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Effect of Pressure on the Superconducting and Mechanical Properties of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ System

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ABSTRACT

Solid state reaction method was used to prepare samples of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$. Superconducting and mechanical properties by Vickers microhardness measurements have been carried out to examine the effects of pressure. Electrical measurement demonstrates the best transition temperature was under 0.7 GPa. An improvement of mechanical properties was found when the pressure increases from 0.3 GPa to 0.9 GPa. On the other side an increases of the pressure to 1.1 GPa decrease in the micro hardness, Young modulus and yield strength.

Keywords: Pressure Effect; Superconductor; Mechanical Properties

1. Introduction

Considerable efforts have been made in the synthesis, processing, and characterization of BiSrCaCuO superconducting ceramics because these materials have a higher T_c and good chemical durability (resistance to moisture), and also they contain no rare earth elements [1-3]. However, the bulks sometimes fracture due to the thermal stress on the cooling process or the electromagnetic force during the magnetization. Thus, it has been recognized that improvement and understanding of the mechanical properties of bulks are indispensable for practical application.

Ahn [4] prepared superconducting BiSrCaCu(Ni)O ceramics by the gel method using an aqueous solution containing a tartaric acid. Their ceramic microstructure were studied using IR, TGA, XRD, resistance measurements, and SEM. They found that the nickel dopant substituting for Cu gives rise to the gradual decrease of the T_c and the pure phase 2212 ceramics were obtained at sintering temperature 1098 K for 24 hs. SEM pictures showed that liquid phase was formed when the samples were sintered temperatures higher than 1098 K.

The effect of silver additions on the mechanical and superconducting properties of sintered bulk YBCO, BSCCO-2212, and BSCCO-2223 has been evaluated by Joo *et al*. [5] their results show that strength and fracture toughness of YBCO and BSCCO bars increased with increasing Ag content up to 30 vol% Ag. These improvements in strength and fracture toughness are due to the presence of Ag particles that may induce compressive stresses in the superconducting matrix and resist crack propagation by pinning the propagating cracks. On the other hand, the hardness of YBCO and BSCCO decreased with increasing Ag contents because of the lower hardness of Ag. Addition of Ag showed no adverse effects on superconducting properties of YBCO or BSCCO superconductors.

Katagiri *et al*. [6] summarize the evaluation process of the mechanical properties for various high-temperature superconducting bulks. The Young's modulus, Poisson's ratio, fracture strength, fracture toughness and hardness are evaluated by tensile, bending, compression and hardness tests. The mechanical properties are anisotropic, mainly due to the crystallographic structure and pre-existing micro-cracks associated with it.

Madre *et al*. [7] measured the flexural strength of 1 wt% Ag-doped $Bi_2Sr_2CaCu_2O_{8+\delta}$ thin rods textured by a laser heated floating zone as a function of the environmental conditions (air versus water) at room temperature. Loading rates spanning three orders of magnitude (1, 10 and 100 μm/min) were used to explore their susceptibility to the environmental conditions. These mechanical tests were completed with electrical characterization (critical current at 77 K and resistivity from 77 to 300 K) of samples submerged in distilled water for different time lengths (0, 12 and 120 h). While $Bi_2Sr_2CaCu_2O_{8+\delta}$ has been shown to be unstable during contact with water molecules, the Ag-doped Bi-2212 textured rods tested

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are very inert to the water environment, with respect to their mechanical and electrical properties, due to the presence of a narrow (≈150 μm) low textured outer ring formed in the growth process.

In the previous work [8], mechanical properties of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ superconducting system pressed under 0.5 GPa were investigated. In this research, effect of pressure on the critical temperature (T_c), oxygen content (δ) and mechanical properties of the superconducting system have been studied.

2. Experimental Part

$Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ samples were prepared by conventional solid-state reaction method. Appropriate amounts of Bi_2O_3(99.9%), Pb_3O_4(99.9%), $SrCO_3$ (99.9%), $BaCO_3$(99.9%), CaO(99.9%), CuO(99.9%) and Ni_2O_3(99.9%) powders were used as starting mate- rials. The powder of precursor was mixed together by using agate mortar. The mixture homogenization takes place by adding a sufficient quantity of 2 - propanol to form a past during the process of grinding from about (1 h). In the second step, the materials were grounded to a fine powder and then calcined in air at 1073 K for 24 hs, the mixture was then pressed into pellets (1.3 cm) in dia- meter and (0.2) cm thick, using hydraulic type (SPECAC), under pressure of 0.3, 0.5, 0.7, 0.9 and 1.1 GPa. The pellets were sintered in air at 1123 K for 140 hs.

Iodometric titration was used to find the oxygen content (δ) in the samples. Four probe dc method at temperature range (77 - 300) K was used to measure the resistivity (ρ) and to determine the critical temperature (T_c).

The mechanical properties, such as the Vickers microhardness (H_V), Young modulus (E) and yield strength (Y) of superconductor samples were calculated as referred in the previous paper [8].

3. Results and Discussion

In order to examine the effect of the pressure on critical temperature T_c, samples of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ were sintered at 1123 K for 140 hs under different pressures (0.3, 0.5, 0.7, 0.9 and 1.1) GPa. The resistivity behavior as a function of temperature for $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ at different pressures are shown in **Figure 1**. From this figure we can see the increase of the critical temperature T_c from 113 K to 117 K with increasing pressure from 0.5 GPa and 0.7 GPa, while an increase of the pressure to 1.1 GPa causes a reduction of transition temperature to 93 K. It is believed that the increase of the critical temperature with increasing pressure from 0.3 to 0.7 GPa, as listed in **Table 1** may be due to the increase of the carrier concentration n_h in the CuO_2 planes, the change of n_h within the unit cell resulting in the improvement of the critical temperature [9]. Also Vonsovsky *et al*. [10] indicate that the deviation from stoichioctry and disordering of these compound lead to decrease the value of T_c with the pressure.

It is found from **Table 1** that the oxygen content (δ) of the samples increases as the pressure increases. This is clearly shown for samples under 0.3 GPa, 0.5 GPa and 0.7 GPa, the oxygen content (δ) is 0.191, 0.246 and 0.368 respectively. The enhancement of the pressure is going to enhance the hole concentration in the Cu-O_2 layers, also enhancing the critical temperature T_c from nearly 110, 113 K to 117 K respectively, while increases the pressure to 1.1 GPa decreases the oxygen content (δ) and the critical temperature T_c as shown in **Figure 2**. This indicates that the increase in the critical temperature T_c and the oxygen content (δ) values is attributed to the increase of oxygen absorption during crystallization process of the superconductors. From the results we can conclude that the oxygen content (δ) equal 0.368 is optimum

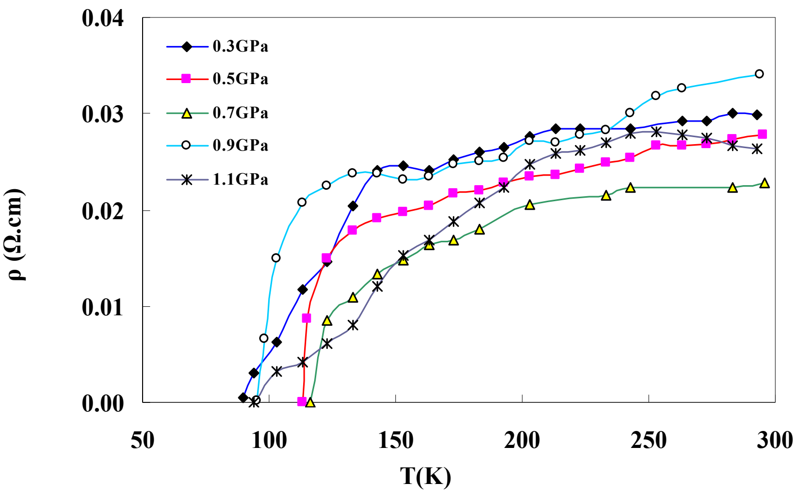

Figure 1. Temperature dependence of resistivity for $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ under different pressure.

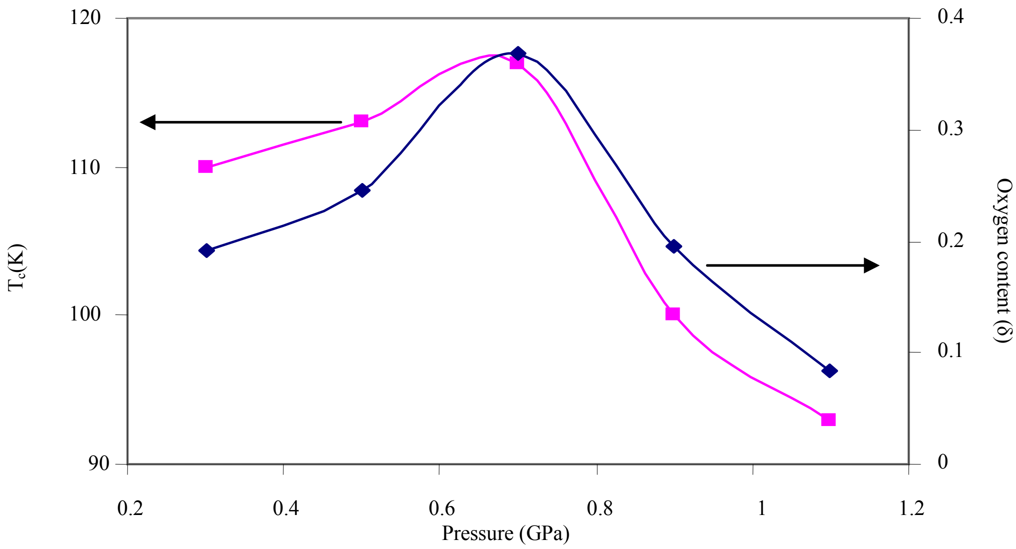

Figure 2. Transition temperature and oxygen content for $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ under different pressure.

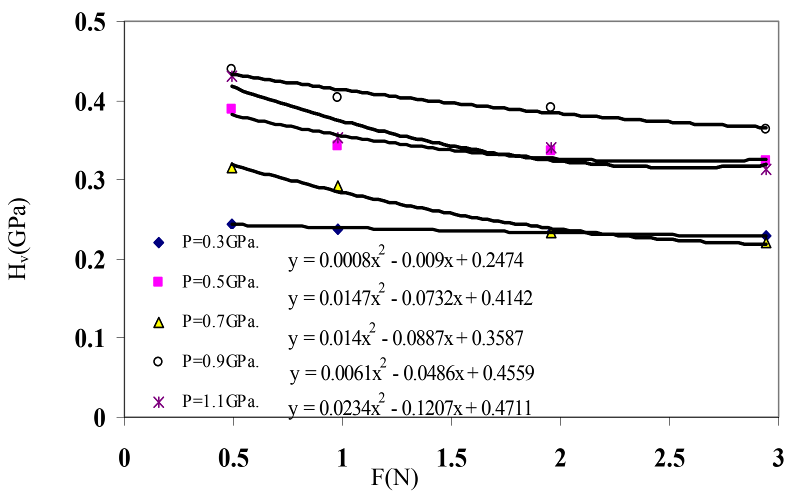

Figure 3. Variation of microhardness with applied load for different pressures.

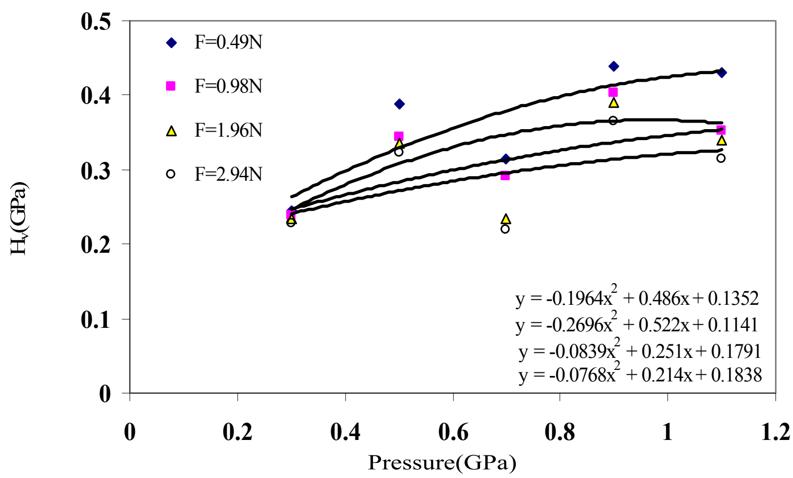

Figure 4. The variations of microhardness (H_v) as a function of pressure for different loads.

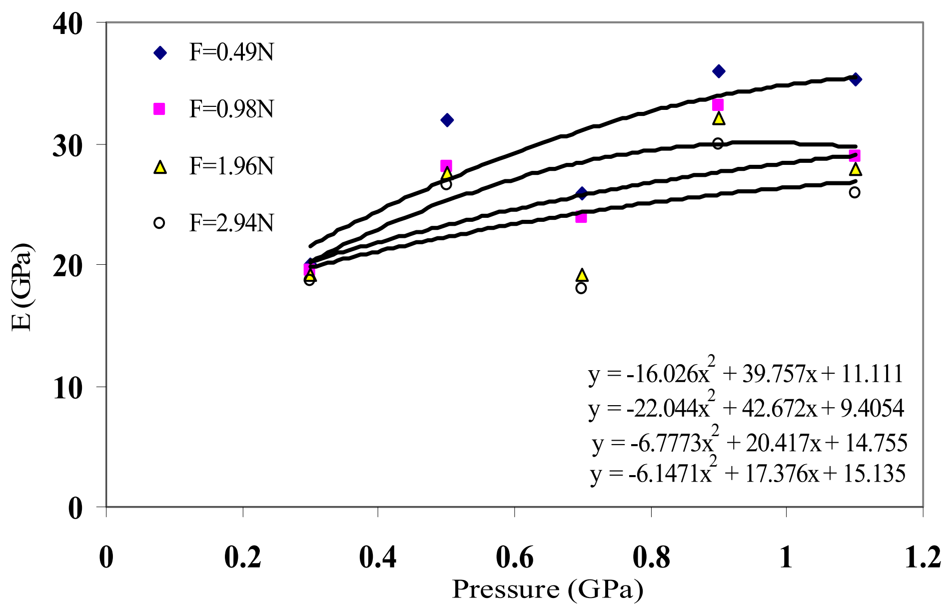

Figure 5. Variations of Young's modulus (E) as a function of pressure for different loads.

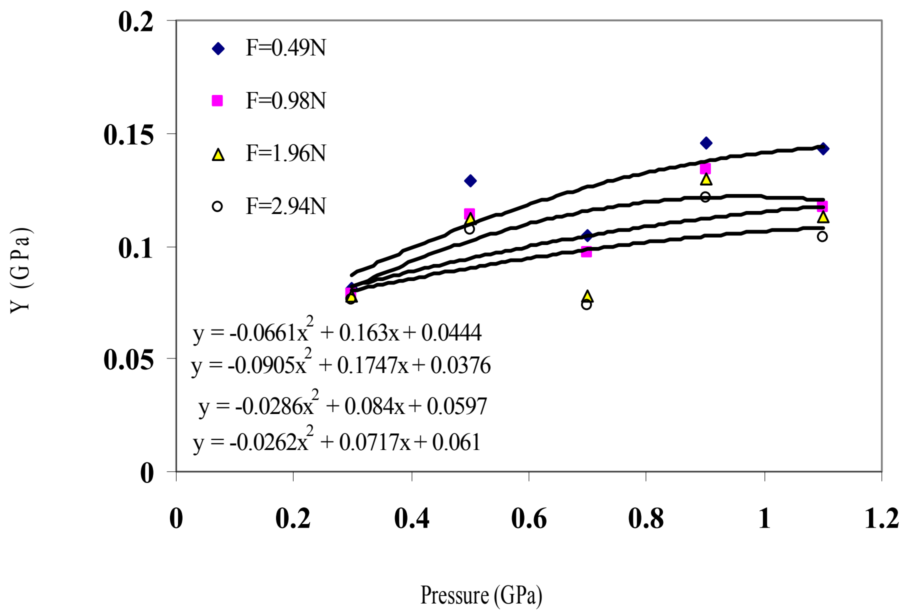

Figure 6. Variations of yield strength (Y) as a function of pressure for different loads.

Table 1. Oxygen content and critical temperature (T_c) for $(Bi_{0.8}Pb_{0.2})_2(Sr_{0.9}Ba_{0.1})_2Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ under different pressures.

Pressure (GPa)	δ	T_c (K)
0.3	0.191	110
0.5	0.246	113
0.7	0.368	117
0.9	0.196	100
1.1	0.083	93

Table 2. Microhardness (H_v), Young modulus (E) and yield strength (Y) for different load for $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ under different pressure and different loads.

Pressure (GPa)	F (N)	Hv (GPa)	E (GPa)	Y (GPa)
0.3		0.244	20.01	0.081
0.5		0.389	31.91	0.129
0.7	0.49	0.315	25.82	0.105
0.9		0.439	36.01	0.146
1.1		0.430	35.28	0.143
0.3		0.238	19.53	0.079
0.5		0.343	28.13	0.114
0.7	0.98	0.292	23.93	0.0973
0.9		0.404	33.11	0.134
1.1		0.352	28.85	0.117
0.3		0.234	19.211	0.078
0.5		0.336	27.57	0.112
0.7	1.96	0.234	19.18	0.078
0.9		0.391	32.07	0.130
1.1		0.340	27.89	0.113
0.3		0.228	18.72	0.076
0.5		0.323	26.52	0.107
0.7	2.94	0.22	18.03	0.0733
0.9		0.364	29.90	0.121
1.1		0.314	25.80	0.104

value for the critical temperature T_c 117 K under pressure 0.7 GPa.

The effects of pressure on the mechanical properties of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{2.2}Ni_{0.8}O_{10+\delta}$ samples were studied. The samples were pressed under 0.3, 0.5, 0.7, 0.9 and 1.1 GPa. It is noticed from **Figure 3** a decreases of the microhardness with increases of load for samples under different pressures. This behavior may attribute to the presence of weak grain boundaries of the superconducting ceramics.

Figures 4-6 and **Table 2** shows the variation of Vickers microhardness, Young modulus and yield strength, as a function of pressure for different loads. An increase of microhardness, Young's modulus and yield strength was observed with increasing pressure from 0.3 GPa to 0.9 GPa. This result indicates that an enhancement of the pressure work on article contacts which get rearranged to fill the voids and pores resulting in more densification of the specimen [11], which leads to a remarkable increase in the mechanical resistance of the samples. On the other side an increase of pressure to 1.1 GPa reduces the microhardness, Young's modulus and yield strength. This decrease of mechanical properties is due to the decrease in strength of bonding between the grains and consequently causes the degradation [12].

4. Conclusions

1) The highest critical temperature was 117 K under 0.7 GPa.

2) A remarkable increase, in the mechanical resistance of the samples was observed with the increase of the pressure from 0.3 GPa to 0.9 GPa. On the other hand an increase of the pressure to 1.1 GPa reduces these properties.

REFERENCES

[1] T. D. Xiao, K. E. Gonsalves and P. R. Strutt, "Synthesis of Aluminum Nitride/Boron Nitride Composite Materials," *Journal of the American Ceramic Society*, Vol. 76, No. 4, 1993, pp. 987-992. doi:10.1111/j.1151-2916.1993.tb05323.x

[2] P. L. Chen and I. W. Chen, "Sintering of Fine Oxide Powders: I, Microstructural Evolution," *Journal of the American Ceramic Society*, Vol. 79, No. 12, 1996, pp. 3129-3135. doi:10.1111/j.1151-2916.1996.tb08087.x

[3] D. R.Yang, D. S. Tsai and H. C. Liu, "Raising Pyrolysis Yield of Preceramic Polymers of Silicon Carbonitride," *Journal of Material Science*, Vol. 30, No. 17, 1995, pp. 4463-4468. doi:10.1007/BF00361532

[4] B. S. Ahn, "Synthesis of BiSrCaCu(Ni)O Ceramics from the Gel Precursors and the Effect of Ni Substitution," *Bulletin Korean Chemical Society*, Vol. 23, No. 9, 2002, pp. 1304-1308. doi:10.5012/bkcs.2002.23.9.1304

[5] J. Joo, J. P. Singh, T. Warzynski, A. Grow and R. B. Poeppel, "Role of Silver Addition on Mechanical and Superconducting Properties of High-T_c Superconductors" *Applied Superconductivity*, Vol. 2, No. 6, 1994, pp. 401-410. doi:10.1016/0964-1807(94)90087-6

[6] K. Katagiri, A. Murakami and K. Kasaba, "Evaluation of Mechanical Properties of High-Temperature Superconducting Bulks Fabricated by a Melt-Processing," *Cryogenics*, Vol. 48, No. 3-4, 2008, pp. 87-94. doi:10.1016/j.cryogenics.2008.02.003

[7] M. A. Madre1, Sh. Rasekh, J. C. Diez and A. Sotelo, "Dynamic Fatigue Behaviour of Ag-Doped Bi-2212 Textured Thin Rods," *Journal of Physics*: *Conference Series*, Vol. 153, No. 1, 2009, Article ID: 012021.

[8] G. Y. Hermiz, B. A. Aljurani and H. A. Thabit, "Mechanical Properties of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}Ca_2Cu_{3-x}Ni_xO_{10+\delta}$ Superconducting System," *Journal of Superconductivity and Novel Magnetism*, Vol. 25, No. 6, 2012, pp. 1629-1634. doi:10.1007/s10948-012-1584-3

[9] X. J. Chen, H. Q. Lin and C. D. Gong, "Pressure Dependence of T(c) in Y-Ba-Cu-O Superconductors," *Physical Review Letter*, Vol. 85, No. 10, 2000, pp. 2180-2183. doi:10.1103/PhysRevLett.85.2180

[10] S. V. Vonsovsk, Yu. A. Lzumov and E. Z. Kurmaev, "Superconductivity of Transition Metals," Springer-Verlag, Berlin, 1982.

[11] V. M. Anandakumar and M. A. Khadar, "Microhardness Studies of Nanocrystalline Calcium Tungstate," *Crystal Research and Technology*, Vol. 43, No. 2, 2008, pp. 193-199. doi:10.1002/crat.200710987

[12] O. Gorur, M. Nursoy, C. Terzioglu, A. Varilci and I. Belenli, "Influence of Annealing Temperature on the Microstructure and Mechanical Properties of MgB_2," *Journal of Physics*: *Conference Series*, Vol. 153, No. 1, 2009, Article ID: 012012.

