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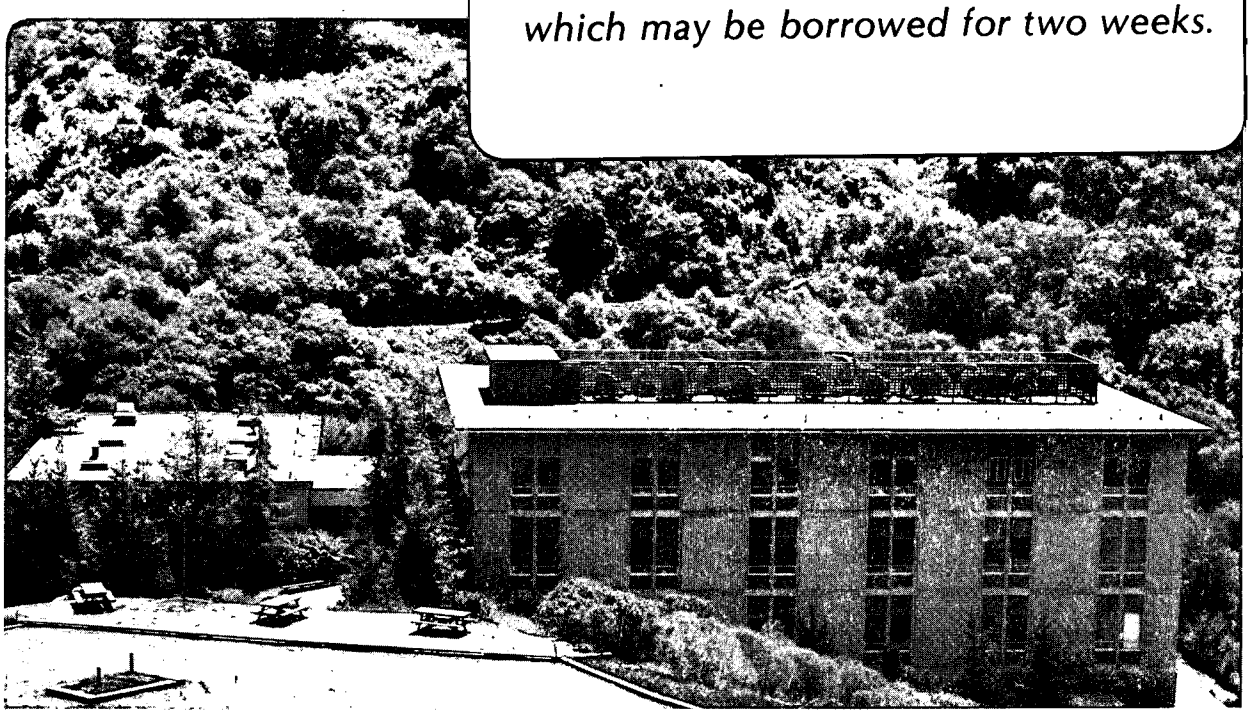

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DECORATION OF FLUX PINNING POSITIONS IN $YBa_2Cu_3O_{7-\delta}$ SUPERCONDUCTORS

C.J. Jou, E.R. Weber and J. Washburn

Department of Materials Science and Mineral Engineering
University of California
Berkeley, CA 94720

and

Materials and Chemical Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

W.A. Soffa

Department of Materials Science and Engineering
University of Pittsburg
Pittsburg, PA 15260

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Flux pinning in the sintered high Tc oxide superconductors, $YBa_2Cu_3O_{7-\delta}$, in the vortex state has been demonstrated for the first time using the Bitter pattern technique and scanning electron microscopy. External magnetic fields of 150 Gauss (G) or 800 G perpendicular to the specimen surfaces were applied during the evaporation of cobalt after the specimens cooled with liquid nitrogen had reached a temperature below Tc. All specimens thus decorated with cobalt show non-uniformly distributed flux pinning positions as would be expected due to the porosity and multiphase character of the specimens as well as the relatively low field applied.

The direct observation of the flux-line arrangement in a type II metallic superconductor, Pb(6.33 at.%)-In, was clearly demonstrated by H. Trauble and U. Essmann[1] using liquid helium cooling, cobalt decoration and replica for transmission electron microscopy to study the effect of defects created by plastic deformation of the specimen on the flux-line arrangement. However, the new high Tc superconductors, $YBa_2Cu_3O_{7-\delta}$, are typically powder-sintered thus have a complicated morphology, e.g., pores and several phases coexisting, as well as a highly anisotropic crystal structure. Therefore, the flux pinning positions, and thus magnetization behavior, can be very different from the classical, homogeneous alloy superconductors. Because at Tc~95°K, we were able to use liquid nitrogen as coolant to perform the flux decoration experiment and to directly observe the inhomogeneous magnetization of the new high Tc oxide superconductors with the scanning electron microscope.

The sintered YBCO material was first carefully polished from both sides down to about 1 mm thickness. A simple levitation test was then performed to assure that the polished material had not been fully degraded. It has been reported that at room temperature, surface degradation occurred in one week and that above 150°C, rapid degradation occurred.[2] The sample was then loaded in a cryostat cooled with liquid nitrogen to achieve a temperature, typically 84°K, below Tc after pumping the system to $<10^{-6}$ torr and backfilling with helium to 10^{-1} torr range. The magnetic field from a solenoid was then applied and cobalt evaporated from a tungsten filament. After warming up to room temperature, the specimens were immediately transferred to the scanning electron microscope chamber and inspected.

Two kinds of specimens were used in these decoration experiments, a low density material (Fig. 1 and 2) in which sintering was very incomplete containing large angular pores and a higher density material (Figs. 3 and 4) having smaller, more rounded and more numerous pores.

Figure 1 shows flux pinning at pores, grain boundaries and also in the bulk. Pinning positions within some of the grains indicate that a bulk superconducting mechanism does occur. However, decorations along the grain boundaries particularly at pores were more frequently observed. A fully decorated fluxsoid revealing the shape of the trapped external flux lines in 3-dimension is shown in Fig. 2. These decorated flux lines were interwoven with the flux lines of nearby pinning fluxsoids and stayed standing after the magnetic field was turned off. On the contrast, a single isolated fluxsoid can't maintain the decorated flux lines standing. A rough estimation from the diameter of the decorated fluxsoid in Fig. 2 gives a value of <2000 Å for the penetration depth.[3] The fields applied in both figures were 800 G.

Figures 3 and 4 show the effect of field strength, 800 G and 150 G, respectively, on the average spacing of flux pinning positions in the higher density material which contain numerous discrete tiny pores. In both cases all the pinning points are at pores, but for the low field the average spacing is about 3.8 micrometers whereas for the high field case the average spacing is about 1.2 micrometer.

The inhomogeneous decoration results observed in these samples raised the possibility that artifacts could have been responsible for the decoration. Therefore three experiments were carried out to check this possibility. Only one parameter was changed during each

experiment. Cobalt was evaporated onto the specimen (1) at 279.5°K instead of 85°K, (2) no field applied, and (3) copper evaporation instead of ferromagnetic cobalt; all other conditions remained as before. All three of these experiments revealed uniform deposition consistent with the interpretation of inhomogeneous decoration as due to flux pinning. The observed inhomogeneous pinning may be attributed to the relatively low applied field, the porosity and the multiphase character of the sintered oxide material as well as the possibility of surface degradation and the anisotropic crystal structure of the superconducting phase.

These superconductors are a multiphase material which may contain CuO, $BaCuO_2$, Y_2BaCuO_5, $YBa_2Cu_3O_{7-\delta}$ (tetragonal) and $YBa_2Cu_3O_{7-\delta}$ (othorhombic).[4-7] Only the last one is a superconducting phase. The superconducting phase, $YBa_2Cu_3O_{7-\delta}$ (othorhombic), is highly unstable and easily degraded in an ambient with moisture.[8] In the vortex state, depending on the applied field and temperature, the $YBa_2Cu_3O_{7-\delta}$ orthorhombic phase can be normal state rich or superconducting phase rich which further reduces the possible decorating area. Finally, the anisotropy of the crystal structure may preclude decoration if the applied field is not nearly parallel to the c-axis of the lattice.

Considering the size of the grains relative to the thickness of the specimen, the fluxsoids have to penetrate many grain diameters to reach the other surface. Therefore the strong anisotropy and numerous pores of this material may play an important role in the location of pinning sites and thus local magnetization behavior. This technique also allows to directly distinguish the superconducting and normal conducting areas

on a microscale. New experiments with single crystal and higher field for full development of a flux lattice are in progress.

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Figure Captions

Fig. 1: Flux lines of the low density $YBa_2Cu_3O_{7-\delta}$ at 800 G are decorated with cobalt. Partial flux lattice were found in the bulk, along the grain boundaries and in the large pores. The average spacing of flux lines is slightly larger than 1 μm.

Fig. 2: Higher magnification of the "root" of the decorated flux lines gives a roughly estimated penetration depth of less than 2000 Å.

Fig. 3: Decorated flux lines of the higher density YBCO at 800 G. Flux lines are pinned at tiny pores mostly. Self-adjustment of flux locations gives an average spacing of about 1.2 μm.

Fig. 4: Same material as in Fig. 3 at 150 G. Average spacing of the partial flux lattice is 3.8 ± 0.2 μm. Again, most flux lines are pinned at tiny pores in this higher density material.

Fig. 1

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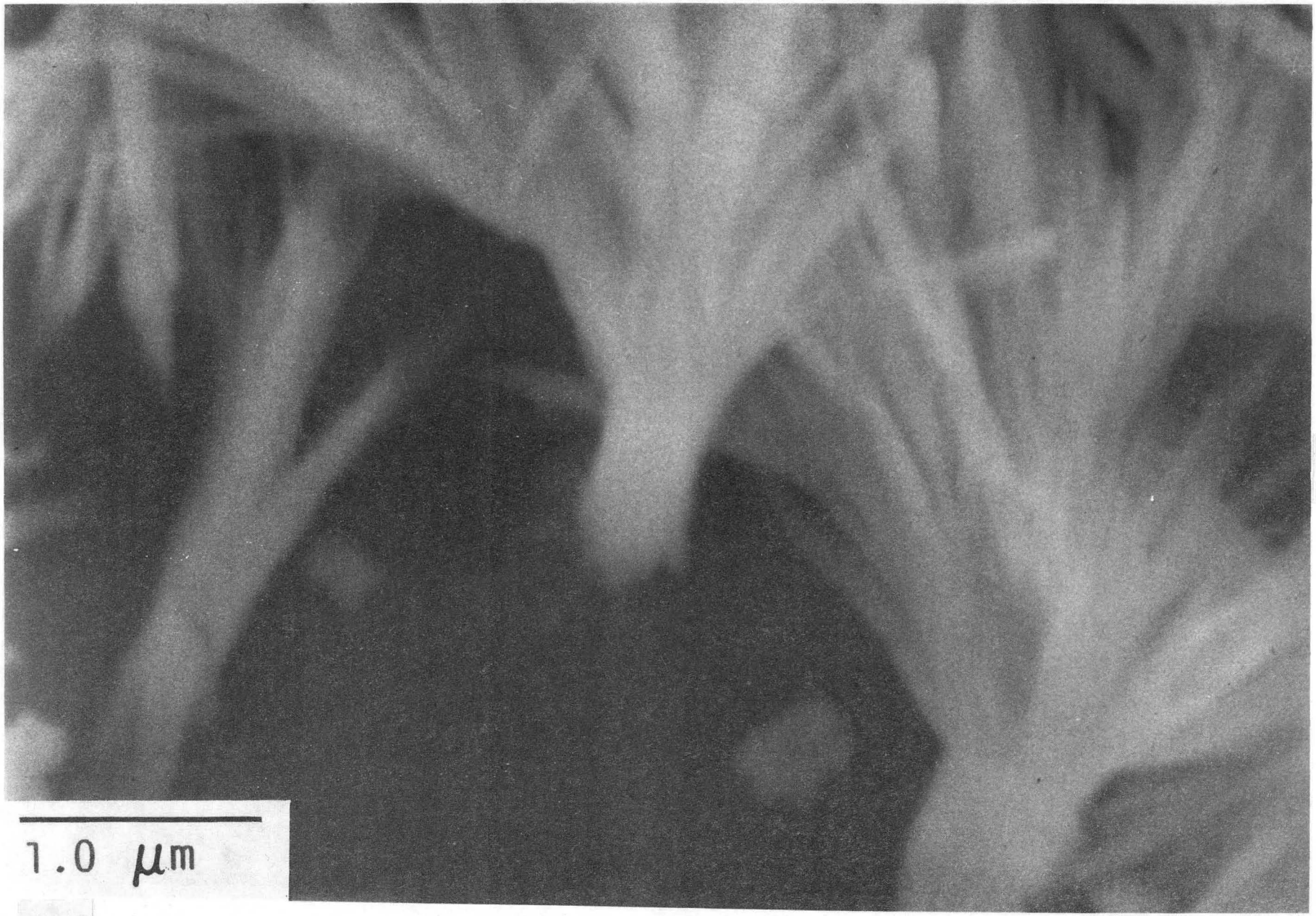

Fig. 2

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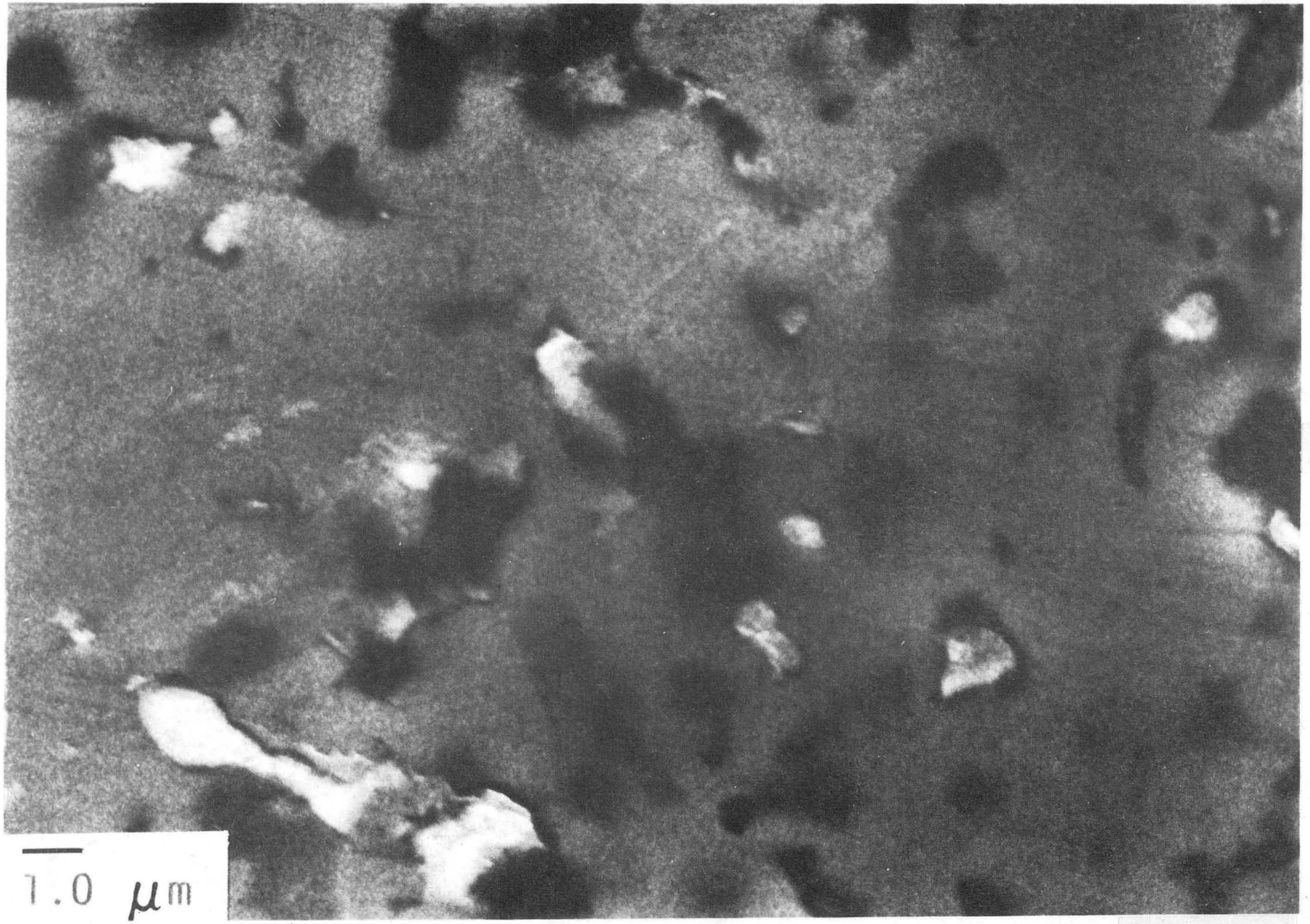

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Fig. 3

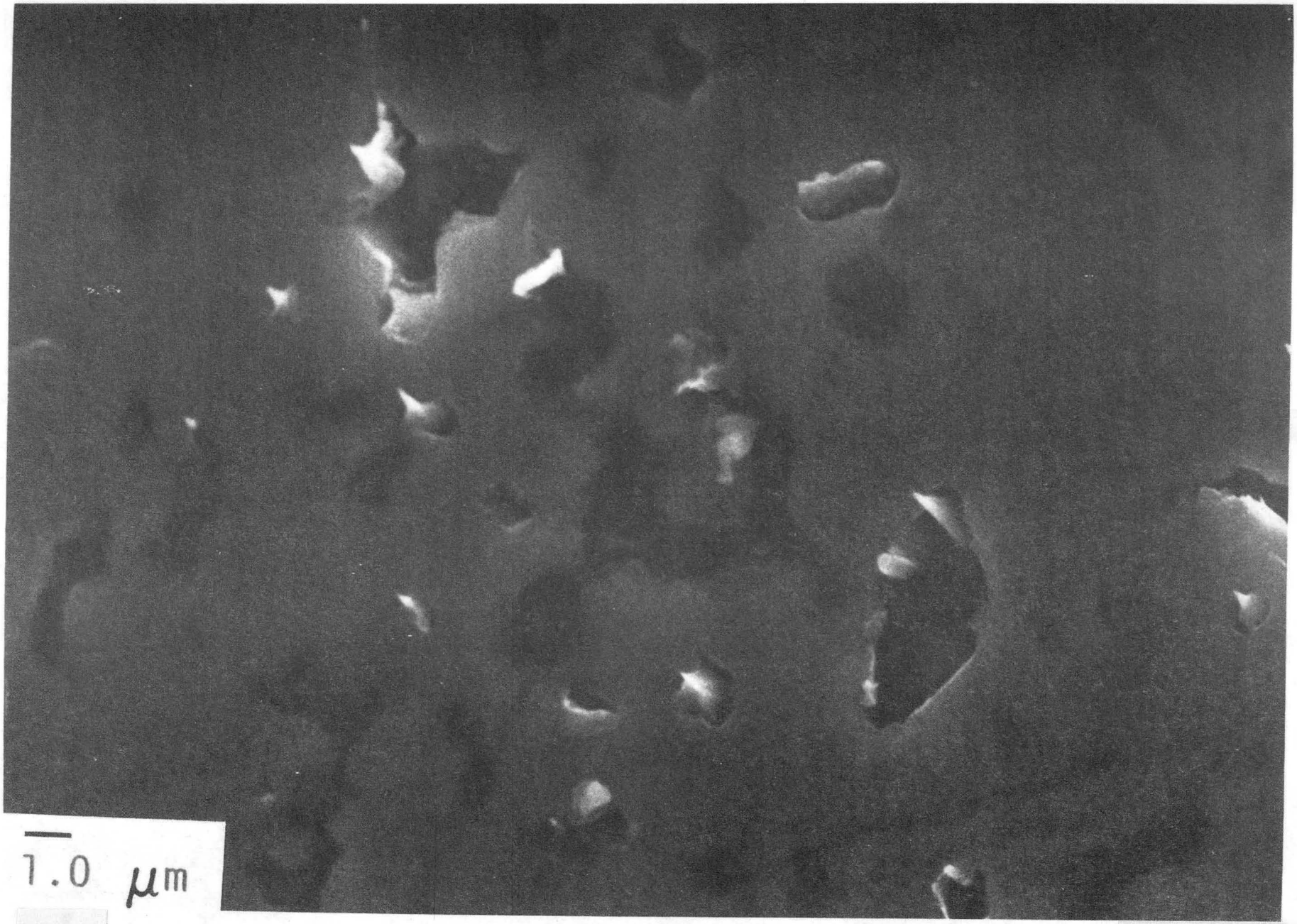

Fig. 4

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