Qatar Univ, Sci, J. (1997), 17(1) : 41-47

Magnetic Studies on High - T_c Bi - Pb- Sr - Ca - Cu - O Ceramics

A.S. Al - Hawery

Solid State Physics Group, King Khalid Military Academy, Riyadh,Saudi Arabia.

الدراسة المغناطيسية للمادة Bi-Pb-Sr-Ca-Cu-O الفخاري

عبد العزيـــز الهويـــري

مجموعة فيزياء الجوامد – كلية الملك خالد العسكرية – الرياض – المملكة العربية السعودية

تمت دراسة وتحليل المادة Bi-Pb-Sr-Ca-Cu-O فائقة التوصيل بواسطة معامل كيو . واتضح ان عمق الاختراق للمادة يتراوح بين ٣٠٠٠ – ٧٠٠٠ انجستروم وهذه النتائج توافقت مع ما تم نشره سابقاً بطرق مختلفة. وكما أن القابلية المغناطيسية للمادة عند درجة حرارة ٧٧ كلفن – ٨٧٤٥٠ جول / تسلة٢ / متر٣.

Key words **:** Q-factor, Penetration depth, Susceptibility, Bi-Pb-Sr-Ca-Cu-O.

ABSTRACT

The superconducting material with a nominal composition $Bi_{1.6}\ Pb_{0.4}\ Sr_2\ Ca_2\ Cu_3\ O_x$ has been recently synthesized and characterized by the authors using the Q- factor method. The Q-factor data reported in this work shows T_c in the range 105K to 110K, in good agreement with previously reported results.

The Q- factor versus temperature plots display a sharp drop near the superconducting transition. The penetration depth was found to vary with temperature, for example λ (77)= 3000 A° and λ (108) = 7000 A° These values are in good order of magnitude agreement with the measurements of other workers . The magnetic volume susceptibility for Bi - Pb - Sr - Ca - Cu - O has been measured at low temperature (77K), below T_c, and found to be χ_v 87 450±100J.T^{-2}. m^{-3} .

1. Introduction :

High temperature superconductivity has been widely studied in Sr- La - Ba - Cu - O and RE -Cu-Ba-O (RE = rare earth) Based compounds . The discovery of superconductivity with transition temerature (T_c) of 85k (low - T_c phase) and 110k (high- T_c phase) in Bi- Pb- Sr-Ca- Cu- O compounds has generated a great deal of interest in the basic properties and mechanisms in the Cu-O superconductors. According to Hideake et al. [1] the high-T_c phase has an excess Cu-O layer relative to the low -T_c phase in the stacking structure. Recently Sang et al, [2] reported that the coherence length $\zeta_o = 23\ \mathring{A}$ the penetration depth $\lambda_o = 2600A^o$ and d.c magnetizationts on the high -T_c $Bi_{1.4}\ Pb_{0.6}\ Sr_2\ Ca_2\ Cu_3\ O_y$ superconductor . Many workers have reported magnetic susceptility (χ) measurements at low temperatures in the literature sang et al, [2] 19, Joo et al, [3] Kiran et al, [4] and Kimihito. [5]. Most of these measurements have been made by magnetization curve methods. From the present point of view it is noteworthy that none of these workers used Gouy method for their magnetic susceptibility determination.

According to the Meissner effect the magnetic field flux is expelled from the specimen at the superconducting transition temperature, In five previous papers, we have out lined the use of inductance probe methods to study the properties of high-T_c superconductors [6-10]. In the most recent work attention was concentrated on the behaviour of Bi- Pb- Sr- Ca - Cu- O superconductors and we found that the inductance- temperature drop is 108k, the lower critical field H_{c1} = 17 gauss, the upper critical Hc_2 = 4T and 25% of the volume of the material is superconducting [10] .

In this work we have studied the effect of the quality factor, penetration depth and magnetic susceptiblity on sintered pellets of a Bi- Pb- Sr- Ca- Cu- O composition.

2. Experimental procedure :

A specimen with a nominal composition of $Bi_{1.6}\ Pb_{0.4}\ Sr_2\ Ca_2\ Cu_3\ O_x$ was prepared in the conventional manner using high purity powders of $Bi_2\ O_3$, pbO, $SrCO_3$,$CaCO_3$ and CuO. The mixture were calcined at 810 C° for 19 hours in air. The calcined material was reground and pressed into pellet form, as small discs of diameter about 6mm. The pellet was sintered at 850 C° for 168 hours and annealed at 950 C° for 24 hours followed by furnace cooling to room temperature in air. phase analysis of the products was carried out by x- ray diffraction using a Hagg- Guinier camera with strictly monochromatic radiation and KC1 as the internal standard. The phase of the specimen on which measurements are reported here was high T_c phase.

The quality factor was measured using a marconi circuit magnification Meter Type 1245 to accuracies of about 3%. The variation of the quality factor was measured as a function of temerature. Temperatures were recorded by a Cu/constantan thermocouple placed in contact with the specimen.

The magnetic susceptibility measurement was made at low temperature (77K) using a conventional Gouy balance technique, with a Newport Type A electro- magnet, i. e. the force (F) exerted on a specimen of volume susceptibility (χ_V) was derived from the relation.

$$F = \frac{1}{2}\chi_v (H_A^2 - H_B^2)\left(\frac{m_o}{\rho L}\right) \qquad (1)$$

where H_A and H_B refer to the field values at the ends of the specimen, ρ the x-ray density of the material, taken as 4.8g. cm^{-3} (4,11) and L and m_o represent the length and the mass of the sample, respectively. Corrections were made for the small susceptibility of the glass specimen tube and the overall accurcy of the measurements was estimated to be ±5%.

3. Results and Discussion:

3.1. Quality Factor:

Figure 1 Shows the variation of Q-factor with temperature for the empty coil. It shows that the empty coil exhibits a steady rise in Q- factor with decreasing temperature from 290 to 77K which is correctly explained quantitatively by the decreasing the resistance of the copper winding of the coil as the temperature is lowered. The teachnique has been established before (7,8) with non-superconducting material, pure aluminum oxide ($A1_2O_3$), and as expected, no sudden drop in the quality factor versus temperature was found.

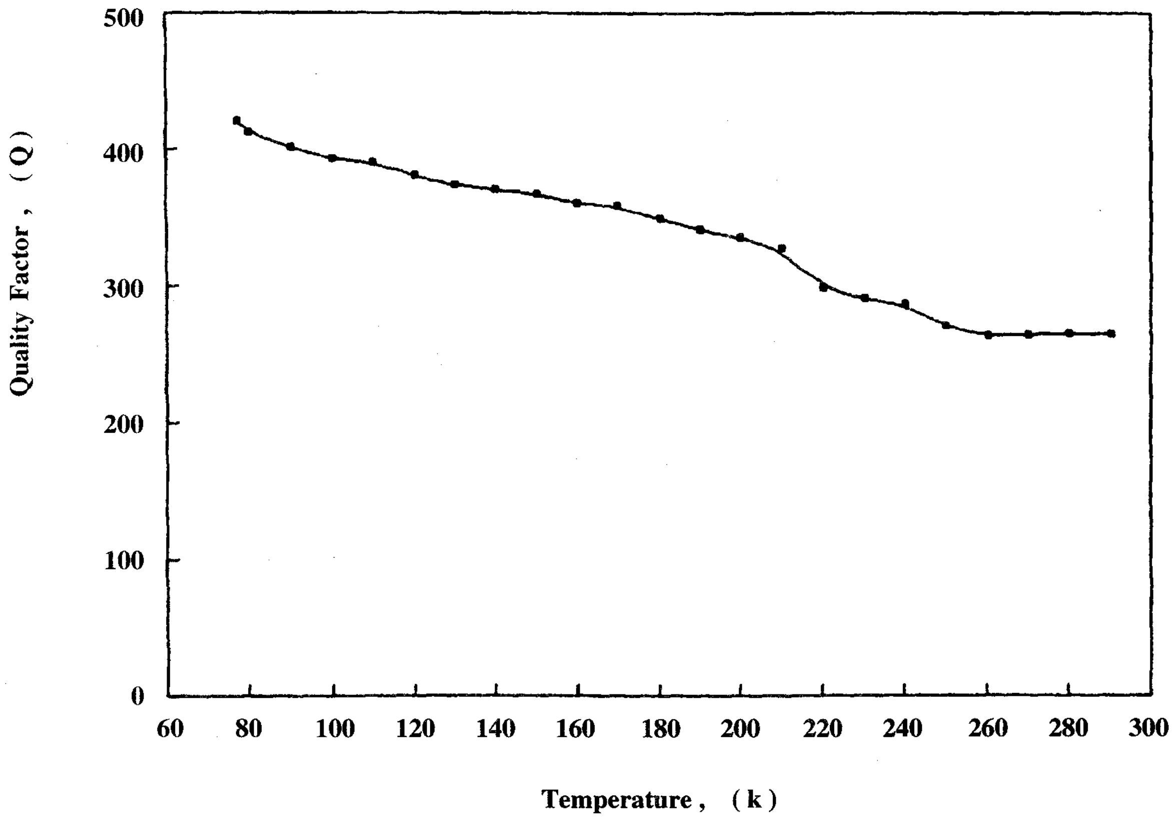

Figure 1. The Variation of the Q-factor with temperature for an empty coil.

The superconducting behaviour of the Bi - Pb- Sr - Ca - Cu-O previously reported (10) showd the temperature variation of inductance in the absence of any applied magnetic field. The results show a clear transition temperature T_c at 108 K. The variation of the quality factor versus temperature for the same coil filled with superconducting meterial Bi-Pb- Sr- Ca- Cu- O is shown in Figure 2. The quality factor firstly steadily increased as the temperature reduced, over the temperature range 293 to 120K, then dropped suddely on approaching the transition temperature and rose again with reducing temperature.

The noticeable features here are that there is again a steady rise in Q-factor as the temperature is reduced from 290 to 120K and that, at any given temperature in this range, the Q- factor of the coil is considerably less than that of the empty coil. The similar behaviour in the same range of temperature, we believe, is due to air in the empty coil and Bi- Pb- Sr- Ca- Cu- O in the filled coil, both of which are insulators.

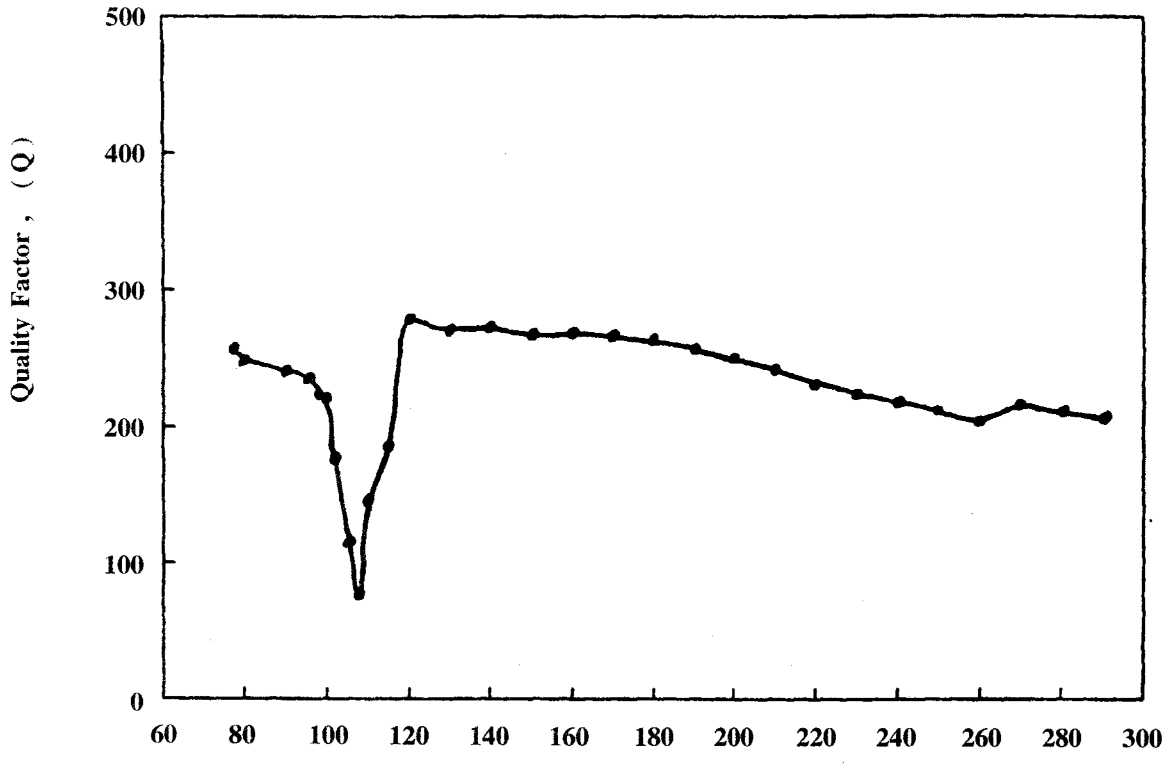

Figure 2. The Variation of the Q-factor with temperature for a Bi-Pb-Sr-Ca-Cu-O sintered pellet.

Comparing the direct inductance versus temperature data, by (10) reproduced in Figure 3, with the Q- factor versus temperature, Figure 2, for the same superconducting material, it appears that both techniques show a great similarity in the general sharp drop at 108K with decreasing temperature.

Similar results have been reported by the author and co-worker for $YBa_2\,CU_3\,O_{7-x}$ (7) and sintered superconducting pellets of 2212 and 2223 T1- Ba- Ca- Cu- O (8), The general features of the Q- factor versus temperature dependence thus appear to be the same for different superconducting materials; the difference is that the minimum occurs near the transition temperature of the respective material.

3.2. Penetration depth:

For a conventional Type II superconductor the penetration depth λ varies with temperature (12), according to the relation.

$$\lambda (T) = \lambda (o) [1-(T/T_c)^4]^{-1/2} \qquad (2)$$

where λ (T) is the value of the penetration depth at a chosen temperature. λ (O) is the value of the penetration depth at absolute zero temperature. T_c is the transition temperature.

Recent theoretical estimates for penetration depth vary from 1720°A to 2600°A have been determined (1,2) Using the later value in our analysis would give for example λ (77) of the order of 3000A° and λ (108) of the order of 7000A° by inserting appropriate values of T and T_c . The experimental results of penetration depth with temperature are shown in Figure 4.

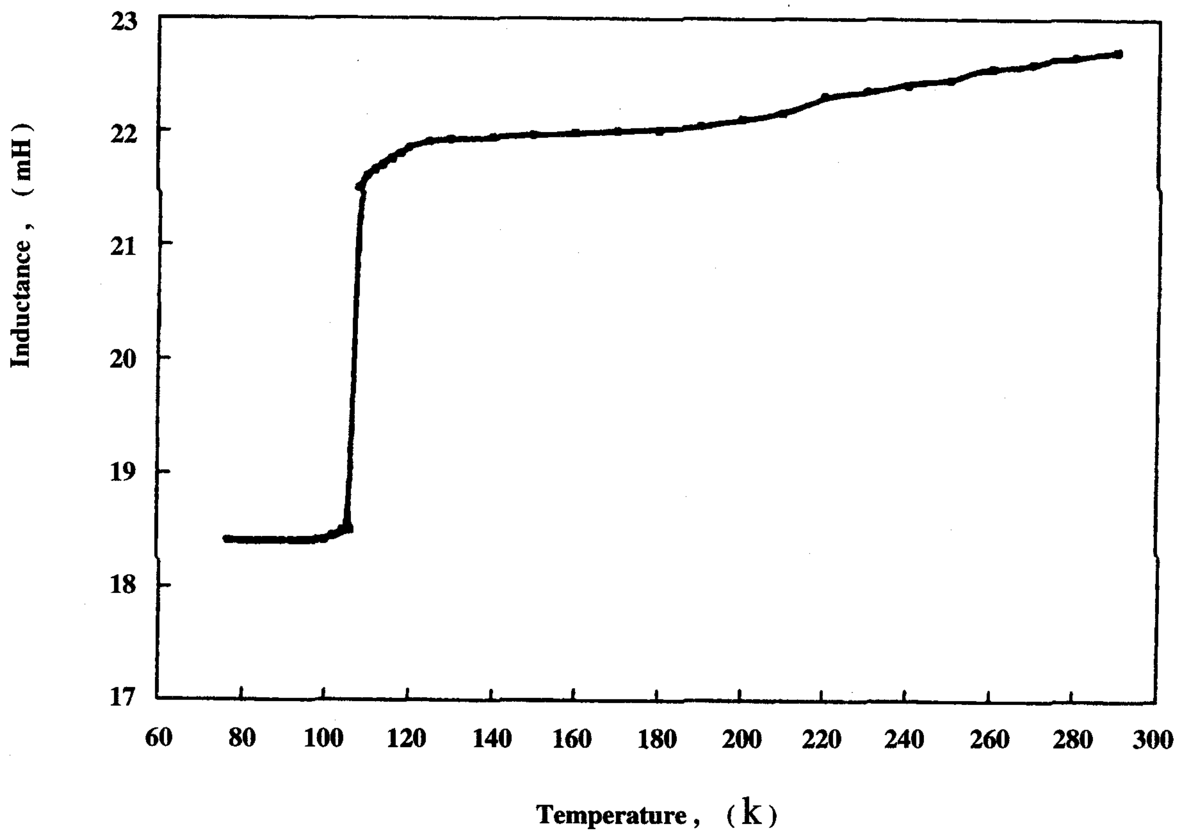

Figure 3. The Variation of Inductance with temperature for a Bi-Pb-Sr-Ca-Cu-O sintered pellet (after Al-Hawery [10]).

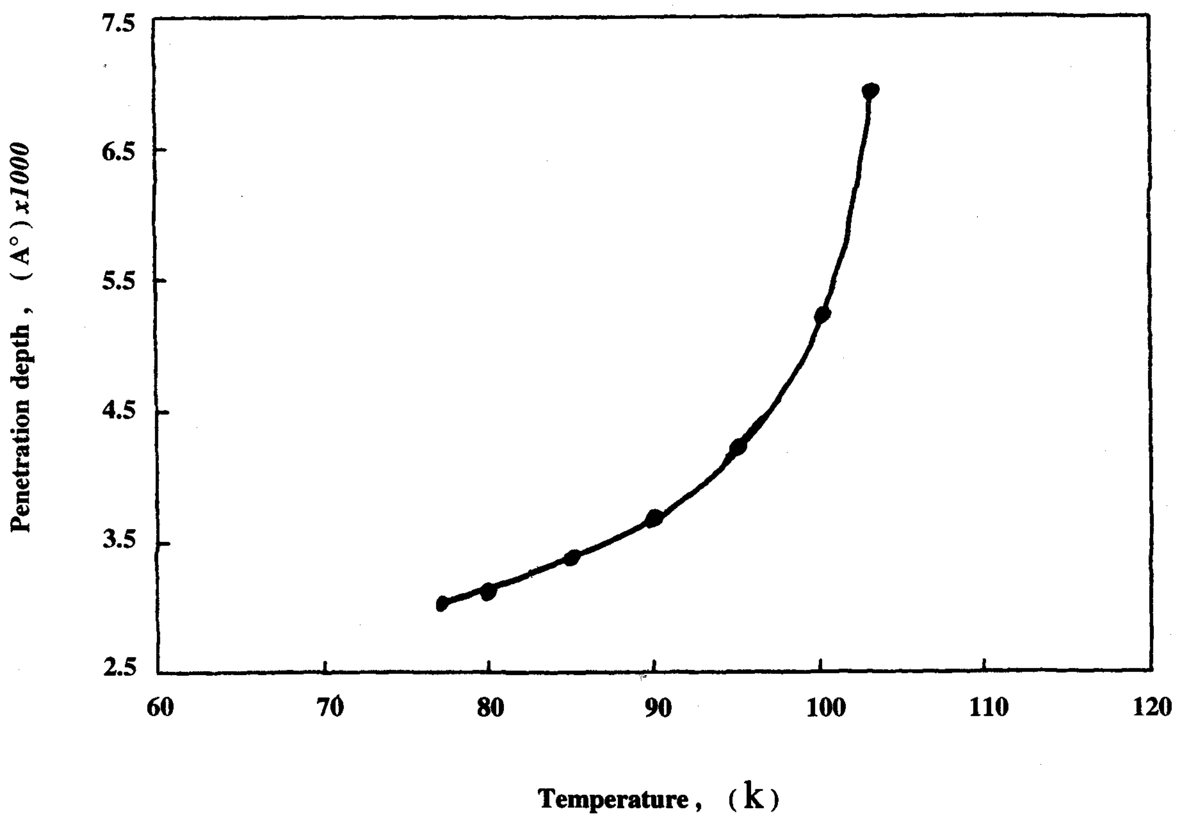

Figure 4. The Variation of the penetration depth with temperature for a Bi-Pb-Sr-Ca-Cu-O sintered pellet .

The penetration depth, is found to vary with temperature approximately as $\{1-(T/T_c)\}^{-1/2}$ and becomes infinite as the temperature approaches the transition temperature. It has been reported by other workers (2) for $Bi_{1.4}\ Pb_{0.6}\ Ca_2\ Sr_2\ Cu_3\ O_y$ superconductor that the magnetic penetration depth is in region of 2600°A . (Ansaldo, (13)) has suggested that the magnetic penetration depth for $Bi_{1.8}\ Pb_{0.2}\ Sr_2\ Ca_2\ Cu_3\ O_{10}$ is in the region of 1720A° . It is generally recognized that the penetration depth often depends critically on the exact composition and stoichiometry of the superconducting material. So we believe that the values of Sang et al, (2), and Ansaldo, (13), are in good order of magnitude agreement with our results.

3.3. Magnetic susceptibility:

At a low temperature (77K), below the T_c , the superconductor should behave as a perfect diamagnetic so that the susceptibility should be negative and have the value of $\frac{1}{\mu_o}$ = - 795000J.T^{-2}.m^{-3}. At low temperature, Figure 5 shows, the forms of the change in force due to magnetization versus magnetic field at a low constant temperature (77K).

The gradient of the plot was negative and steep at low field values. Clearly the specimen was strongly diamagnetic at low temperature. The diamagnetic susceptibility of the sample was not constant and decreased as field strength increased. It was not possible to calculate one single susceptibility value since this depended on the varying field strength. However, it is possible to obtain a susceptibility value by defining two points on the plot, calculating the gradient between them and using it in equation (1) to determine an average value for the susceptibility. The average volume susceptibility =87450J.T^{-2}.m^{-3} (estimated error ±100J.T^{-2}.m^{-3}).

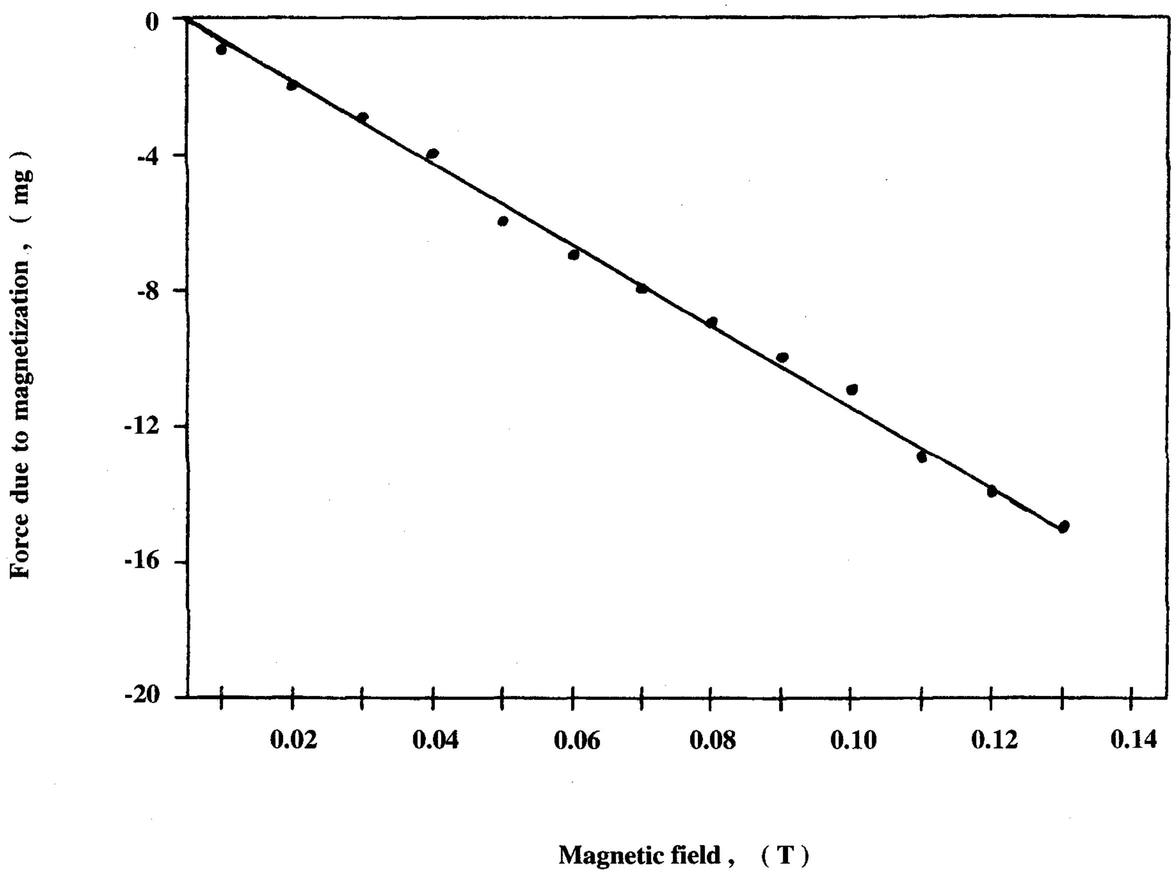

Figure 5. The variation of the force due to magnetization with the magnetic field for Bi-Pb-Sr-Ca-Cu-O sintered pellet at low temperature (77K)

Strictly speaking, there is a big difference between the magnetic susceptibility values of ideal superconductors, ($-795000J.T^{-2}.m^{-3}$), and our specimen, ($-87450J.T^{-2}.m^{-3}$), but considering the different preparation conditions, one might expect that, as was found experimentally, the ideal superconductor specimen is 100% superconductor and our specimen is 25% superconductor. Joo et al, (3), reported that the magnetization in $Bi_{1.7}$ $Pb_{0.3}$ Sr_2 Ca_2 O_y is qualitatively quite similar to YBCO compound.

4. Conclusion :

In conclusion, the behaviour of the quality factor of the $Bi_{1.6}$ $Pb_{0.4}$ Sr_2 Ca_2 Cu_3 O_x is quite similar to that observed before in YBa_2 Cu_3 $O_{(7-x)}$ (9) with a different transition temperature drop. The penetration depths have been estimated between 3000A° at 77K and 7000A° at 108K. We have measured the magnetic volume susceptibility at low temperatures and found it to be λ_v=-87450 ±100JT^{-2} m^{-3}.

Acknowledgement.

I wish to thank Dr. J.S.Thorp for his personal interest and encouragement.

References :

[1] **Hidetaka N., K. Takeshi, E. Hiroyuki, S. Jae Soo, T. Yoshiki, M. Natsuki, O. Hajime (1991)**, Effect of Ni and Cu in 110K phase of (Bi, Pb) -Sr-Sr-Ca-Cu-O superconductors, Jap. Jour. App. Phys. 30: 461-463.

[2] **Sang-Geun Lee, Chong-Yun Park, Young- Cheol Kim, Kyung-Soo Yu, Min-Su Jang and Seong- Cho Yu, (1990)**, Magnetic properties of High- Tc Bi1.4 Pb0.6 Ca2 Sr2 Cu3 Oy superconductors, Jap. Jour. Appl. Phys. 29: 1259-1260 .

[3] **Joo-II Lee, M.Kim, S.Yu, S.Oh,W. Lim and Min-Su Chang (1991)**, Field- Induced anistropy in Bi1.7 Pb0.3 Sr2 Ca2 Cu3 Oy superconductors, Jap. Jour. Appl. Phys. 30: 665-666 .

[4] **Kiran Jain, D.K. Suri, K.C. Nagpal, S.U.M. Rao and B.K.Das (1990)**, Preparation of highly oriented microstructure in the (Bi, Pb)2 Sr2 Ca2 Cu3 Ox sintered oxide superconductors, Jap.Jour. Appl. Phys. 29: 576-579 .

[5] **Kimihito Tagaya (1990)**, ESR and non-resonant microwave absorption in the high-Tc phase of the Bi (Pb)-Sr- Ca- Cu-O system, Jap. Jour. Appl. Phys. 29: 656-657.

[6] **Thorp J. S. and A.S.Al-Hawery (1990)**, Inductaprobe methods for determination of superconducting properties, Jour. Magn. Magn. Mate. 88: 299-310 .

[7] **Thorp J.S., A.S.Al-Hawery and F.Robb (1991)**, Examination of superconducting ceramics by modified inductance probe methods, Jour. Magn. Magn. Mate., 94: 119-126 .

[8] **Thorp J. S., A.S.Al-Hawery, R.J.D.Tilley and J.S.Lees (1991)**, Inductance probe examination of superconducting Tl-Ba-Ca-Cu-O ceramics, Jour. Magn. Magn. Mate., 97: 112-118 .

[9] **Beales T. P., J.S. Thorp and A.S. Al- Hawery (1992)**, A 124K transition in YBa_2 Cu_3 O_{7-x} measured by an inductance probe method, Jour. Mater. Scie. Lett., 11: 192-193 .

[10] **Al-Hawery A. S. (1992)**, Inductance probe examination of a superconducting Bi-Pb-Sr-Cu-O ceramics, The Arab. Jour Scie. Engin., 17, 4A: 492-496 .

[11] **Yusheng H. , H. Yujing , L. Menglin , M. Sining, C.Liying, W.Ying, Z.Jincang, H.Aisheng, W.Jinsong and Y.Xiaohua (1991)**, Fabrication characterization and welding of Bi(Pb) -Sr-Ca-Cu-O superconducting fibers, Supe. Sci. Tech. 4: 158-164 .

[12] **Rose-Innes A. C. and E.H. Rhoderick (1976)**, "Introduction to Superconductivity", 2nd. ed., Pergamon Press, U.K.

[13] **E. J. Ansaldo, 1989**, Review of recent results in the application of μSR to magnetic properties of gigh- T_c oxides, Physica C, 164: 259-2.