SMALL-ANGLE NEUTRON SCATTERING AND FRACTAL PROPERTIES OF SUPERCONDUCTING CERAMICS $YBa_2Cu_3O_{7-\delta}$

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It is well known that superconducting ceramics are porous systems, and below T_c their electrodynamical properties are determined by weak Josephson links between granules of high-T_c material. Moreover, the pinning of the magnetic flux lines to a great extent is determined by interaction with the pores of the ceramical medium. Up to now almost nothing is known about the size, distribution and geometrical properties of these pores. The first results in this field with the use of small-angle neutron scattering are presented /1/. Two sets of $YBa_2Cu_3O_{7-\delta}$ ceramic samples were studied with densities $\varrho=3.5\ g/cm^3$ and $\varrho=5.15\ g/cm^3$. The range of transferred momentum q was determined by the conditions $0\leqslant q\leqslant 2.6\cdot 10^{-2}$ Å and $\Delta q=3\cdot 10^{-3}$ Å. Special precautions have been taken to avoid multiple scattering. In fig. 1 the log-log plot is presented for q-dependence of the scattering intensity where the dashed line is the intensity $I(q)\ \alpha\ q^{-n}$ where $n=3.85\pm 0.10$ convoluted with the experi-

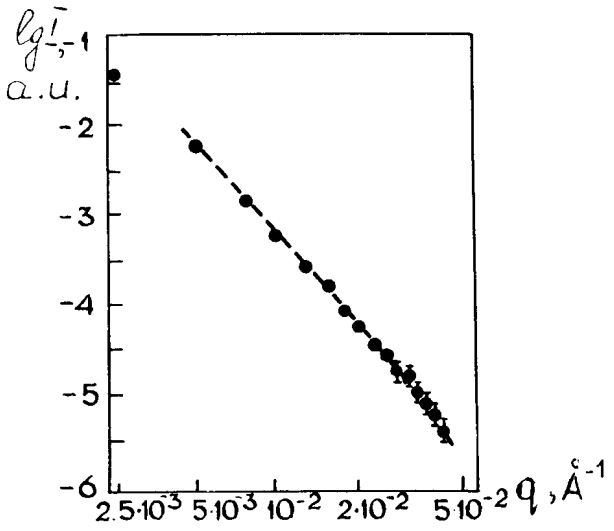

Fig. 1

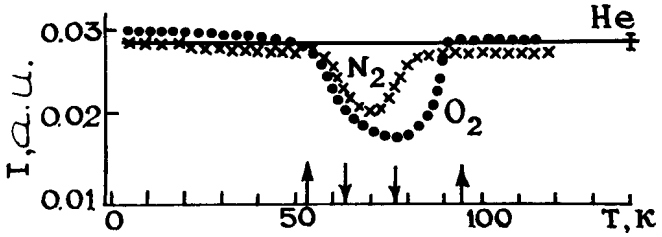

Fig. 2. Temperture dependence of scattering intensity at $q=5\ 10^{-3}$ Å. Arrows | and | denote boundaries of liquid phases of O_2 and N_2

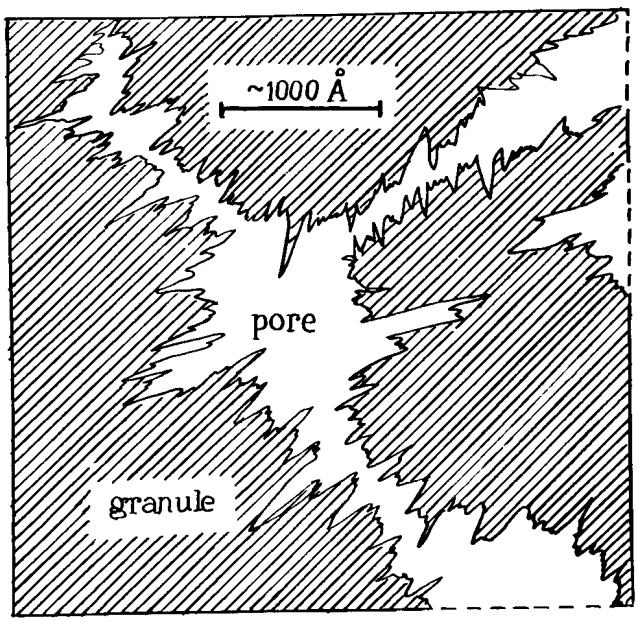

Fig. 3

mental resolution. At first sight the value of the exponent n corresponds to the Porod Law which described scattering by pores with sizes smaller than $1/q_{min}$. But if we assume that all pores which have the minimum size are consistent with this condition ($R>3.5\ q_{min}^{-1}$) the scattering intensity will be described by

$$\frac{\partial I}{\partial \Omega}=I_0\frac{\Delta\rho}{\rho_0}(N_0b)^2\frac{6\pi\alpha L}{Rq^4}, \tag{1}$$

where $\alpha\sim1$, $\varrho=6.4\ g/cm^3$ is the normal density of $YBa_2Cu_3O_7$, $\Delta\varrho_0=\varrho_0-\varrho$, N_0b — is the density of the scattering amplitude, L — is the sample thickness and I_0 — is the incident beam intensity. This equation gives us the upper boundary for scattering by small pores. But the observed intensity is much larger than predicted by eq. (1). Therefore we conclude that the Porod Law is inapplicable. In this case we must take into account the difference between the observed exponent $n=4-\Delta$ where $\Delta=0.15\pm0.10$ and the exponent of the Porod Law $n_0=4$. Such a q-dependence takes place if the pores possess a 'strongly expanded' surface, which could be described as a fractal surface with the dimension $2+\Delta$. In this case the scattering intensity is described by

$$\frac{\partial I}{\partial \Omega}=I_0(N_0b)^2\frac{\Delta\rho}{\rho_0}\frac{6\pi\alpha L}{Rq^4}\left[\left(\frac{R}{a}\right)^{\Delta}\cdot(Rq)^{\Delta}\right], \tag{2}$$

where $\alpha \sim 1$, and a — is the minimum size of the surface roughness. We assume that $a \sim 10$ Å, i. e. about unit cell size. In this case the factor inside the square brackets is much larger than the unity. Therefore the intensity given by eq. (2) is greater than it is for the Porod Law. As a result we can explain the observed intensity if $R \cong 10^3$ Å $> 3\, q_{min}^{-3}$ and $\Delta = 0.2...0.3$. This value lies within the experimental errors for Δ. From the above we conclude that the main parts of pores in the 1—2—3 superconducting ceramics have the size of the order of 10^3 Å and a fractal surface with the dimension $D = 2.1...2.3$.

It was observed also that the scattering intensity is diminished in the temperature range where the gas surrounding the sample becomes a liquid (see fig. 2). This was explained as a condensation of gas in the pores. Therefore we conclude that these pores are connected with the sample surface as shown in fig. 3. This explains why ceramical samples so freely exchange their oxygen with the surrounding space during annealing. Also it should be concluded from our data that high-T_c ceramics absorb O_2 more easily than N_2.

REFERENCE

1. *Okorokov A. I., Runov V. V., Tretyakov A. D., Maleyev S. V., Toperverg B. P.* Preprint LNPI-1526, Leningrad. 1989. 31 p.