JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 3, June 2006, p. 1065 - 1071

Pressure effect on optical conductivity for bulk (Bi,Pb)-2223 samples

A. HARABOR*, N. A. HARABOR[a]
Faculty of Physics, University of Craiova, 13 Al. I. Cuza Str.,Craiova-200585, Romania
[a]*„Politehnica" University, Bucharest, Romania*

We report on optical conductivity (in the range from 230 nm to 900 nm) of single phase bulk (Bi,Pb)-2223 superconductor samples (pressed isostatically at 200 MPa and 150 MPa and pressed uniaxially at 40 MPa and at 20 MPa), above and below the transition temperature. The reflectance spectrum, performed with an Ocean Optics Spectrometer S-2000 UV-VIS by using a detector CCD with an Interface ADC500, shows the so called "transparency of the metals in ultraviolet" in normal as well in superconducting states only for the sample pressed at 20 MPa and 40 MPa. Under the critical temperature a different feature with some spectacular peaks in UV range of reflectance spectrum has been observed in the case of samples pressed isostatically at 200 MPa and 150 MPa. If $T<T_c$ it is also observed a linear increasing of plasma frequency versus the pressure, that was apprehended by a similar pressure dependence of critical temperatures (appreciated by diamagnetic transition). The shape of optical conductivity in visible range is consistent with the theoretical mechanisms that assume the existence of large polaronic carriers.

(Received March 15, 2006; accepted May 18, 2006)

Keywords: Superconductors, Reflectance, Optical conductivity

1. Introduction

In the theory of electromagnetic response for high T_c superconductors a clean limit is accepted at low temperature because of their very short coherence length and controversial discussions about the interplay between s or d wave symmetry of gap parameter still remain. This is in contrast with the electromagnetic response in the case of conventional superconductor system, where the dirty limit applies and the symmetry of the gap parameter is generally accepted to be s wave.

In ref. [1] Carbotte et al. noted that in the case of high T_c it should take into account inelastic as well as elastic (impurity) scattering. The authors of that ref. [1] have made a theoretical study and have deduced by numerical methods the real part of conductivity as a function of normalized frequency for both d wave and s wave superconductors. Discussing the behavior around the Holstein region (mid IR) where the absorption proceeds through the creation of an electron-hole pair and an accompanying boson, they concluded that only d-wave approach are in agreement with the experimental optical data for normal and superconducting state of single $YBa_2Cu_3O_{6.95}$ crystals. Devereaux et al. [2] have discussed a mechanism involving the charge transfer fluctuation between the two oxygen ions in the CuO_2 plane coupled with the crystal field perpendicular to the plane and evaluated the resulting electron-phonon coupling. They investigated for a $d(x^2-y^2)$ gap symmetry, the Fano line shape of the B1g phonon in the normal state and the change of the line width with temperature below Tc and obtained results in agreement with the Raman spectrum of $YBa_2Cu_3O_7$. In ref. [3] is presented an infinite-dimensional Hubbard model with the result that the Mott-insulating character of the ground state at half filling drives many of the anomalous features present in normal state properties of cuprate superconductors. It is suggested also that the free carriers initially have a hole like character and then (at 1/4 filling) an electron like character. A linear temperature increasing of Drude width for these carriers above T_0 (the Kondo-like scale), a linear increasing with doping of Drude weight and a temperature dependence of mid-IR peak are predicted.

Usually the anomalous behaviors in experimental optical conductivity are attributed to polarons or impurities. A polaron is a quasiparticle composed of a self-trapped electronic carrier taken together with the pattern of atomic displacement that produces the self-trapping. There are large polarons (due to the long-range columbic interactions between an electronic carrier and a solid's ion) and small polarons when a short-range electron-lattice interaction (such as the deformation-potential interaction) is dominant [4]. A large polaron's photoionization produces a temperature-independent absorption band that is asymmetric (the absorption intensity on the high energy side exceeding that of the low energy side of the peak) [4]. The small polaron band is also asymmetric but with an opposite feature. The high frequency absorption bands are consistent with the existence of large-polaronic carriers. Usually the free carrier absorptions and dc transport in SC depart from the expectation of independent polaronic carriers. If the carriers in high T_c superconductors are polarons their transport in normal state is collective [4].

Because the purely polaronic theory has difficulty in explaining the magnetic insulating character of the ground state at half filling the authors of ref. [3] claimed the necessity of a comprehensive theory for normal state of high T_c that should incorporate both the effects of strong electron correlation and the electron-phonon interaction. Zha at al. [5] have reviewed a gauge-invariant formalism for the electromagnetic response of a superconductor and emphasized the coupling between collective modes and impurity scattering. Their study has focused on the c axis charge dynamics behavior that has been found to be insensitive to the nature (s-wave or d- wave) of the order parameter symmetry. In an early paper [6] Zhao at al. reported the first theoretical calculation on the interband optical properties of $YBa_2Cu_3O_7$ crystal and suggest an excitonic-enhanced high T_c superconducting mechanism. The idea is based on the formation of excitons in the conduction band minimum and holes at the maximum of the unfilled valence band [6], the total gap being equal with $\Delta^2 = \Delta^2_{BCS} + \Delta^2_{exciton}$. They remarked also that at that moment (November 1987) did not exist in literature any experimentally measured optical data on $YBa_2Cu_3O_7$ in the ultraviolet or visible frequency range because of difficulty in obtaining sufficiently large single-phase crystals and of performing the proper surface treatment. The situation is not too much changed concerning this range of frequency. The majority of experimental optical studies are focused on the mid. IR and far IR range of frequency (the most studied being $YBa_2Cu_3O_7$ and only few works about $Bi_2Sr_2CaCu_2O_8$ and $Tl_2Ba_2Ca_2Cu_3O_{10}$ exist) in order to elucidate the electron-phonon mechanism. In this context we think that our investigation of the near IR, visible and near UV optical properties (in the range from 360 nm to 850 nm) of some high quality and single phase superconductor samples as that of (Bi, Pb)-2223 pressed at 20 MPa, 40 MPa, 150 MPa and 200 MPa with T_c slightly depending of the pressure, should be of interest for the scientists who want to elucidate the mechanism of the superconductivity in this high Tc compound. Several models have been proposed to account for the pressure dependence of T_c in terms of the so-called pressure–induced charge transfer (PICT) from the CuO_2 planes (responsible for the superconductivity in the cuprate superconductors) to the electron reservoirs (as for example the CuO chains in the case of $YBa_2Cu_3O_{7-x}$).

One might take a look to the expression of plasma frequency ω_p (given in section II of this paper) to see its dependence versus carrier density n and then should make the connection with the expression of the slope of the resistivity versus temperature $d\rho/dT=8\pi\gamma/\omega_{pl}$, where $\gamma=N(0)V$ is the coupling constant, involved in the expression for T_c. The evident conclusion is that the pressure is an important parameter, which has clearly an influence on the plasma frequency. In the analysis of the optical properties (in section II) of four bulk (Bi, Pb)-2223 samples, pressed at 20 MPa, 40 MPa, 150 MPa and 200 MPa, the values obtained for plasma frequency from the reflectance measurements were connected with the values of critical temperatures given by susceptibility data. The results were consistent confirmation of the above considerations.

2. Some classical theoretical considerations

2.1 The optical reflectance in the framework of Drude formalism

In the classical theory of electromagnetic response of metals (the same behavior is available for the superconductors in normal state) the discussion of the optical proprieties takes into account the dielectric function of the simple Drude form for free carriers [7]:

$$\varepsilon(\omega) = \varepsilon_0 + i\frac{4\pi ne^2}{m^*\omega(\Gamma - i\omega)} \tag{1}$$

where ε_0 is the background dielectric constant due to high-energy electronic excitations, Γ is the scattering rate, m^* is the effective mass, e is the charge and n is the carrier density.

The reflectivity is defined by

$$R = \left|\frac{\sqrt{\varepsilon} - 1}{\sqrt{\varepsilon} + 1}\right|^2 \tag{2}$$

The comparison of the above expression for $\varepsilon(\omega)$ with the one obtained from the Maxwell-Ampère equation and the Ohm law leads to the frequency dependence of the electric conductivity [7]:

$$\sigma = \frac{ne^2}{m^*(\Gamma - i\omega)} \tag{3}$$

In the case of metals is often used the following approximate formula in which the optical conductivity is directly obtained from reflectance data:

$$\sigma = \frac{16\pi c\varepsilon_0}{\lambda(1-R)^2} \tag{4}$$

Here $c = 3\times 10^8\,m/s$ and λ is the wavelength the light

For low frequency the electric conductivity is essential real non-frequency dependent but at $\omega > 10^{11}s^{-1}$ the conductivity is a complex function depending on ω. In fact the free electrons are the valence electrons of the isolated atoms, which become quasi-free and are moving without dissipation in the crystalline lattice. The attenuation is due to the collisions that are accompanied by an impulse and energy transfer from the electrons to the lattice vibration or to the imperfection or impurities of the lattice. In the case of high frequency the dielectric function take the approximate form [7]:

$$\varepsilon(\omega) = \varepsilon_0(\omega) - \frac{\omega_p^2}{\omega^2} \tag{5}$$

where $\omega_p = 4\pi ne^2/m^*$ is the plasma frequency.

For $\omega \ll \omega_p$ the incident radiation is almost entirely reflected like in plasma but at a higher frequency (ultraviolet range) when $\varepsilon(\omega)>0$, the metal becomes transparent to the radiation and the reflectivity is drastically modified. We have the so-called “transparency in ultra-violet “ of the metals.

The reflectance measurements may give some important information concerning the plasma limit frequency, which is directly connected with the density of states. In this way we note that the electron-phonon interaction may manifest itself in the resistivity as seen by looking at the expression for the resistivity [8]:

$$\rho = \frac{8\pi}{\omega_p^2}\gamma T \qquad (6)$$

where, ω_p is the plasma frequency, γ=N(0)V is the coupling constant, the most important parameter characterizing the magnitude of electron-phonon interaction in metals depending on the density of electron states on the Fermi level, N(0), and on the electron attraction matrix element, V, involved in the expression for T_c. Thus the slope of the curve $\rho(T)$ enables one to obtain γ [8].

2.2 The model of pressure-induced charge transfer (PICT)

It is well known that the pressure has played an important role in the history of the development of classical as well of the high T_c superconductors. Many experiments have been performed in order to understand the pressure dependence of the superconducting transition temperature T_c. Two were essentially the motivations in doing this kind of experiments: (i) to elucidate the mechanism of high T_c superconductivity; (ii) to find new materials with higher T_c by using chemical pressure by means of chemical substitutions. It was shown that strong T_c enhancement under pressure essentially occurs for underdoped compounds [9]. If the compounds are near the optimum doping level the effect of pressure is much less evidenced. Within the PICT model [9] it is also shown that dT_c /dp is not constant but decreases when the pressure increases until the saturation of T_c is obtained and then a decline in the value of T_c under pressure is recorded. In the cuprate superconductors it was established an inverted parabolic dependence of critical temperature versus hole concentration n in CuO_2 planes. Until a certain minimum concentration n_{min} of holes is obtained in CuO_2 planes, the compounds are nonmetallic and non superconducting. Then T_c begins to rise with increasing n and a maximum value $T_c^{\max}$ is attained for an optimum concentration of holes n_o. For larger n this process is followed by a decline of T_c and a drop to zero for $n=n_{max}$. The following equation can explain this behavior:

$$T_c = b(n - n_{min})(n_{max} - n) \qquad (7)$$

where γ is a constant. The condition $\frac{dT_c}{dn} = 0$ that gives the maximum for T_c allows us to obtain n_{0p} (optimum value for n):

$$n_{op} = \frac{n_{min} + n_{max}}{2}\ ;\ T_c^{max} = b\left(\frac{n_{max} - n_{min}}{2}\right)^2 . \qquad (8)$$

Finally we obtain a generalized expression for T_c that include the effect of pressure [9]:

$$T_c(p) = T_c^{max}(p)\left\{1 - \alpha\left[n_{op} - n(p)\right]^2\right\} \qquad (9)$$

where $n(p) = n_0 + \Delta n(p)$ and $T_c^{max}(p) = T_c^{max} + \Delta T_c^{max}(p)$. Here n_0 and T_c^{max} are the values at $p=0$, but $n(p)$ and $T_c^{max}(p)$ are their values at pressure p; $\alpha = \frac{1}{(n_{op} - n_{mn})^2}$. As seen above, the change in the value of T_c occurs from two sources: the pressure induced charged in the hole concentration $\Delta n(p)$ and the change in $\Delta T_c^{\max}$ that is due to the other factors such as the electron-phonon interaction, the coupling between the CuO_2 planes, etc., that are directly related to the mechanism responsible for the superconductivity.

3. Experimental results and discussion

3.1 Samples characterization

Since the discovery of the system Bi-Sr-Ca-Cu-O [8] by H.Maeda (1988) a considerable effort has been made by the research workers all around the world to separate the single phase in the Bi-Ca-Sr-Cu-O system where, usually three phases with modulated structures are coexisting together: 2201 phase with $T_c \cong 20$ K; 2212 phase with $T_c \cong 80$ K and 2223 phase with $T_c \cong 110$ K. Some different strategies were adopted to optimize the yield of the 2223 phase. The partial substitution of Pb for Bi introduces a Pb-type modulation that is coexisting with Bi-type modulation. The optimal ratio and the adequate heat treatment have a positive effect on the formation of 2223 phase. Our experience confirmed that the combination of a Cu-rich starting composition with the addition of Pb, the prolonged heat treatment followed by quenching in partial N_2 atmosphere might be a successful attempt in separated 2223 phase, starting from an off-stoichiometric composition of the type $Bi_{1.8}Pb_{0.3}Ca_2Sr_2Cu_{3.3}O_y$. The (Bi, Pb)-2223 single-phase bulk sample was prepared by the solid-state reaction method as shown in ref. [10].

The microstructure of the sample was investigated by XRD, SEM analysis performed on a PHILIPS PW 1710 equipment with CuK_α radiation and a JEOL T100 type microscope, respectively [11]. The composition of the oxide was determined by energy dispersive X-ray analysis (EDX). In [11] we have presented XRD patterns obtained for different sintering time showing that the amount of (Bi,Pb)-2223 phase increases when the sintering time increases. The final treatment (in total, 25 sintering days) has eliminated the (Bi, Pb)-2212 phase. The unit cell of 2223 material was indexed as tetragonal structure with the following lattice constants: a= b=5.39Å and c= 37.05 Å.

EDX data confirm in general the homogeneity of the samples.

By AC susceptibility measurements performed with a LAKE SHORE Susceptometer Model 7000, at different external AC magnetic fields (in the range 0.4 A/m to 800 A/m) and at a frequency of 777.7 Hz, in ref. [10] we made a study of the evolution of superconducting properties after each sintering process [10]. The rectangular samples were introduced in a magnetic field parallel to the uniaxial pressure. An evident increase of the diamagnetic response with the sintering time, due to the continuous increase of the (Bi,Pb)-2223 phase amount in the samples, was observed.

It is known that the measurements of the complex AC susceptibility, $\chi = \chi' + i\chi''$ give to us qualitative information regarding intergranular coupling properties. The real part χ' represents the diamagnetic shielding of the sample while the imaginary part χ" represents the hysteresis loss in the sample [11]. Usually the AC susceptibility measurements show two separate contributions from intergranular and intragranular properties. This is the case of granular high-T_c superconducting material where, the grains are weakly coupled by Josephson junctions. In well-coupled materials the separation of contributions from the intergranular and intragranular regions becomes indistinguishable because of high pinning force density in the intergranular region. It was found that the cooling and annealing processes are crucial parameters [11] influencing the microstructure of the samples. We remarked that pressure for making pellets is also an important parameter which can influences the intergranular coupling between grains as shown by AC imaginary susceptibility [11].

In this way we report on an interesting feature for a single phase (Bi-Pb)-2223 sample pressed first uniaxially at a pressure of 50 MPa and then isostatically at 200 MPa. The results of the AC susceptibility measurements at low magnetic fields (0.4 A/m) (presented in Fig. 1) show only intergranular peaks as they give the largest contribution to the energy looses.

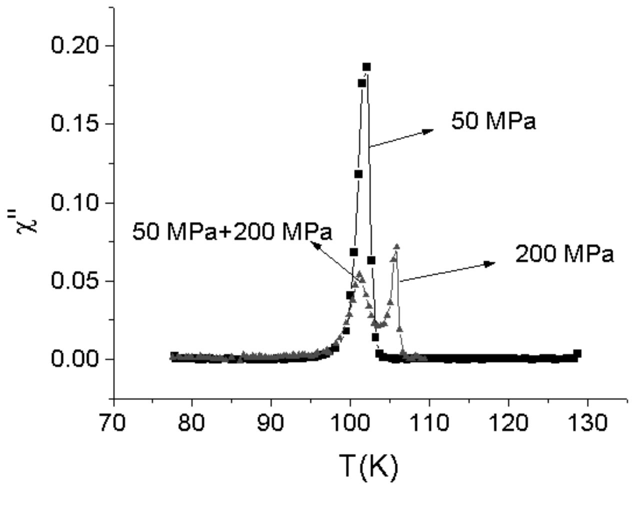


Fig. 1. The dissipation peaks for the two samples: A and B (see the text).

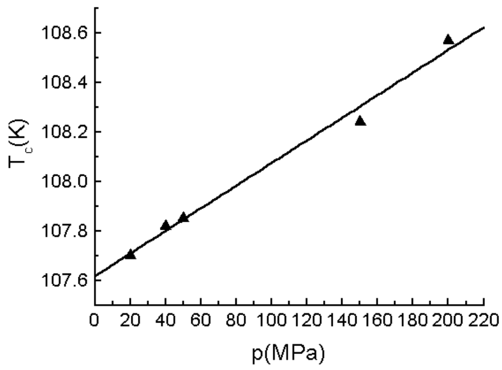


Fig. 2. Critical temperature versus pressure for the (Bi,Pb)-2223 samples.

The two unusual intergranular loss-peaks in the imaginary part of the AC susceptibility (the curve marked by solid triangle) has been observed in susceptibility data performed in low magnetic fields (0.4 A/m), for the (Bi, Pb)-2223 sample (sample A) pressed both at 50 MPa uniaxially and 200 MPa isostatically: one might be determined by the intergranular dissipation caused by the first pressure of 50 MPa (the left one) and the another that shifts to higher temperature could be attributed to the intergranular dissipation caused by the isostatic pressure of 200 MPa. This has a good confirmation as we add on the same graph the dissipation curves of susceptibility (curve marked by solid quadrate) for the samples pressed only at 50MPa uniaxially (sample B). Indeed we can see that the left peak of the sample A is at the same temperature as the peak (the higher one) of sample B. From the intensity of the peaks it is obvious that the pinning force density is higher in the case of sample A. This means that we have also a higher critical current density if the pressure is increased.

The flux penetrates first the intergrain region, which has the weaker pinning force, and then the intergrain region that has a higher pinning force. The anisotropy of the compound was also related in [10], by the plots of AC-susceptibility data performed at two different direction of the field.

From the diamagnetic onset measured at 0.4 A/m we have appreciated the critical temperature for the samples pressed at 200 MPa, 150 MPa, 50 MPa, 40 MPa and 20 MPa.

The fit (solid line) for the plots T_c=f(p) represented in Fig. 2 was found by a linear regression. The slope of the linear fit is $dT_c / dp = (4.57 \pm 0.28)\ K/GPa$.

The conclusion is that in this range of pressure we have for our samples (with the stoiechiometry mentioned above) almost a linear dependence of critical temperature versus pressure.

3.2 Reflectance measurements and optical conductivity

Near-UV, visible and near-IR reflectance measurements above and below the transition temperature were performed with an Ocean Optics Spectrometer S-2000 UV-VIS by using a detector CCD of 2048 pixels with an Interface ADC 500. An optical microscope IOR-MC5 to perform the measurements for normal reflectance in the same geometrical arrangement [12] for all the samples and a Keithly Multimeter 2000 to measure the sample temperature given by a Cr-Al thermocouple, have been used. During the measurement, the reflectance for the plane surface of a glace sample was measured to obtain a reference spectrum.

In Fig. 3 are plotted three reflectance spectra at T_1=223 K, T_2=108.15 K and T_3=77.15 K, respectively) obtained in the case of the sample A(with the onset of the diamagnetic transition at 108.57 K).

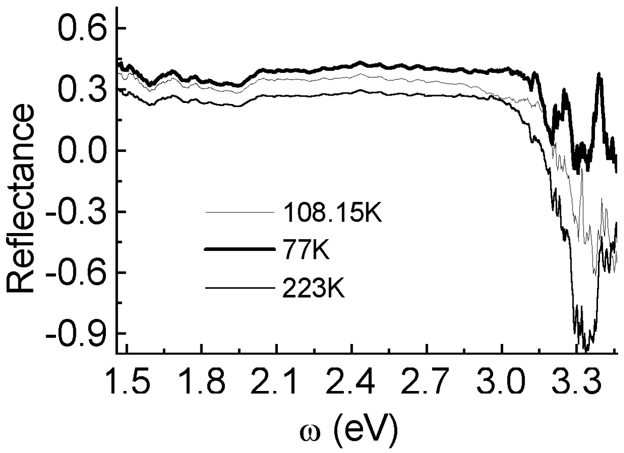


Fig. 3. Three reflectance spectrums performed at T_1=223 K, T_2=108.15 K and T_3=77.15 K for the sample A (first uniaxially pressed at 50 MPa and then isostatically at 200 MPa).

One observes a Drude normal-state reflectance in our superconducting bulk samples of (Bi, Pb)-2223 type. The behavior above the transition temperature is in conformity with the predictions of classical electrodynamics. Indeed at T=223 K (the sample being in the normal state) it is seen that between 3.16 eV and 6 eV, we have a region characterized by the so-called ''transparency in ultra-violet '' of the metals. From 2.04 eV to 2.99 eV there are no significant modifications in reflectance spectrum. We could have some attenuation effects from 1.45 eV to 2.04 eV due to the collisions of the free electrons with the lattice vibrations, the imperfections and the impurities present in the crystalline lattice. Another important characteristic is that the plasma frequency above the critical transition temperature does not depend on temperature and shown a value of 3.16 eV. Under the transition from normal to the superconducting state, plasma frequency is temperature dependent, and is increases from 3.21 eV to 3.28 eV while the temperature is decreases from 108 K to 77 K. There are known some experimental works ([13], [14], [15]) where is evidenced an unconventional measured reflectance of cuprates that exhibits a quasilinear drop as a function of frequency from the infrared to visible optical range. This is different from the ordinary Drude behavior that characterizes the metals like Au, Ag, Cu, Pb [16]. The interpretation of this phenomenon was in terms that damping is linear in frequency and if this persist to zero frequency requires a logarithmically divergence for quasiparticle effective mass as the temperature decreases (the so called ''marginal'' Fermi liquid [16]). Rieck at al. [16] developed a theory considering an isotropic energy gap on a NFL (nested Fermi-liquid) damping as a function of frequency and temperature and obtained a infrared reflectivity providing quantitative evidence for weak-coupling energy gap [16].

Looking at the spectrums of our samples, one can see this kind of behavior (that is much evident in optical conductivity curves), the drop from IR to visible range being at 1.59 eV for all the investigated samples.

Some spectacular events should be observed in near-ultraviolet region only for temperatures smaller than the critical transition temperature (<108.57 K) from normal to the superconductivity state. So one can see that if the temperature is diminished under the transition temperature the reflectance in near-ultraviolet region is drastically enhanced with some characteristic peaks of intensity higher then zero. The most important peaks for T=77 K are given in the following table:

Table 1.

Frequency (eV)	3.256	3.392	3.889	3.912	4.094	4.651	4.787	4.822	5.014	5.358
Intensity	0.205	0.336	0.347	0.434	0.108	0.230	0.227	0.455	0.145	0.013

In the visible range the increase of reflectance with the decrease of temperature occurrs for all the wavelengths. To illustrate this we present in Fig. 4 the plot of reflectance versus temperature for an arbitrary chosen visible wavelength of λ= 460.22 nm (2.699 eV). The theoretical fit (solid line) is an exponential function of the type:

$$R = R_0 + A_1 \exp\left(-\frac{T - T_0}{t_1}\right) \tag{10}$$

where R_0=0.338, A_1=0.053, T_0=75 and t_1=13.21.

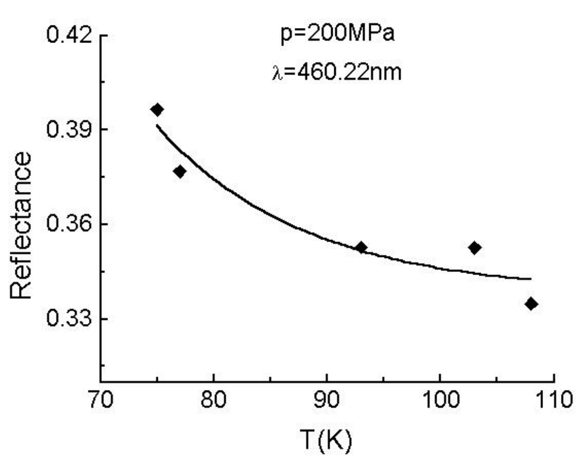


Fig. 4. Reflectance versus temperature for λ=460.22 nm (2.699 eV)(visible region).

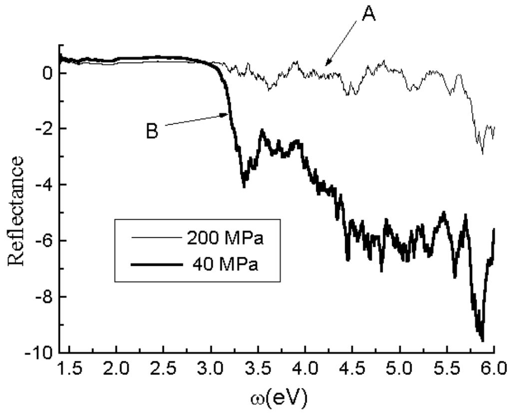


Fig. 5. Reflectance spectrum at 77 K for the: sample A and sample B.

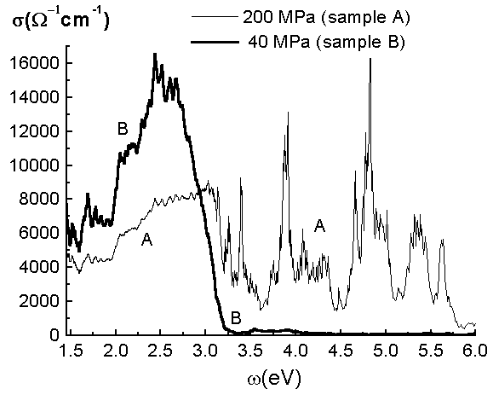


Fig. 6. Optical conductivity at 77K for the two samples: A and B.

In Fig. 5 are presented the spectra obtained at 77 K for a couple of two samples: the sample A described above and another 2223 sample, pressed uniaxially at 40 MPa, named sample B (unfortunately, the sample pressed uniaxially at 50 MPa has been lost before the reflectance experiment). In the case of sample B, we were surprised to see that near UV region phenomena mentioned for the sample A, is not occurring.

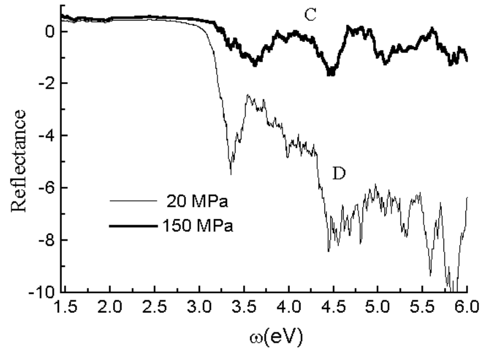
Comparing the reflectance spectrums for the two samples obtained, it is interesting to observe that in the visible range the reflectance for the sample A, pressed isostatically at 200 Mpa, is less than the reflectance measured for the sample B, pressed uniaxially at 40 MPa.

A possible explanation of this behavior is that a high and isostatic pressure is not favorable for obtaining preferential orientation of the crystallites, compared with the effect of uniaxial pressure. Higher pressure means a better coupled material and a higher T_c as confirmed both by susceptibility measurements and as seen from the Table 2:

Table 2.

Pressure (Mpa)	T_c (K)	$T_{spectrum}$ (K)	ω_p (eV)
200	108.57	77	3.28
150	108.24	77	3.24
40	107.82	83	3.094
20	107.70	77	3.069

The real part for optical conductivity at 77 K for the sample B and for the sample A, obtained by Kramers-Kronig analysis, is plotted in Fig. 6. Again it is observed that $\sigma_A^{visible} < \sigma_B^{visible}$ but $\sigma_A^{UV} > \sigma_B^{UV}$ (an opposite behavior of conductivity in visible range compared with that in UV range).



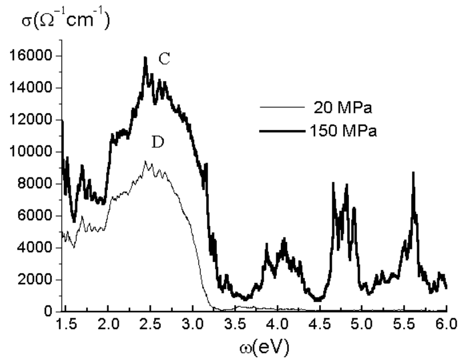


Fig. 7. Reflectance spectrum and optical conductivity for the samples C and D.

The general shape of optical conductivity curve is consistent with the existence of large polaronic carriers as predicted by David Emin [4]. In analyzing the optical transition data in high frequency range for YBCO samples, Sulewski at al. [17] found that they have to use the plasmon frequency value of 2.6 eV to obtain a good fit. Orenstein et al. [18] have used a value of ω_p=3.0 eV to obtain an excellent fit to their reflectivity spectrum. Zhao at al. [6] who reported a first theoretical calculation extracted from the interband optical conductivity found a value of ω_p=2.8 eV. These values are consistent with our experimental results for ω_p in the case of our (Bi, Pb)-2223 samples as seen from the Table 2.

The pressure dependence of plasma frequency measured at 77 K, given in Fig. 8, is well described within the range of pressure from 20 Mpa to 200 Mpa by the following linear function,

$$\omega_p = 3.0464 + 0.00117\,p \tag{11}$$

where the increasing rate of plasma frequency is

$$\frac{d\omega_p}{dp} = (1.17 \pm 0.087)\frac{eV}{GPa}\,. \tag{12}$$

From the Table 2 it is clear that we have the following relationship between plasma limit frequencies for the four pressures used in preparing the sample:

$$\omega_p^{200MPa} > \omega_p^{150MPa} > \omega_p^{40MPa} > \omega_p^{20MPa}$$

This behavior has been expected from the following relationship between critical temperatures (deduced from susceptibilty measurements) as seen from the Table 2):

$$T_c^{200MPa} > T_c^{150MPa} > T_c^{40MPa} > T_c^{20MPa}$$

Sulevski et al. [17] argued that free carriers are present and conductivity can be analyzed in terms of Drude model when interband optical conductivity is followed. Far and mid infrared intraband optical data have led to very different interpretations from those of conventional free-electron like metal.

4. Concluding remarks

Near-UV, visible and near-IR reflectance spectra in the range from 1.4 eV and 6 eV performed on four bulk single phase (Bi, Pb)-2223 superconductor samples, pressed at 20 MPa, 40 MPa, 150 MPa and 200 MPa (above and below the transition temperature) lead to the following conclusions: 1) a characteristic behavior in UV range of frequency, in accordance with the "transparency of the metals in ultraviolet", for all the samples investigated in the normal state; 2) for the highest pressures of 200 MPa and 150 MP, under the critical temperature, some spectacular peaks in the reflectance spectrum appear in UV range, sometimes with the intensity higher that recorded in visible region; 3) linear dependences of critical temperature and plasma frequency measured at 77 K, respectively, versus pressure in the range from 20 MPa to 200 MPa have been found, in agreement with the theoretical predictions. 4) The shape of optical conductivity in visible range is consistent with the theoretical mechanisms that include the existence of large polaronic carriers.

Acknowledgments

This work was partially supported by Belgium Government.

References

[1] J. P. Carbotte, C. Jiang, D. N. Basov, T. Timusk, Phys. Rev. B, **51**(17) 11798-11805 (1 May 1995).
[2] T. P. Devereaux, A. Virosztek, A. Zawadowski, Phys. Rev. B, **51**(1) 505-514 (1 January 1995-I).
[3] M. Jarrell, J. K. Fredrick, Th. Pruschke, Phys. Rev. B, **51**(17) 11704-11711 (1 May 1995).
[4] Emin David, Phys. Rev. B, **48**(18), 13691-13702 (1 November 1993-II).
[5] Y. Zha, K. Levin, D. Z. Liu, Phys. Rev. B, **51**(10) 6602-6616 (1 March 1995).
[6] G. L. Zhao, Y. Xu, W. Y. Ching, K. W. Wong, Phys. Rev. B, **36**(13), 7203-7206 (1987).
[7] “Classical Electrodynamics", John Wiley&Sons, Inc., New York-London-Sydney-Toronto, 1974.
[8] H. Maeda, Y. Takana, M. Fukutumi, T. Asano, Phys. Rev. B. **27**, L 209 (1988).
[9] R. P. Gupta, M. Gupta, Phys. Rev. B, **51**(17), 11760-11766 (1995).
[10] A. Harabor, R. Deltour, M. Ye, J. Schroeder, H. Hancotte, Superlattices and Microstructures **21**, Suppl., 229-233A (1997).
[11] A. Harabor, R. Deltour, M. Ye, J. Schroeder, G. Moortgat, M. Deletter, Journal de Physique III, **6**, C3-283-288 (1996).
[12] I. Palarie, C. Florea, J. Optoelectron. Adv. Mater. **7**(2), 997 (2005).
[13] G. A. Thomas, J. Orenstein, Phys. Rev. Lett. **61**, 1313 (1988).
[14] K. Kamaras, S. L. Herr, C. D. Porter, N. Tache, D. B. Tanner, S. Etemad, T. Venkatesan, E. Chase, A. Inam, X. D. Wu, M. S. Hegde, B. Dutta, Phys. Rev. Lett. **64**, 84 (1990).
[15] Z. Schlesinger, R. T. Collins, F. Holtzberg, C. Field, S. H. Blanton, U. Welp, G. W. Crabtree, Y. Fang, J. Z. Liu, Phys. Rev. Lett. **65**, 801 (1990).
[16] C. T. Rieck, W. A. Little, J. Ruvalds, A. Virosztek, Phys. Rev. B, **51**(6), 3772-3782 (1995).
[17] P. E. Sulevski, T. W. Noh, J. T. McWhirter, A. J. Sievers, Phys. Rev. B **36**, 2357 (1987).
[18] J. Orenstein, G. A. Thomas, D. H. Rapkine, C. G. Bethea, B. F. Levine, R. J. Cava, E. A. Rietman, D. W. Johnson Jr., Phys. Rev. B **36**, 729 (1987).
[19] T. M. Rice, Z. Phys. B **67**, 141 (1987).

*Corresponding author: harabor@central.ucv.ro