LOCAL ELECTRIC FIELD MICROWAVE ELECTRODYNAMICS OF HIGH-T_C SUPERCONDUCTOR METAL OXIDES

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ABSTRACT

Phenomenological model of microwave electrodynamics of the metal oxide high-T_c superconductors (HTSC) is presented. The model takes into account the effects of the finite complex dielectric permittivity and of the local (acting) electric fields in semiclassical interpretation of the current carrier dynamics. The effects should be significant due to the layered structure and the metal-insulator type instability of HTSC metal oxides. Microwave electrodynamics of the superconducting state of HTSC is described on the base of the general two-fluid principles. The full expressions for the complex dielectric permittivity and for the surface impedance are derived and used to relate the current carrier parameters with the data of microwave measurements.

1. INTRODUCTION

The microwave measurements have played an important role in establishing the phenomenology of the superconductivity. Crucial information on both the superfluid and quasiparticle properties is derived from the real and imaginary parts of the surface impedance $Z=R+iX$ depending on the permittivity $\varepsilon=\varepsilon'-i\varepsilon''$ as $Z=(\mu_0/\varepsilon)^{1/2}$, where μ_0 is the permeability of vacuum and the electric field is $E\sim\exp(i\omega t)$. The permittivity of the conductive medium can be expressed as $\varepsilon=\varepsilon_p-i\sigma/\omega$, where σ is the current carrier conductivity and ε_p is the permittivity of the background. In metals the contribution of ε_p is negligible and to a quite good approximation Z is governed by σ the conductivity of free carriers in a macroscopic field E. This approximation could not be necessarily valid for the HTSC metal oxides and the permittivity of the bound charges (soft dipoles) ε_p should not be omitted in the total ε. The layered structure and the tendency to undergo metal-insulator phase transitions in these compounds result in the significant effects of the finite complex permittivity ε_p in the local electric fields acting on the current carrier dynamics [1-3]. In this paper we include these effects in a phenomenological model of the microwave electrodynamics of the metal oxide HTSC and use the model estimations to relate the HTSC parameters with the data of microwave measurements.

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2. MODEL

The local electric fields are coming in the semiclassical equation of current carrier dynamics via a replacement of E by $E+bP/\varepsilon_0$ [1,2], where P is the polarization and bP/ε_0 the Lorentz contribution. In the two-fluid approximation with the total density of current carriers $n=n_n+n_s$ dynamical equations of normal (n_n) and superconducting (n_s) carriers to be as follows

$$\frac{dj_n}{dt} = \frac{n_n e^2}{m}\left(E + b_n \frac{P}{\varepsilon_0}\right) - \left(\frac{j_n}{\tau}\right),$$

$$\frac{dj_s}{dt} = \frac{n_s e^2}{m}\left(E + b_s \frac{P}{\varepsilon_0}\right),$$

the real and imaginary parts of ε and *Z* are given by [2]

$\varepsilon' = \varepsilon'_p - ((n_n/n)(1-b_n+b_n\varepsilon'_p/\varepsilon_0)\tau^2)/(\lambda_0^2\mu_0(1+(\omega\tau)^2)) - ((n_s/n)(1-b_s+b_s\varepsilon'_p/\varepsilon_0))/(\lambda_0^2\mu_0\omega^2)$,

$\varepsilon'' = \varepsilon''_p + ((n_n/n)(1-b_n+b_n\varepsilon'_p/\varepsilon_0)\tau)/(\lambda_0^2\mu_0\omega(1+(\omega\tau)^2))$,

$Z_n \cong [(\mu_0\lambda_0(\omega/2\tau)^{1/2})/(1-b_n+b_n\varepsilon'_p/\varepsilon_0)^{1/2}](1+i)$

for $T>T_c$, $\omega\tau<1$ and $|\varepsilon''_p/\varepsilon'_p|<1$,

$Z_s \cong [\mu_0\lambda_0\omega/((n_s/n)(1-b_s+b_s\varepsilon'_p/\varepsilon_0))^{1/2}][(n_n/2n_s)(\omega\tau)\times((1-b_n+b_n\varepsilon'_p/\varepsilon_0)/(1-b_s+b_s\varepsilon'_p/\varepsilon_0))+i]$

for $T<T_c$, $\omega\tau<1$ and $|\varepsilon''_p/\varepsilon'_p|<1$,

where $\lambda_0^2 = m/(\mu_0 n e^2)$ and *m, e*, τ are the effective mass, charge and scattering time, j_n and j_s are the normal and superconducting current densities. Assuming $b_n \cong b_s \cong b$ [2], $T_n>T_c$ and $T<T_c$, we obtain an expression

$R_s(T)/R_n(T_n) \cong (\omega\tau)^{3/2}(n/2n_s(T))^{1/2}\times$

$((1-b+b\varepsilon'_p(T_n)/\varepsilon_0)/(1-b+b\varepsilon'_p(T)/\varepsilon_0))^{1/2} n_n(T)/n_s(T)$,

for the ratio which is commonly used as a direct experimental measure of the exponential decrease of $n_n(T)$ at $T<T_c/2$. To avoid the difficulties predicted by this equation due to the $\varepsilon'_p(T)$ temperature dependence it is possible to use in the analysis of microwave data for HTSC the following ratio

$R_s/X_s \cong (\omega\tau)(n_n(T)/2n_s(T))$.

3. DISCUSSION AND CONCLUSION

As an example, within the presented model the temperature independent ratio of both the linear-on-temperature R_s and X_s in the HTSC single crystal at $T<T_c/2$ [4] can be attributed to the dominant contribution in $n_n(T)$ from the density of thermally independent residual quasiparticles (residual microwave loss) in a combination with the temperature dependence of $\varepsilon'_p(T)$.This explanation is in accord with results of our model calculations of $\varepsilon_p(T)$ from the available adequately full microwave data [5,6] and with data of our direct measurements of frequency of the previously observed [7] dielectric resonance. Figs.1 and 2 show the smooth temperature dependence of $\varepsilon'_p(T)$ at $T<T_c/2$ which is practically identical for different samples.

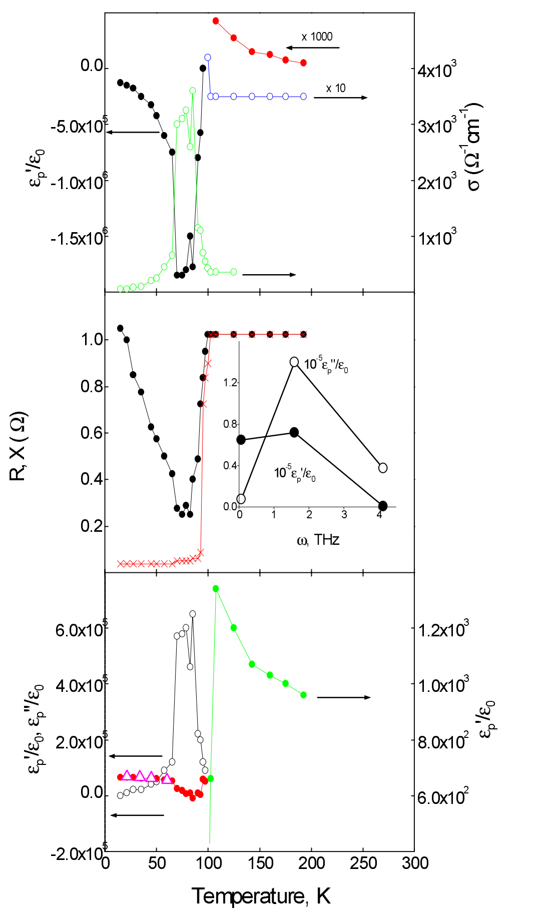

Figure 1. Results of model analysis of microwave data [5] and of direct measurements (triangles) of the dielectric resonance frequency [7] for YBa2Cu3-O7-x ceramic samples at ω=58 GHz. The inset sum-marizes frequency dependence of ε′p and ε′′p at T≤ 10 K obtained from data [5-7] within the model. ε′p and ε′ - full circles, R-crosses.

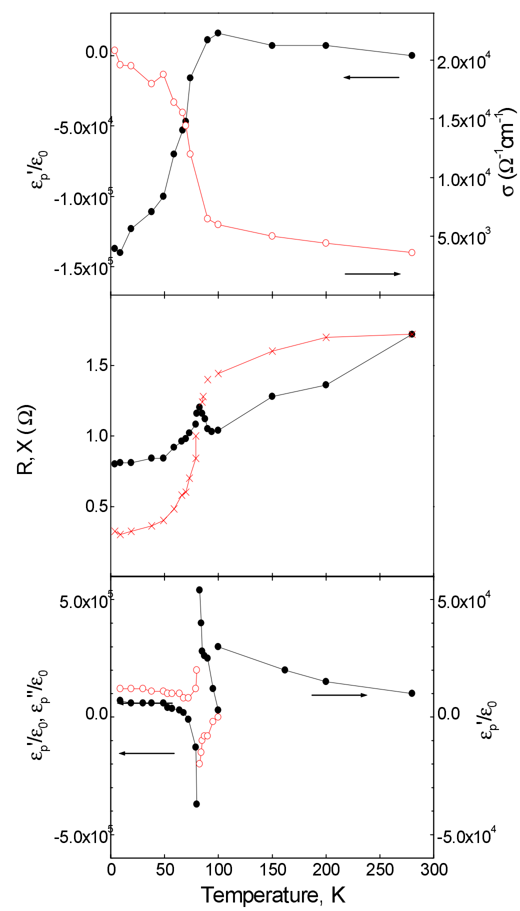

Figure 2. Results of model analysis of microwave data [6] obtained for YBa2Cu3-O7-x thin film at ω= 1.69 THz and 4.12 THz (not shown). ε′p and ε′ - full circles, R-crosses.

The ratio $2\Delta/kT_c \cong 3.5$ and the current scattering rate $\tau^{-1} \cong 3 \div 4$ THz were found in the model fitting procedure for all analyzed samples. The last value strongly correlates with the rise of ε''_p at ω around 3 THz (inset in Fig.1) and indicates the interplay of relaxation and scattering processes. It can be concluded that the effects of the finite complex dielectric permittivity and of the local electric fields in microwave electrodynamics of the metal oxide high-T_c superconductors should be taken into account in interpretations of the experimental microwave data and in comparisons with theoretical models of high-T_c superconductivity.

REFERENCES

1. A.S. Shcherbakov *at al.*, Fiz.Met.Met. 64 (1987) 735; *ibid.*, 742; JETP Lett. 49 (1989) 121.
2. A.L. Karuzskii *et al.*, Preprint FIAN No.215, (1988); A.I. Golovashkin *et al.*, Preprint FIAN No.217 (1988).
3. V. Müller *et al.*, Solid State Commun. 67 (1989) 997; Ferroelectrics 130 (1992) 45.
4. D.A. Bonn *et al.*, Czech. J. Phys., 46, S6 (1996) 3195.
5. T.M.P. Percival *et al.*, Electronic Lett. 23 (1987) 1225.
6. B.P. Gorshunov, G.V. Kozlov *et al.*, Proc. M^2S-HTSC-I, Interlaken, Switzerland, 1988.
7. V.A.Dravin *et al.*, Physica C 235 (1994) 2072.