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Effect of the Structural and Electrical Properties of Bi2-xPbxBa2Ca2Cu3O10+δ Superconductors with Partial Substitution of Lead by Bismuth

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Keywords: Bismuth, Lead, Superconducting Properties, Solid State Reaction Method, Electrical Conductivity, Tetragonal Structure.

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Abstract:

This manuscript discusses the preparation of $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compounds by the method of solid-state reaction at the annealing temperature 850 C°. Under pressure of 8ton/cm^2 with a presence of enough oxygen and these are considered as ideal conditions according to the previous researches in the preparation of electric superconductors of high degree temperatures the effect of partial substitution was on Lead (Pb) element in the Bismuth (Bi) element was studied to produce a compound with formula of $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ and for different ratios of x to know the effect of partial substitution to form Bi2223 phase at the annealing time 72 hrs and we concluded from study of diffraction of x-ray that the compound kept its tetragonal structure , and critical temperature(Tc) degrees were obtained Tc= 128K,130K, 135K, 132K, and that's at substitution ratios x=0,0.15,0.25,0.3, respectively it was clear the best substitution ratios of pb in Bi was when x=0.25.

Keywords: Bismuth, Lead, Superconducting Properties, Solid State Reaction Method, Tetragonal Structure.

تأثير الخواص التركيبية والكهربائية لموصلات $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ الفائقة عند الاستبدال الجزئي للرصاص بالبزموث

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الخلاصة:

يدرس هذا البحث إعداد مركبات $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ باستخدام طريقة التفاعل في الحالة الصلبة عند درجة حرارة تلبيد تبلغ 850 درجة مئوية، وتحت ضغط 8 طن/سم²، مع وجود كمية كافية من الأوكسجين، وتُعتبر هذه الظروف مثالية بناءً على الأبحاث السابقة في تحضير الموصلات الفائقة الكهربائية ذات درجات الحرارة العالية.تمت دراسة تأثير الاستبدال الجزئي لعنصر Pb بعنصر Bi لإنتاج مركب بصيغة $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ و لتراكيز مختلفة لـ x، وذلك لمعرفة تأثير الاستبدال الجزئي على تكوين الطور Bi2223 عند زمن تلبيد بلغ 72 ساعة. ومن خلال دراسة حيود الأشعة السينية(XRD) ، تبين أن المركب يحافظ على صفته الرباعية (tetragonal)، وتم قياس درجات الحرارة الحرجة حيث كانت القيم 128K، ١٣٠K، ١٣٥K، ١٣٢ Kعند نسب استبدال $x = 0, 0.15, 0.25, 0.3$ على التوالي. وقد كان واضحًا أن أفضل نسبة استبدال لعنصر Pb ب عنصر Bi هي عند $x = 0.25$.

الكلمات المفتاحية: البزموث، الرصاص، خصائص الموصلية الفائقة، طريقة التفاعل في الحالة الصلبة، التركيب الرباعي.

1. Introduction:

When materials are cooled to a specific temperature, known as the Tc, they become superconducting, allowing electric current to flow without resistance and with no magnetic flux at all. This property is crucial for many applications in electronics, connectivity, and medical equipment. [1,2]. After the discovery of some ceramic materials with a temperature of more than 90 K, which were referred to as high-temperature superconductors, superconductors entered a new stage. The ability to use liquid nitrogen for cooling [3] and liquid nitrogen at a temperature of (77 K), which can be obtained readily and at an affordable price [4,5], and the discovery of these materials have mad.

High temperature superconducting materials, including the BBCCO system, have been identified and synthesize [6] is an abbreviation for HTSC, composed of e1ement oxides (bismuth, barium, calcium, copper) with the typical chemica1 formula ($Bi_{2-x}Pb_xBa_2Ca_{n-1}Cu_nO_{6+\delta}$), where (n = 1, 2, 3). It is of significant significance because of its high frequency, elevated temperature tolerance, and excellent chemica1 resistance to moisture. Consequently, significant efforts have been devoted to examining the preparation methods, treatments, and properties of this system [7,8]. The superconducting system (BBCCO) exhibits a 1ayered structure including copper oxide 1ayers (CuO) with Critical temperatures (Tc) of 110, 80 and 10 K, respectively, at which the electrica1 resistance reaches zero (R=0) [9,10].The superconducting and transition properties of high-temperature CuO compounds are very different [11,12]. The unsupported alternating conductivity at frequency, coupled with a low insulation constant at high frequencies (60 GHz) at room temperature, and the material's polarization may necessitate the use of frequency-dependent conductivity [12].

The discovery of high temperature superconducting material initiated a revolutionary advancement in industrial applications and materials science [13,14]. High temperature superconducting systems include Bi-2201, Bi-2212, and Bi-2223 [15], which are distinguished by their two-dimensional basis and 1-ayered structure, comprising three phases: Bi-2201, Bi-2212, and Bi-2223. A final numeral for each phase denotes the quantity of CuO layers, which corresponds to the Tc (10K, 80K, and 110K); the latter signifies the temperature at which electrica1 resistance is zero (R = 0) [16] . The Bi-2223 phase is challenging to synthesize, although it possesses the advantage of being a single phase with the highest Tc (110 K) among 204 effects of partial substitution of silver and copper on the structural and electrica1 characteristics of Bi2Ba2Ca2Cu3O10+δ superconductors across three phases [17]. The characteristics of superconductors can be adjusted by incorporating or eliminating an element with varying ionic radius and bonding properties, and the enhancement or decline in superconducting properties is contingent upon the attributes of the added or substituted e1ements that differ in radius and bonding. The majority of the research concentrates on enhancing the morphology and characteristics of (Bi-2223) through substitution studies [18-20]. This current work discusses the temperature-dependent electrical characteristics and structural properties of the Bi2-xPbxBa2Ca2Cu3O10+δ samples and at concentrations x=0,0.15,0.25 and 0.3.

2. Material and methods:

The molecular weights of these materials relative to the weight of the element in each of the base material and the compound (sample) to be generated were used to calculate the weight ratios of the materials that contribute to the creation of the $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compound.

The oxides and carbonates are weighed out, combined, and then put into granules. These materials are then ground finely for 30 minutes using an agate grinder so that the mixture becomes homogeneous. An isopropanol solution is added during the grinding process to prevent falling or losing powder during the grinding process. The isopropanol alcohol is then removed from the grinder by placing it in an electric oven set between (50°C, 60°C).

These powders are put in a convection oven, which is heated to 850°C and heated at a pace of 120°C per hour in an air-saturated environment. This form is kept at (850 C) for (12) hours before being lowered to allow it to cool to a specific temperature. The model is taken out of the furnace at room temperature with a cooling rate of 30°C/hr and temperature control using a thermocouple. To prevent vaporization and loss, the powder is then combined and continuously processed for another 30 minutes. The ester of is solution is then added. 50˚C, 60˚C).

The powder is then manufactured under pressure (8 Ton/cm) in the form of tablets. These tablets had (12 mm) diameters and ranged in thickness from (0.8 mm) to (1.2 mm). These discs are put in an electric oven, where the temperature is progressively increased to (850 C˚) at a pace of (120 C˚ /hr) and held there for 12 hours before being gradually lowered at a rate of (30 C˚). After acquiring the samples that were made in the shape of tablets from the previous sentence, the process of heating and cooling takes place in an atmosphere that is saturated with oxygen until it reaches room temperature. This process is known as sintering. The prepared samples are obtained as tablets, which are then placed in an electric oven and heated to (600 C˚) at a rate of (120 C˚ /hr) from room temperature. The sample is then kept at this temperature for (12) hours before the temperature is raised. The oven heats up to 850 degrees Celsius at a rate of 120 degrees Celsius per hour, where it stays for 24 hours in an oxygen-rich environment. The model then cools to 600 degrees Celsius at a rate of 30 degrees Celsius per hour, where it stays for another 12 hours before being cooled to room temperature at a rate of 60 degrees Celsius per hour to room temperature. Tablet-shaped samples are obtained, and after being processed, they will be examined using an X-ray diffraction instrument to determine their structural characteristics and to look at their electrica1 properties with the four probes method.

3. Results:

When the element pb is partially substituted for the element Bi in the compound $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compound, with x=0,0.15,0.25,٠,٣ the structural properties of the compound have been studied. However, the structural properties of the compound $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$, which was prepared at an annealing temperature of 850 and under a hydrostatic pressure of 8 tons/cm^2 are different. When creating the models with the X-ray device and putting the value of x into the compound, the X-ray diffraction investigation of these samples revealed. The regularity of the crystalline structure and the appearance of distinct peaks are noticed as shown in **Figure 1**.

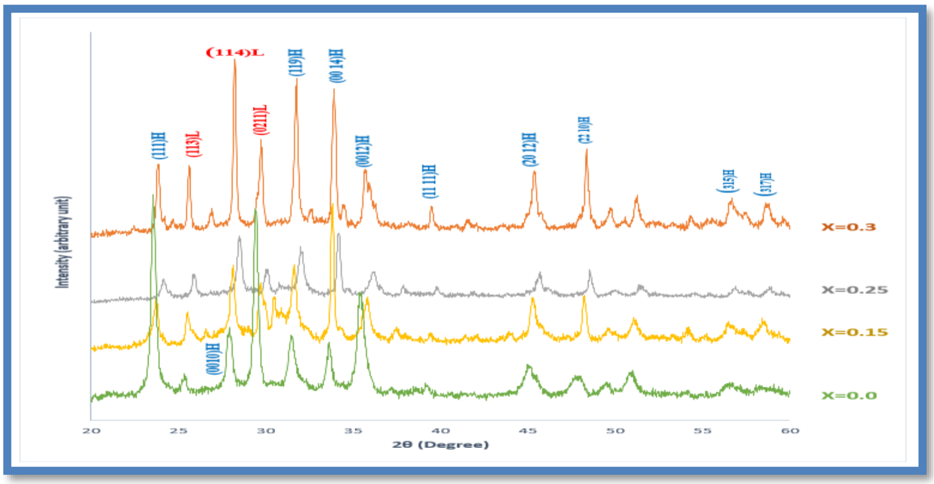

Figure 1. X-ray diffraction of $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compound as function of 2Θ, with indicated values of x=0,0.15,0.25, x=0.3

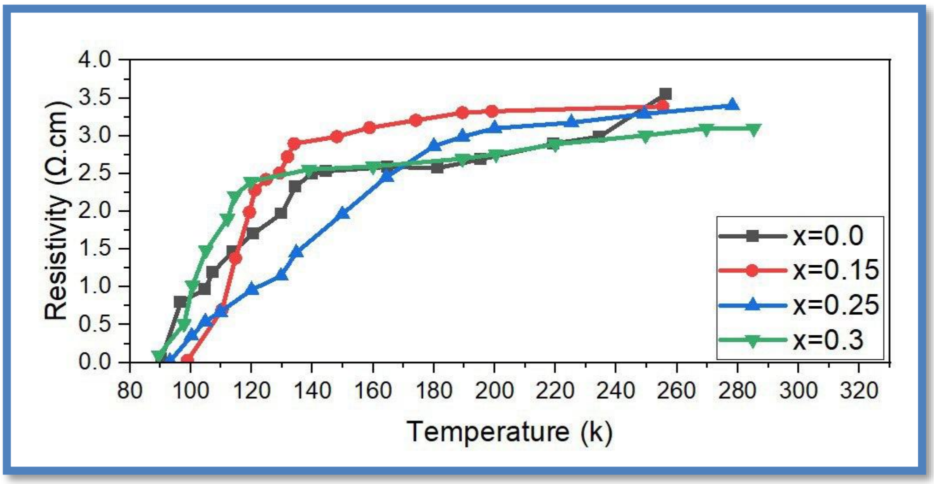

Figure 2: Resistivity of $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compound as function of pb, with indicated values of x=0,0.15,0.25, x=0.3

Figure 2 presents the electrical resistance behavior as a function of temperature for the four samples, both before and during the partial replacement. The maximum zero-resistivity (Tc) of 135 K was achieved at x = 0.25; however, at other concentrations, Tc increased with x concentration, as shown in **Table 1**.

Table (1): Values axes a, c, Tc(onset), ΔT and Tc(offset) of $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compound as function of pb, with indicated values of x=0,0.15,0.25,0.3

X	a (°A)	c (°A)	c/a	Tc (OFF)(K)	Tc (ON) (K)	Tc(K)
0	5.0923	35.017	6.97	95	150	123
0.15	5.339	36. 895	6.91	198	160	129
0.25	5.432	37.028	6.81	100	170	135
0.3	4.973	36.962	7.64	99	122	110

4. Discussion

The regularity of the crystalline structure and the appearance of distinct peaks are noticed as shown in Figure 1.

Miller coefficients hkl are then discovered, and using a particular BASIC software, the values of the unit cell's dimensions are discovered. a = b = 5.09A0 and, c = 35.01A0 for x= 0, where: a = b = 5.33 A0, c = 36. 89 A0 for x= 0.15, a = b = 5.43A0 and, c = 37.02 A0 for x= 0.25, as shown in Table 1. The table indicates that elevating the concentration of partially transcendent elements results in a significant alteration of both the network constants and their size. An increase in the value of c resulted in variations in the concentrations x = 0.0, 0.15, 0.25, 0.3, attributed to disturbances in the number of CuO chains and CuO2 levels that govern the various isotropic materials and the Tc of superconducting materials. A decrease in the coefficient c diminishes the intensity of the fermi energy levels, thereby lowering the Tc, causing imbalance and variability, and affecting the unit cell volume in a compound [21]. The change in 1attice constants arises from the variation in ionic radii of the substituted e1ements resulting from an increase in substitution concentration. X-ray diffraction measurements indicated that the crystalline structure remained tetragonal [22], with a noticeable reduction in the c-axis length when the compensation ratio increased to x = 0.3, attributed to the relocation of atomic defects or oxygen deficiency. The vacuoles or abnormalities of the positive ions result in the accumulation of stacking faults. The distortion of the crystal structure eventually results from the influence along the (c) axis [23].

As shown in Figure 2 the results indicate that all samples exhibited metallic behavior, with the Tc rising in accordance with the increasing x concentration. The electrica1 resistance decreases as the temperature decreases in the region preceding (Tc(onset)), as the material transitions from its natural state. The change to the superconducting state occurred in several stages, influenced by several transitions arising from the various phases present in the sample, as well as the presence of certain crystals and impurities. The findings indicated that the Tc varies with increasing x concentration [22]. The maximum zero-resistivity (Tc) of 135 K was achieved at x = 0.25; however, at other concentrations, Tc increased with x concentration, as shown in Table 1.

This result can be explained by the compound playing the perfect role in the crystal structure [20], and this percentage of compensation caused the Tc to rise as a result of an increase in the high phase 2223 with an increase in the lead concentration in the samples.

Using the four-probe approach, the electrical characteristics of the compound were investigated in order to determine Tc(onset) and Tc(offset) for calculating the electrical resistivity as a function of temperature after the element pb was partially substituted in the Bi element of the $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ compound.

5. Conclusions

The effect of partial bismuth replacement with lead on the superconducting characteristics of $Bi_{2-x}Pb_xBa_2Ca_2Cu_3O_{10+\delta}$ is examined in this publication with x = 0, 0.15, 0.25and 0.3. The solid-state reaction approach was used to prepare the samples. The four-probe method was used to evaluate the electrical conductivity in order to calculate the Tc. The Tc was observed to rise as the quantities of silver in all produced samples increased. The optimal compensation ratio for x was also discovered to be 0.25, which results in the highest Tc. X-ray diffraction was used to examine the samples' ultrastructural characteristics. All of the prepared samples had a tetragonal structure, with a distinct change in the lattice constants, according to an X-ray diffraction investigation. The ideal role that the compound played in the crystal structure can be utilized to explain this result. This percentage of compensation led to an increase in the Tc and an increase in the high phase 2223 with an increase in the lead concentration in the samples.

References

[1] Jassim AHA, Saleh CAZ, Jasim KA. Improving the electrical and thermal conductivity of Pb1-xHgxBa2Ca2Cu3O8+ d superconducting compound by partial replacement of lead with mercury. In: AIP Conference Proceedings. AIP Publishing; 2023. https://doi.org/10.1063/5.0129549

[2] Saleh CAZ, Jassim AHA, Jasim KA. Partial substitution of lead with nickel on the structural and electrical properties of Pb1-xNix Ba2Ca2Cu3O8+ δ superconducting compound. In: AIP Conference Proceedings. AIP Publishing; 2023. https://doi.org/10.1063/5.0171582

[3] Jasim KA, Saleh CAZ, Jassim AHA. Synthesis and Analysis of the Impact of Partial Mercury Replacement with Lead on the Structural and Electrical Properties of the Hg1-xPbxBa2Ca2Cu3O8 Superconductor. Korean Journal of Materials Research. 2024;34(1):21–6. https://doi.org/10.3740/MRSK.2024.34.1.21

[4] Jassim, K. A., Jassim, W. H., & Mahdi, S. H. (2017, The effect of sunlight on medium density polyethylene water pipes. Energy Procedia, 2017, 119, pp. 650–655) https://doi.org/10.1016/j.egypro.2017.07.091

[5] Woch WM, Zalecki R, Kołodziejczyk A, Deinhofer C, Gritzner G. The Irreversibility Fields of ($Tl_{0.5}Pb_{0.5}$) ($Sr_{0.85}Ba_{0.15}$)$_2$ Ca_2 Cu_3 O Film on Polished Silver Substrate. Acta Phys Pol A. 2007;111(5):737–43. http://przyrbwn.icm.edu.pl/APP/ABSTR/111/a111-5-9.html

[6] Haider HMJ, Wadi KM, Mahdi HA, Jasim KA, Shaban AH. Studying the partial substitution of barium with cadmium oxide and its effect on the electrical and structural properties of HgBa2Ca2Cu3O8+ δ superconducting compound. In: AIP Conference Proceedings. AIP Publishing; 2019. https://doi.org/10.1063/1.5116960

[7] Maeda H, Tanaka Y, Fukutomi M, Asano T. A new high-Tc oxide superconductor without a rare earth element. Jpn J Appl Phys. 1988;27(2A):L209. https://doi.org/10.1143/JJAP.27.L209

[8] Bhardwaj JK, Harkrishan, Tyor AK. Sublethal effects of imidacloprid on Haematological and biochemical profile of Freshwater fish, Cyprinus carpio. JOURNAL OF ADVANCED ZOOLOGY. 2020;41(1):75–88. https://doi.org/10.17762/jaz.v41i01-02.59

[9] Xiao TD, Gonsalves KE, Strutt PR. Synthesis of aluminum nitride/boron nitride composite materials. Journal of the American Ceramic Society. 1993;76(4):987–92. https://doi.org/10.1111/j.1151-2916.1993.tb05323.x

[10] Kareem Ali Jassim, Structure and electrical properties of lanthanum doped Bi2Sr2Ca2-xLaxCu3O10+δ superconductor, Turk J. Phys. 36, 245 – 251). (2012). https://journals.tubitak.gov.tr/physics/vol36/iss2/10/

[11] Choudhary NL, Chishty N. Copulation Behaviors of Indian Vulture (Gyps Indicus) in Udaipur District, Rajasthan, India. J Adv Zool. 2021;42(1):7–19. https://www.academia.edu/76012911/Copulation_Behaviors_of_Indian_Vulture_Gyps_Indicus_in_Udaipur_District_Rajasthan_India

[12] Gul IH, Rehman MA, Ali M, Maqsood A. Effect of vanadium and barium on the Bi-based (2223) superconductors. Physica C: Superconductivity and its applications. 2005;432(1–2):71–80. https://doi.org/10.1016/j.physc.2005.07.013

[13] Cantoni, M., Schilling, A., Nissen, H., & Ott, H., Physica C: Superconductivity, Volume 215, Issues 1–2, 20 September 1993, Pages 11-18. https://www.sciencedirect.com/journal/physica-c-superconductivity-and-its-applications/vol/215/issue/1?utm_source=chatgpt.com

[14] Xu Q, Chen Z, Meng G, Peng D. Microstructure and Superconductivity in Bi–Sr–Ca–Cu–O System Doped with Pb and Sb. Jpn J Appl Phys. 1990;29(10R):1918. https://link.springer.com/article/10.1007/BF00624506

[15] Jasim KA, Alwan TJ. Effect of Oxygen Treatment on the Structural and Electrical Properties of Tl 0.85 Cd 0.15 Sr 2 CuO 5− δ, Tl 0.85 Cd 0.15 Sr 2 Ca 2 Cu 2 O 7− δ and Tl 0.85 Cd 0.15 Sr 3 Ca 2 Cu 3 O 9− δ Superconductors. J Supercond Nov Magn. 2017;30:3451–7. https://doi.org/10.1007/s10948-017-4147-9

[16] Jassim KA, Hussein HS. Effect of Partial Substitution of Lanthanum (La) on the Structural and Electric Properties of Bi2Sr2Ca2Cu3xLaxO10+ Î´. Ibn AL-Haitham Journal For Pure and Applied Sciences. 2017;30(3):35–43. https://jih.uobaghdad.edu.iq/?utm_source=chatgpt.com

[17] De Biasi RS, Araujo SM V. Influence of the annealing parameters on the volume fraction of the high-Tc phase in the Bi-Sr-Ca-Cu-O system. J Magn Magn Mater. 1992;104:471–2. https://www.sciencedirect.com/science/article/pii/030488539290881N?utm_source=chatgpt.com

[18] Nkum RK, Datars WR. Weak link in ceramic In-doped Bi-Pb-Sr-Ca-Cu-O. Supercond Sci Technol.1995;8(11):822. https://scholar.google.com/citations?hl=en&user=n4mN6lcAAAAJ&utm_source=chatgpt.com

[19] Gul IH, Amin F, Abbasi AZ, Anis-ur-Rehman M, Maqsood A. Effect of Ag2CO3 addition on the morphology and physical properties of Bi-based (2223) high-Tc superconductors. Physica C: Superconductivity and its applications. 2006;449(2):139–47. http://dx.doi.org/10.1016/j.physc.2006.08.004

[20] Zhigadlo ND, Petrashko V V, Semenenko YA, Panagopoulos C, Cooper JR, Salje EKH. The effects of Cs doping, heat treatments on the phase formation and superconducting properties of (Bi, Pb)–Sr–Ca–Cu–O ceramics. Physica C Supercond. 1998;299(3–4):327–37. https://www.sciencedirect.com/science/article/abs/pii/S0921453497018662?utm_source=chatgpt.com

[21] Jasim KA, Mohammed LA. The partial substitution of copper with nickel oxide on the Structural and electrical properties of HgBa2 Ca2 Cu3xNix O8+ δ superconducting

compound. In: Journal of Physics: Conference Series. IOP Publishing; 2018. p. 012071. https://www.researchgate.net/publication/325354696_The_partial_substitution_of_copper_with_nickel_oxide_on_the_Structural_and_electrical_properties_of_HgBa_2_Ca_2_Cu_3x_Ni_x_O_8d_superconducting_compound?utm_source=chatgpt.com

[22] Jasim KA. Superconducting Properties of Hg 0.8 Cu 0.15 Sb 0.05 Ba 2 Ca 2 Cu 3 O 8+ δ Ceramic with Controlling Sintering Conditions. J Supercond Nov Magn. 2012;25:1713–7. https://jih.uobaghdad.edu.iq/index.php/j/article/view/3309?utm_source=chatgpt.com

[23] Azzouz F Ben, M'chirgui A, Yangui B, Boulesteix C, Salem M Ben. Synthesis, microstructural evolution and the role of substantial addition of PbO during the final processing of (Bi, Pb)-2223 superconductors. Physica C Supercond. 2001;356(1–2):83–96. https://www.researchgate.net/publication/276489457_Optimizing_the_Preparation_Conditions_of_Bi-2223_Superconducting_Phase_Using_PbO_and_PbO2?utm_source=chatgpt.com