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EFFECT OF SHOCK PRESSURE ON THE STRUCTURE AND SUPERCONDUCTING PROPERTIES OF Y-Ba-Cu-O IN EXPLOSIVELY FABRICATED BULK METAL-MATRIX COMPOSITES

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While it is now well established that copper-oxide-based powder, or virtually any other ceramic superconductor powder, can be consolidated and encapsulated within a metal matrix by explosive consolidation,[1,2] the erratic superconductivity following fabrication has posed a major problem for bulk applications. The nature of this behavior has been found to arise from microstructural damage created in the shock wave front, and the residual degradation in superconductivity has been demonstrated to be directly related to the peak shock pressure, as illustrated in Fig. 1a-d. The explosively fabricated or shock loaded $YBa_2Cu_3O_x$ ($x \cong 7$) examples exhibit drastically altered ρ (or R) - T curves (Fig. 1c-d). The normal state resistivity is increased by as much as 20 to 100 times after explosive (shock wave) processing and shows a negative temperature dependence having essentially the same slope; characteristic of semiconductor-like behavior. The superconducting transition is considerably broadened to lower temperatures with increasing shock pressure. Correspondingly, as shown in Fig. 1a, the range of order is reduced and the orthorhombic peak broadening is increased in proportion to increasing shock pressure (Fig. 1b).

The deterioration in superconductivity is even more noticeable in the measurement of a.c. magnetic susceptibility and flux exclusion or shielding fraction (χ/χ_0) which is also reduced in proportion to increasing peak shock pressure. The high-frequency surface resistance (in the GHz range) is also correspondingly compromised in explosively fabricated, bulk metal-matrix composites based on $YBa_2Cu_3O_7$.

The superconducting as well as the normal-state conducting behavior of $YBa_2Cu_3O_x$ is known to be sensitive to the value of x.[3] Since the oxygen atoms in the b chain are the most weakly bound, the loss of oxygen during shock loading or explosive fabrication was originally suspected to be the cause of the degradation observed in Fig. 1c-d. However, comparative thermogravimetric analysis of the samples subjected to the lower peak shock pressures indicated that while the shocked samples exhibited higher chemical reactivity, consistent with the peak broadening ($\Delta 2\theta$) shown in Fig. 1a-b, there was no loss of oxygen,[4] and this was further supported by the fact that, as shown in Fig. 1e-f, the samples failed to recover T_c upon annealing and cooling in flowing oxygen until about 930°C. This difficulty in recovering the resistivity-temperature signature in shock-loaded, bulk $YBa_2Cu_3O_7$ is in marked contrast to the behavior of ion-beam irradiated thin films where the damage is easily annealed out and T_c restored even at room temperature.[5] Consequently, the nature of the damage (the microstructural defects generated) may be very different in each case. Furthermore, variations in oxygen stoichiometry (x) have been shown to shift the T_c onset (T_c decreasing with decreasing x)[3] while the onset remains at $T_c \cong 90K$ at low shock pressures (Fig. 1c).

Transmission electron microscopy (including lattice imaging techniques) is being applied in an effort to elucidate the fundamental (microstructural) nature of

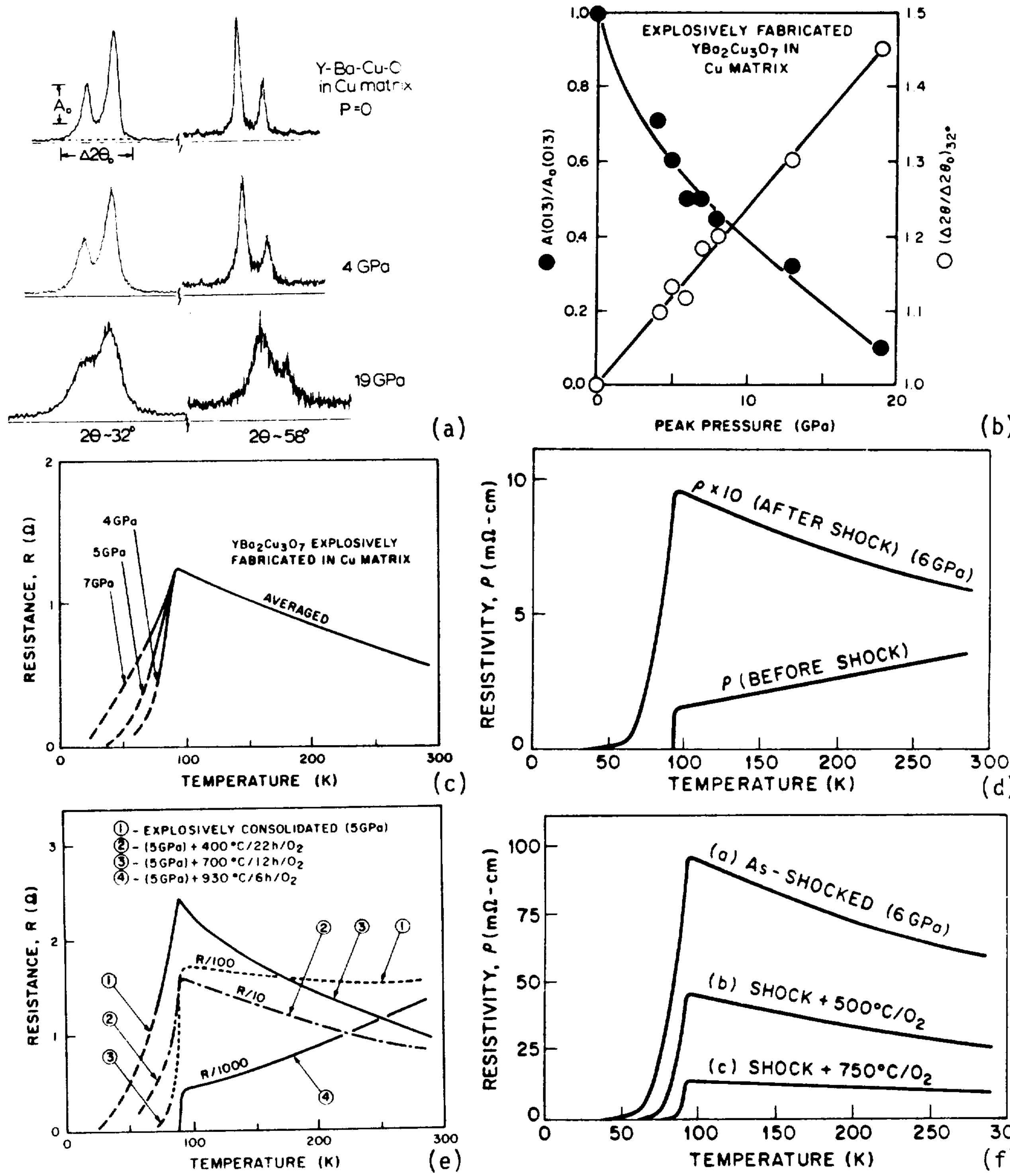

FIG. 1: X-ray (orthorhombic) split-peak signature variation for explosively fabricated $YBa_2Cu_3O_7$ powder (a) and quantitative variation with pressure (b). (c) and (d) show ρ (or R) - T curves for explosively fabricated (consolidated) $YBa_2Cu_3O_7$ powder extracted from a copper matrix and sintered bar of $YBa_2Cu_3O_7$ before and after plane-wave shock loading, respectively. (e) and (f) show corresponding annealing and T_c recovery of explosively fabricated and plane-wave shock loaded $YBa_2Cu_3O_7$ (data in (d) and (f) are reproduced from reference 4).

the shock-induced degradation of superconductivity and normal state conductivity. One "focus" of TEM observations has assumed that, as illustrated schematically in Fig. 2a-b, oxygen displaced from b-chains rather than oxygen-vacancy disorder in the basal plane of oxygen deficient $YBa_2Cu_3O_x$ (6.75 > x > 6.25) may be a prime mechanism. Shock-wave displaced oxygen may also be locked into new positions or interstitial clusters or chemically bound to displaced metal (possibly copper) atoms to form precipitates, or such displacements may cause the equivalent of local lattice cell changes as a result of stoichiometric changes. Some evidence for these phenomena are illustrated in the TEM images reproduced in Fig. 2c-d.

While the shock-induced suppression of T_c is not desirable in the explosive fabrication of bulk metal-matrix superconductors, we hope it may be turned into an advantage if the atomic-scale distortion can be understood and controlled as local flux pinning sites. The peak shock pressure cannot be lowered without compromising the cladding of the metal matrix assembly and some requisite density for the consolidated, encapsulated superconducting powder. Consequently, some adjustments must be made in other process or materials parameters.

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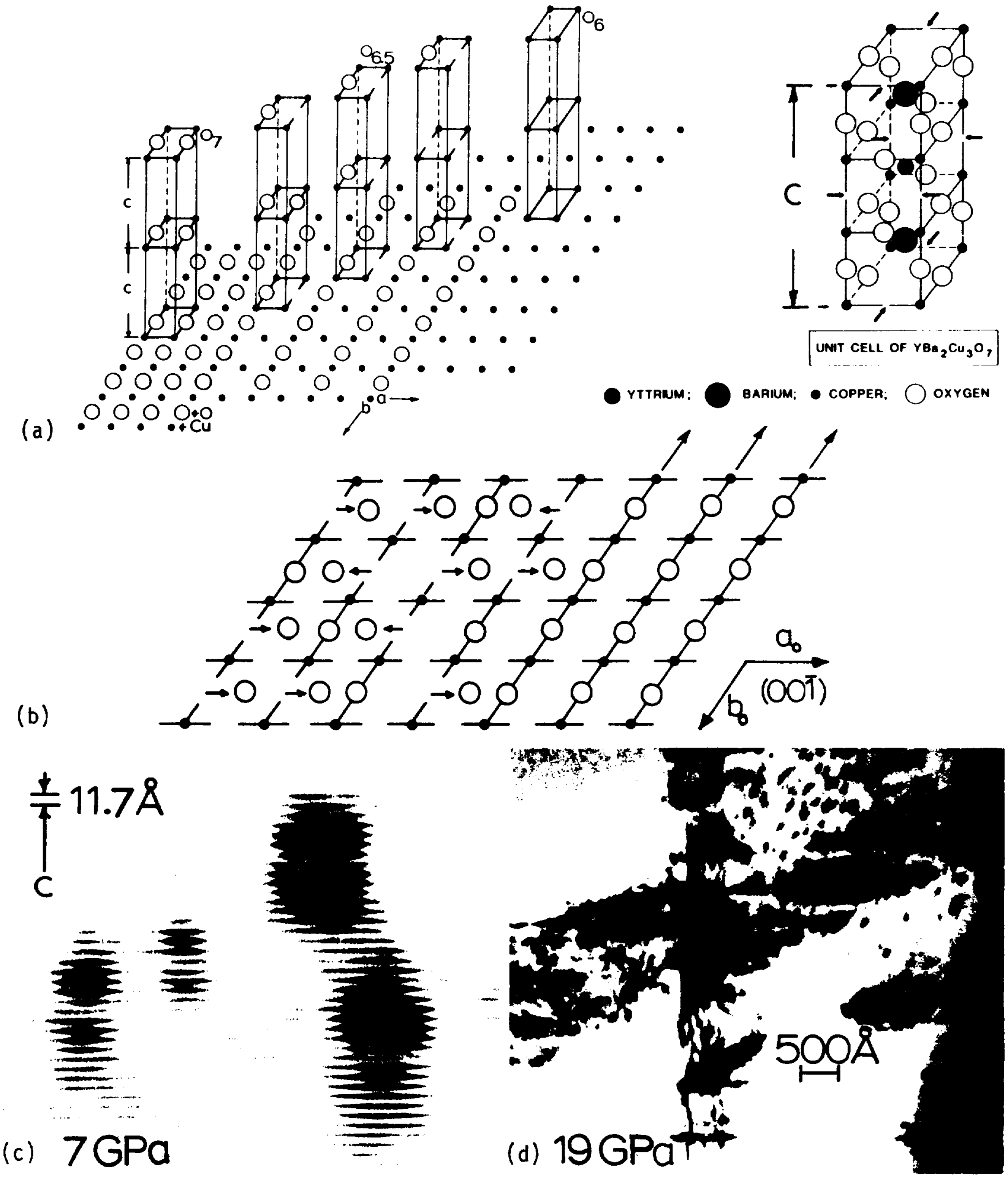

FIG. 2: Basal-plane oxygen (vacancy) order-disorder along b-chains with decreasing oxygen (a) and simple oxygen displacement creating interstitial defects in the shock front (b). (c) and (d) show TEM lattice and diffraction contrast images of atomic clusters, loops, and lattice strain in the explosively consolidated $YBa_2Cu_3O_7$.