that of the ablation beam. The probe beam, which is at right angles to the ablation beam, is allowed to pass, grazing the sample surface. A position-sensitive detector located at about 50 cm away from the sample mea-

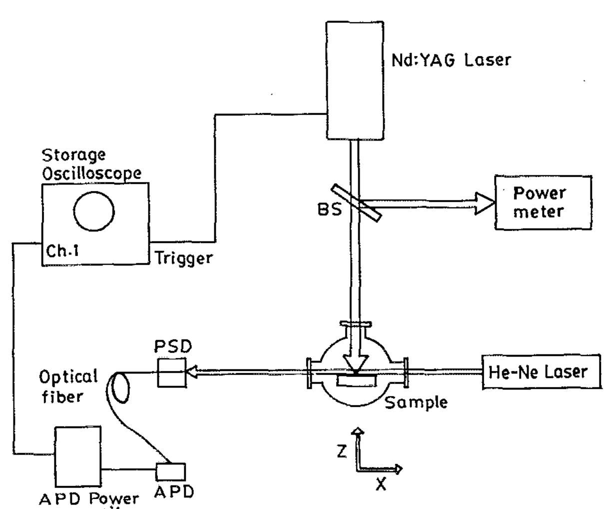


FIG. 1. Schematic diagram of the experimental setup.

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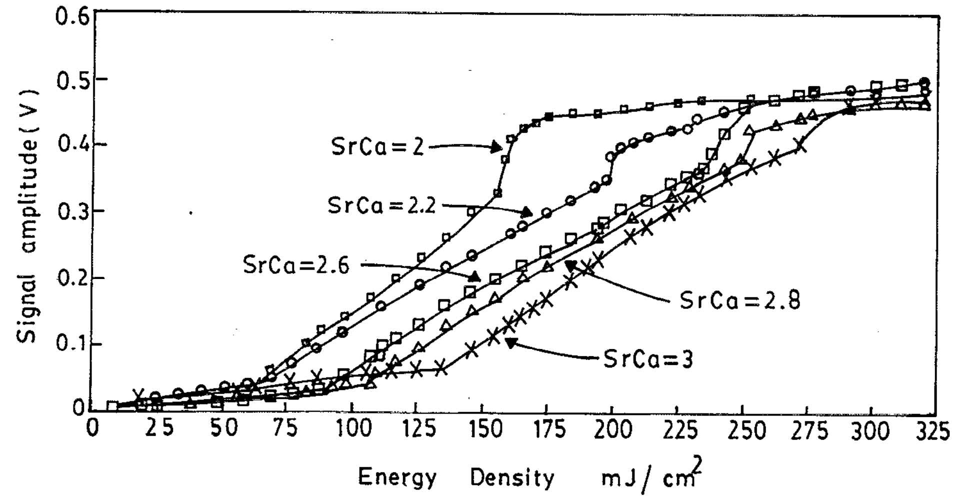


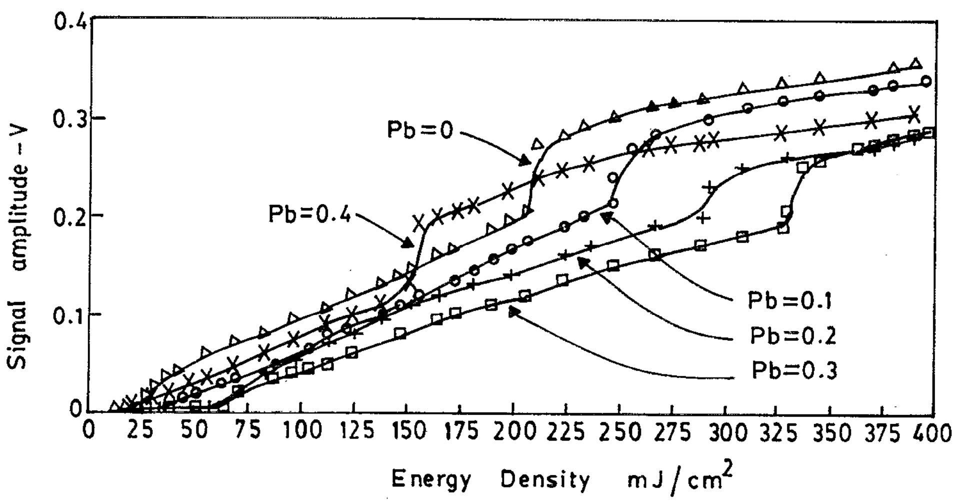


FIG. 2. Plot of laser energy density for (a) $Bi(SrCa)_xCuO$ for various $x$ values; (b) Bi $(Pb)_x SrCaCuO$ for various $x$ values.

sures the deflection of the probe beam due to the transient refractive index gradient generated above the laser-heated sample. The position-sensitive detector consists of the polished tip of a multimode optical fiber (200/380 $\mu$m) at one end and the other end is coupled to an avalanche photodiode.[10] The deflection signal amplitude was monitored with a cathode ray oscilloscope (CRO) (Tektronix model 466) for different pump energy densities. The incident laser power was measured using an on-line power meter (Delta Developments).

## III. RESULTS AND DISCUSSION

A plot of the incident energy density versus the signal amplitude is shown in Figs. 2(a) and 2(b). As the energy density is increased, an abrupt change in the deflection signal amplitude occurs corresponding to the onset of damage in the sample. At still higher fluences the signal amplitude keeps on increasing until it reaches a point where another abrupt change of slope occurs. This region evidently corresponds to the threshold of ablation. It should also be noted that at the ablation threshold, the CRO trace of the signal (Fig. 3) suddenly changes its overall shape. The ablation product has a focusing effect as far as the probe beam is concerned and consequently the signal goes momentarily positive before it begins to indicate the regular PTD signal shape. A similar thermal lensing effect at ablation has been observed by others.[7]

Variations in the damage as well as ablation threshold values were determined by changing the Pb and Sr-Ca concentrations of the superconducting samples [Figs. 4(a) and 4(b)]. Results obtained in various samples are given in Table I. It is observed that with increasing Sr, Ca concentration, both thresholds increase linearly, but in the case of Pb-doped samples, ablation and damage thresholds initially increase, reach a maximum value, and then begin to decrease with increase in Pb concentration. These results imply that incorporation of Sr,Ca with increasing concentration enhances the optical strength and/or thermal stability of the material while for Pb-doped samples there is an optimum concentration for which the ablation and damage thresholds attain maximum values. It is really striking to note that an exactly similar variation is observed in $T_c$ values also in the case of Pb-doped samples in which the stabilization of the 110 K superconducting phase takes place almost at the same value of $x$. The variation of laser-

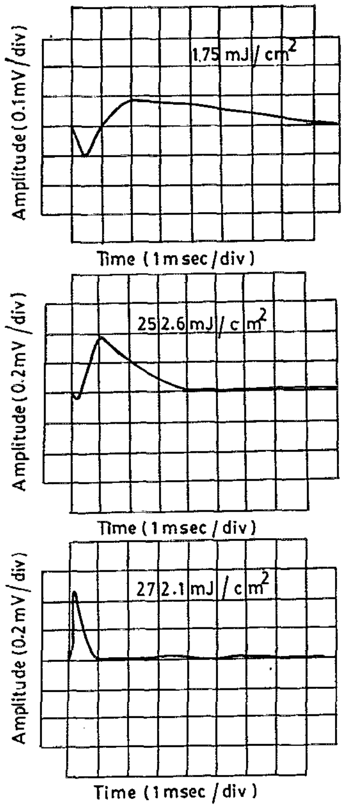


FIG. 3. CRO trace of the signal at different laser energy densities.

TABLE I. Laser-induced damage and ablation threshold and $T_c$ values for the superconducting samples.

| Sample | Damage threshold ($mJ/cm^2$) | Ablation threshold ($mJ/cm^2$) | $T_c$ (K) |
|---|---|---|---|
| $Bi_2Sr_2Ca_2Cu_3O_y$ | 58.03 | 172.32 | 79.2 |
| $Bi_2Sr_{2.2}Ca_{2.2}Cu_3O_y$ | 68.74 | 198.2 | 79.7 |
| $Bi_2Sr_{2.6}Ca_{2.6}Cu_3O_y$ | 93 | 235 | 80 |
| $Bi_2Sr_{2.8}Ca_{2.8}Cu_3O_y$ | 108.2 | 250 | 80.5 |
| $Bi_2Sr_3Ca_3Cu_3O_y$ | 136 | 272 | 81.5 |
| $Bi_{1.6}Pb_0Sr_2Ca_2Cu_3O_y$ | 26 | 203 | 85 |
| $Bi_{1.6}Pb_{0.1}Sr_2Ca_2Cu_3O_y$ | 42 | 247 | 93 |
| $Bi_{1.6}Pb_{0.2}Sr_2Ca_2Cu_3O_y$ | 55.1 | 287 | 100 |
| $Bi_{1.6}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ | 68.8 | 329 | 110 |
| $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_y$ | 23 | 155 | 104 |

induced damage and ablation thresholds follows the changes in $T_c$ with $x$, indicating that structural stabilization occurs at an optimum value of Pb concentration for the superconducting sample of BiSrCaCuO. This observation is in good agreement with the results of x-ray-diffraction studies of the above samples.[11–13]

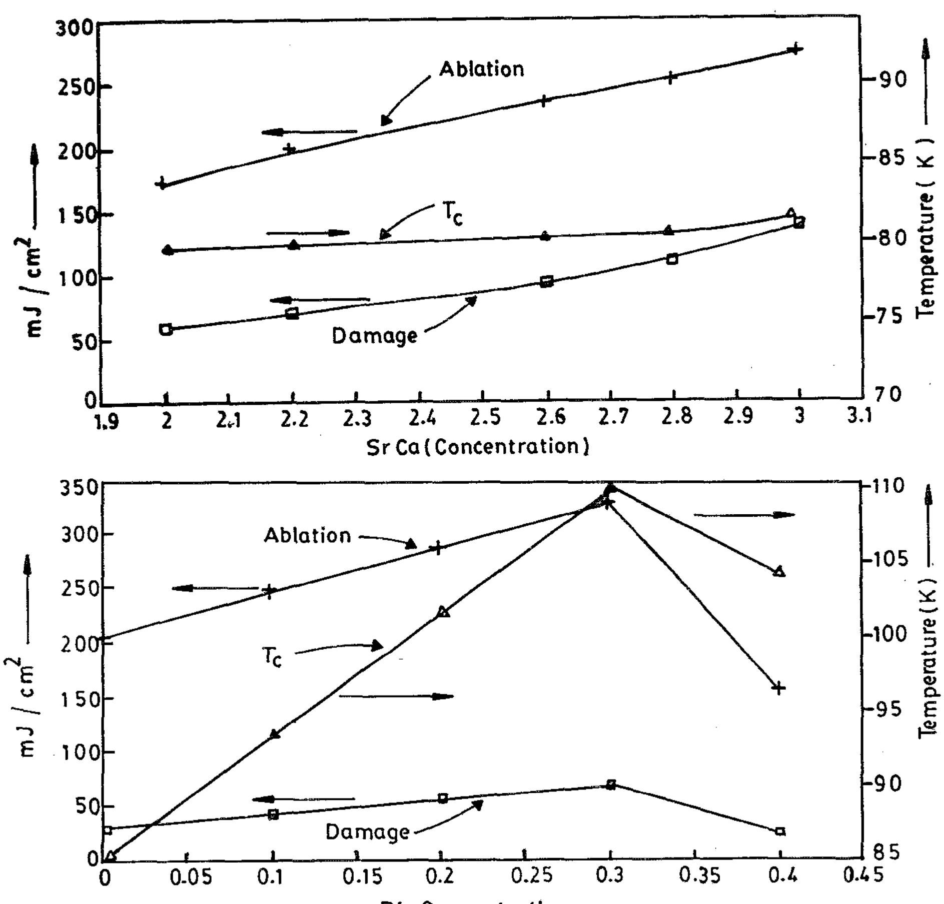


FIG. 4. Damage and ablation thresholds for various (a) SrCa concentrations, and (b) Pb concentrations.

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