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Comparative Study of Structural and Superconducting Properties of Ni-Substituted and NiO-Added $YBa_2Cu_3O_{7-\delta}$ Superconductors

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ABSTRACT

This study investigates the structural and superconducting behavior of $YBa_2Cu_3O_{7-\delta}$ (YBCO) superconductors doped with nickel through two distinct approaches: substitutional doping at the yttrium site and physical addition of NiO nanoparticles. Polycrystalline samples of $Y(1-x)NixBa_2Cu_3O_{7-\delta}$ and $(YBCO)_{1-x}(NiO)_x$ with x ranging from 0.02 to 0.10 were synthesized using the solid-state reaction method. The crystal structures were characterized by X-ray diffraction (XRD), while superconducting transition temperatures (Tc) were determined through AC susceptibility measurements. XRD analysis confirmed the orthorhombic phase of YBCO for all Ni-substituted samples up to x = 0.06, beyond which slight peak broadening indicated lattice distortion and microstrain. In contrast, NiO-added samples exhibited secondary NiO phases at the grain boundaries, increasing with NiO concentration. AC susceptibility measurements revealed that substitutional Ni doping resulted in a gradual reduction of Tc due to magnetic pair-breaking effects and oxygen stoichiometry variations, while NiO addition caused severe suppression of superconductivity at higher concentrations by disrupting intergranular coupling. The results demonstrate that Ni substitution mildly modifies intrinsic superconducting properties, whereas NiO addition significantly deteriorates intergranular connectivity. Controlled substitutional doping is therefore more effective in tailoring YBCO properties for enhanced superconducting performance.

Keywords: $YBa_2Cu_3O_{7-\delta}$ (YBCO); Nickel Doping; NiO Addition; High-Temperature Superconductors; Structural Properties; AC Susceptibility; Critical Temperature; Flux Pinning; Grain Boundaries

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Introduction:

High-temperature superconductors (HTS) have garnered extensive research interest since the discovery of Yttrium Barium Copper Oxide ($YBa_2Cu_3O_{7-\delta}$, or YBCO) in 1987 by Wu et al., which marked a significant breakthrough because of its critical temperature (Tc) near 92 K, exceeding the boiling point of liquid nitrogen (77 K). This discovery opened the door for practical and cost-effective applications of superconductivity in technologies such as magnetic levitation, power transmission, superconducting magnets, and electronic devices (Maeda, 2016). The relatively high Tc of YBCO considerably reduces the complexity and expense of cooling compared to conventional low-temperature superconductors that require liquid helium, making it a material of choice for many applied superconductivity fields (Gao, Luo, Liu, & Liu, 2024).

YBCO is a layered cuprate superconductor with an orthorhombic perovskite-like crystal structure consisting of Cu–O planes and Cu–O chains. The Cu–O planes are primarily responsible for its superconducting properties, where the Cooper pairs responsible for zero resistance form and move. The oxygen content (oxygen stoichiometry, δ in $YBa_2Cu_3O_{7-\delta}$) plays a critical role in tuning the charge carrier concentration within the Cu–O planes and hence in determining the superconducting behavior. Variations in δ can induce changes from orthorhombic superconducting phases to tetragonal non-superconducting phases, impacting the critical temperature and the material's overall superconducting performance (Hussein, Hussein, & Hasan, 2023). Structural integrity, oxygen stoichiometry, and the introduction of dopants or secondary phases are therefore essential factors influencing YBCO's superconducting properties. Doping with transition metals such as nickel (Ni), iron (Fe), and cobalt (Co) has been widely investigated to modify and potentially improve the microstructure and superconducting characteristics (Tolendiuly, Sovet, & Fomenko, 2023). Transition metal dopants can alter carrier concentration, induce additional flux pinning centers, and affect grain boundary connectivity, which is crucial for enhancing the critical current density (Jc) under magnetic fields (Hussein et al., 2023; Tolendiuly et al., 2023).

Nickel is particularly interesting due to its comparable ionic radius to yttrium (Y^{3+}), enabling substitution at the yttrium site or introduction as a secondary NiO phase. Substitutional doping of Ni can modify the local lattice environment and electronic structure, leading to changes in Tc and superconducting volume fractions. Meanwhile, the addition of NiO nanoparticles can act as pinning centers that enhance current carrying capabilities without significantly altering the bulk crystal structure. Such dual approaches of Ni incorporation enable systematic evaluation of intrinsic versus extrinsic effects on superconductivity (Jeon, Yazici, White, Friedman, & Maple, 2014).

In this study, two doping strategies are explored to understand their influence on the structural and superconducting properties of YBCO: (i) substitution of Ni at the yttrium site in $Y(1-x)NixBa_2Cu_3O_7-\delta$, and (ii) formation of composites by adding NiO particles to YBCO, resulting in $(YBCO)_{1-x}(NiO)_x$ materials. Characterization methods including X-ray diffraction (XRD) and AC susceptibility measurements allow determination of phase purity, crystallographic changes, and shifts in Tc, offering valuable insight into how these different nickel doping pathways affect the

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material. Understanding the role of nickel doping in YBCO not only advances the fundamental knowledge of high-temperature superconductivity but also contributes to developing optimized materials for future superconducting devices and applications, particularly where enhanced flux pinning and stable superconducting phases are required.

Materials and Methodology

Sample Preparation

Polycrystalline samples of $Y(1-x)NixBa_2Cu_3O_{7-\delta}$ with doping concentrations x = 0.02, 0.04, 0.06, 0.08, and 0.10 were synthesized using the conventional solid-state reaction method. The high-purity precursors used were Y_2O_3, $BaCO_3$, CuO, and NiO powders (≥99.9% purity). Appropriate stoichiometric amounts of the starting materials were weighed and thoroughly mixed using an agate mortar and pestle for uniform blending. The mixture was calcined in air at 900°C for 12 hours and then ground again to ensure homogeneity. The calcination process was repeated twice to achieve complete reaction.

The resulting powders were pressed into pellets under a uniaxial pressure and sintered at 940°C for 24 hours in an oxygen-rich atmosphere, followed by slow cooling to room temperature to optimize oxygen stoichiometry. For the NiO addition experiments, pure YBCO was first prepared following the same procedure as above. Afterward, varying amounts of NiO (x = 0.02–0.10) were physically mixed with the prepared YBCO powders to form $(YBCO)_{1-x}(NiO)_x$ composites. These mixtures were then pelletized and subjected to a secondary heat treatment at 920°C for 10 hours in air, followed by oxygen annealing to ensure phase stability (Alotaibi et al., 2021; Sato, Petrykin, Yasuoka, & Kakihana, 2012).

Structural Characterization

The X-ray diffraction (XRD) patterns of all samples were recorded using an X'Pert diffractometer equipped with Cu-Kα radiation (λ = 1.5406 Å). The diffraction data were collected over a 2θ range of 10°–80° with a step size of 0.02°. The obtained spectra were analyzed using the X'Pert High Score software by matching with the International Centre for Diffraction Data (ICDD) standard database to identify the crystal phases and lattice parameters. The sharp and well-defined peaks in the diffraction patterns confirmed the polycrystalline nature of the synthesized materials (Hadi-Sichani, Shakeripour, & Salamati, 2018; Khan, Alam, Azam, & Khan, 2012).

AC Susceptibility Measurements

The superconducting transition temperature (Tc) and magnetic response of the doped YBCO samples were determined through AC susceptibility measurements. Both the real (χ′) and imaginary (χ″) components of susceptibility were recorded using a standard AC suscept meter. Measurements were carried out under an applied magnetic field of 0.6 Oe for substitutional Ni-doped samples and 0.1–1.0 Oe for NiO-added samples. The temperature dependence of susceptibility was measured from 300 K down to 77 K to observe the superconducting transition behavior (Terzioğlu, Kalkan, Varilci, Öztürk, & Terzioglu, 2025).

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Results:

Structural Analysis of Ni-Doped YBCO

The XRD spectra of the $Y(1-x)NixBa_2Cu_3O_7-\delta$ system with various nickel concentrations (x = 0.02, 0.04, 0.06, 0.08, 0.10) are presented in Figure 1. All samples exhibit sharp and intense diffraction peaks characteristic of a single-phase orthorhombic perovskite structure, confirming that the samples are polycrystalline YBCO. The absence of significant secondary peaks in lower doping levels ($x \leq 0.06$) indicates that nickel atoms successfully substitute Y^{3+} ions in the lattice without major structural distortion. However, at higher doping concentrations ($x \geq 0.08$), slight broadening and reduction in peak intensity can be observed, suggesting the onset of microstrain or local lattice distortion due to excess Ni incorporation. This behavior implies that Ni ions are incorporated into the crystal lattice up to a solubility limit, beyond which they may form minor impurity phases or induce lattice stress. The phase identification using X'Pert HighScore and ICDD standard data confirmed that the orthorhombic YBCO phase remains dominant even at higher doping levels, though the degree of orthorhombicity slightly decreases with increasing Ni content. These structural modifications are consistent with reports that Ni substitution tends to affect the oxygen content and local Cu–O plane ordering, both critical for superconductivity.

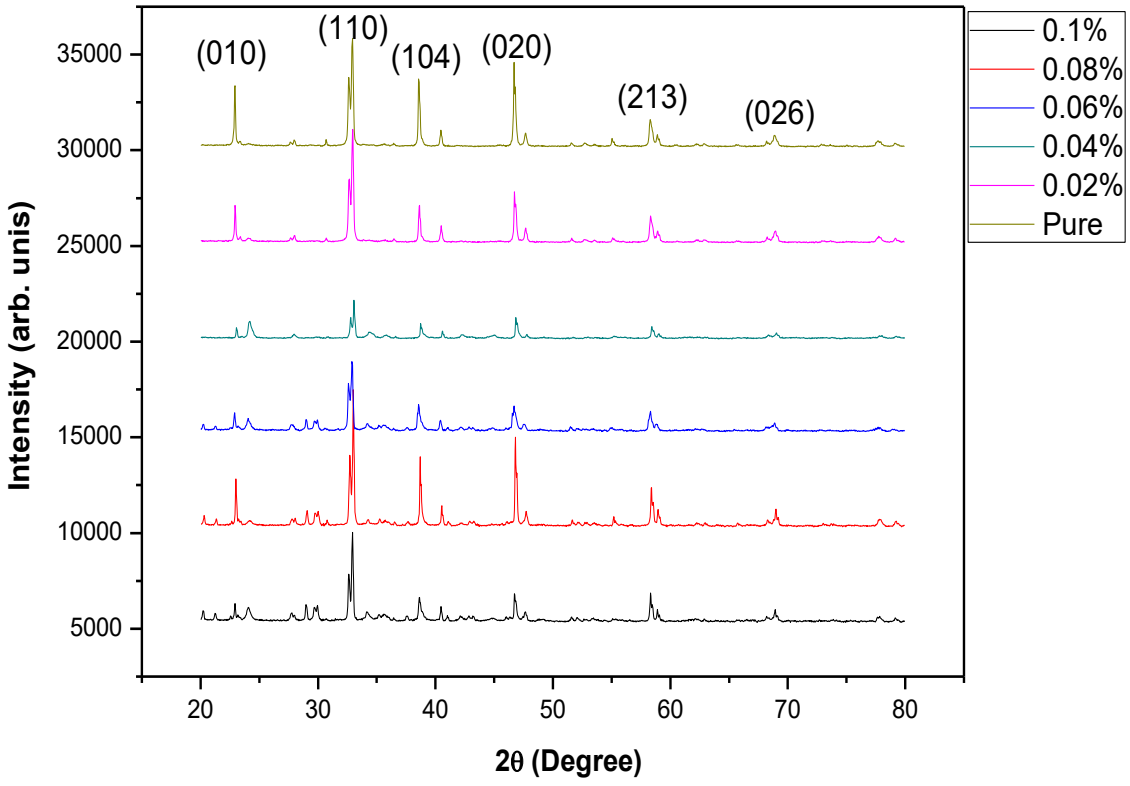


Figure 1. The XRD spectra $Y_{(1-x)}Ni_xBa_2Cu_3O_{7-\delta}$ superconductor system with different doping concentration, x.

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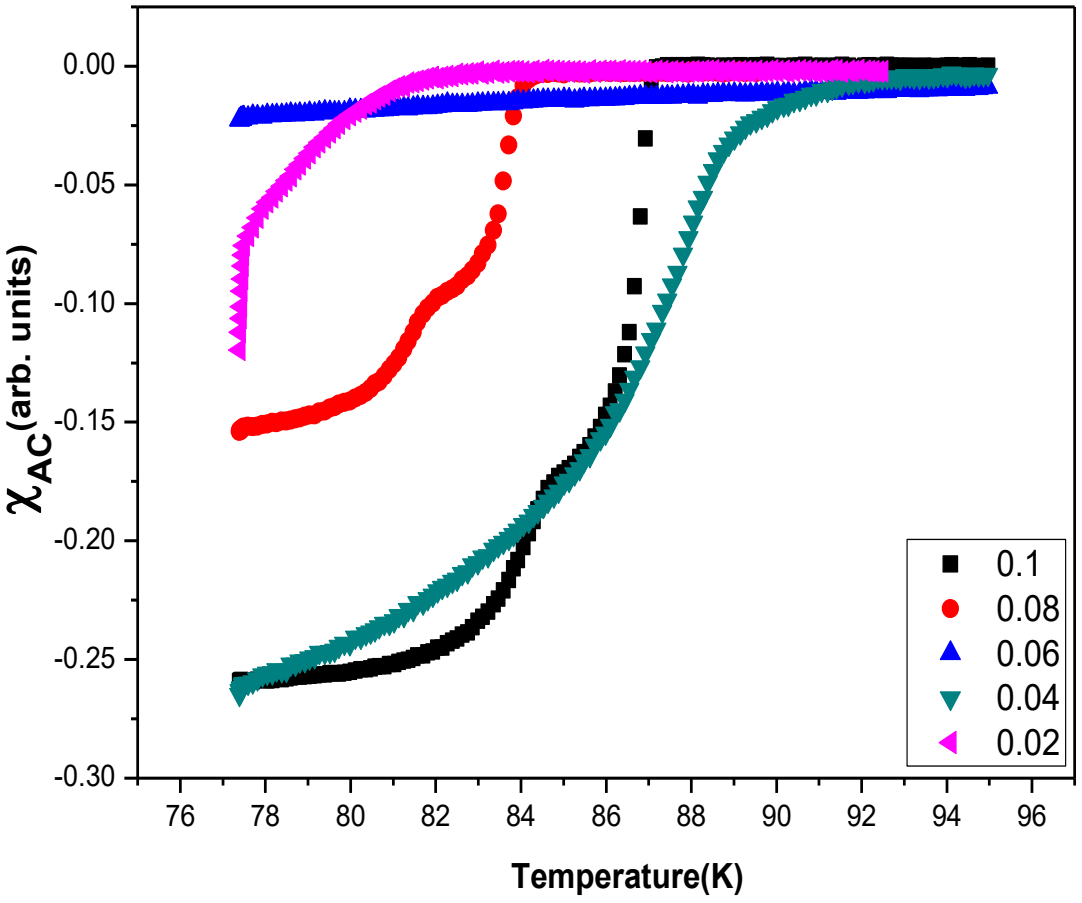
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AC Susceptibility of Ni-Doped YBCO

The AC susceptibility measurements (Figure 2) provide direct evidence of superconducting transition behavior for the Ni-doped samples. Both the real (χ') and imaginary (χ'') parts of susceptibility show clear transitions, confirming superconductivity in all samples. The real part (χ') decreases sharply at the critical temperature (Tc), indicating the onset of diamagnetic shielding, while the imaginary component (χ'') shows a corresponding peak related to magnetic energy dissipation at the flux-pinning threshold. As Ni concentration increases, a gradual decrease in Tc and broadening of the transition width are observed.

This suppression of superconductivity is attributed to the magnetic nature of Ni^{2+} ions, which can introduce pair-breaking effects by disrupting the Cu–O plane charge carrier dynamics. Furthermore, Ni substitution may alter the oxygen stoichiometry, reducing hole concentration in the CuO_2 planes. These results are consistent with prior studies reporting that transition metal doping generally weakens superconducting coupling in YBCO beyond a certain doping limit.

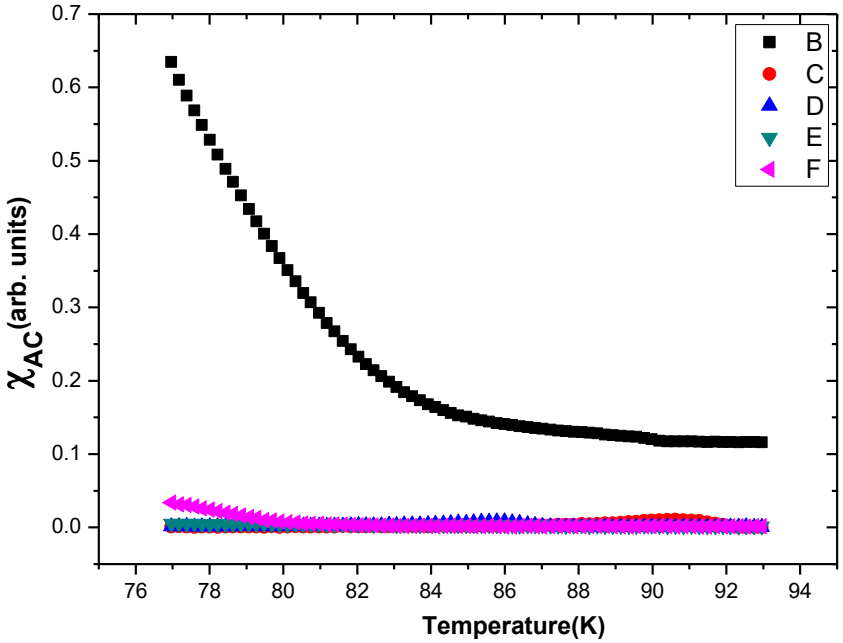


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(b)

Figure 2. (a) Imaginary part of susceptibility for $Y_{(1-x)}Ni_xBa_2Cu_3O_{7-\delta}$ (b) real part of susceptibility for $Y_{(1-x)}Ni_xBa_2Cu_3O_{7-\delta}$.

Structural Behavior of NiO-Added YBCO

The XRD patterns for $(YBCO)_{1-x}(NiO)_x$ composites with x = 0.02–0.10 are shown in Figure 3. Unlike the substitutional doping series, the NiO-added samples display additional diffraction peaks corresponding to NiO and minor secondary phases. The presence of these peaks confirms that NiO remains partially unreacted and segregated at the grain boundaries rather than substituting into the YBCO lattice. As the NiO addition increases, the relative intensity of these secondary peaks rises, and the main YBCO reflections become weaker and broader, signifying increased structural disorder and grain boundary formation. The system transitions from a predominantly superconducting phase to a resistive behavior at higher concentrations (x ≈ 0.10), indicating that excessive NiO impedes current percolation paths between superconducting grains.

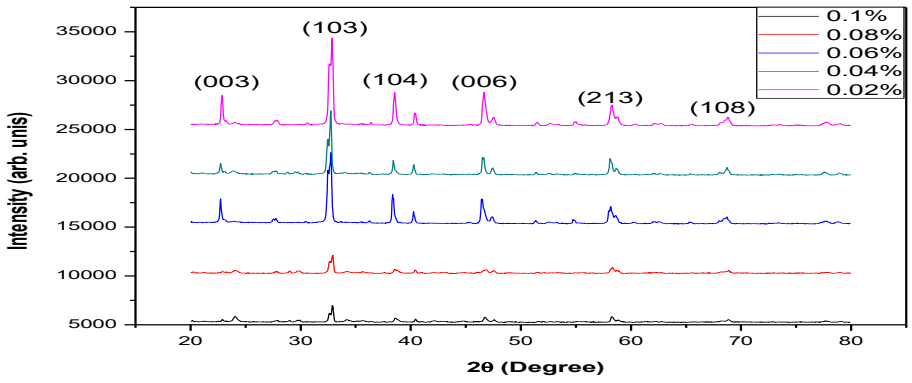


Figure 3. The XRD of $(YBCO)_{1-x}(NiO)_x$ superconductor.

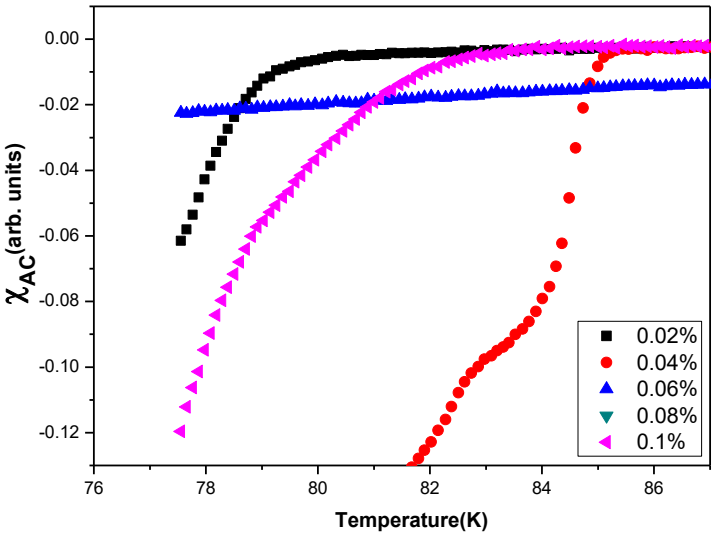
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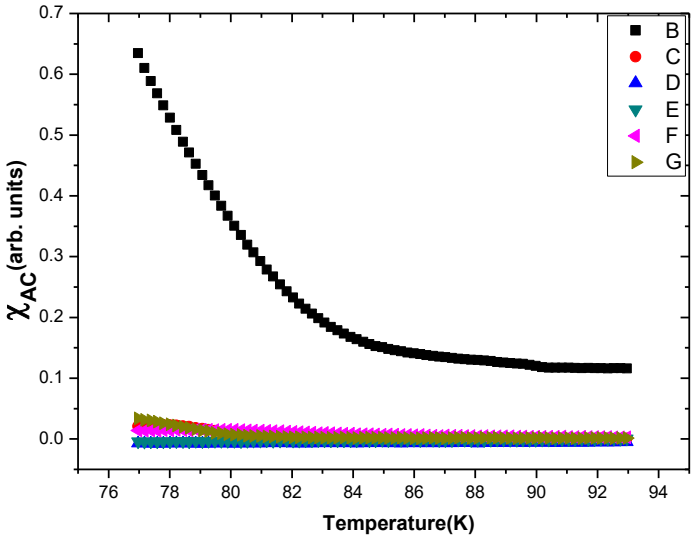
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AC Susceptibility of NiO-Added YBCO

The AC susceptibility results for NiO-added YBCO samples are presented in Figure 4. In contrast to Ni-substituted samples, the NiO-added composites exhibit a marked degradation in superconducting response. The real part of susceptibility (χ') shows diminished diamagnetic shielding, while the imaginary part (χ'') peak shifts toward lower temperatures and becomes less pronounced with increasing NiO content. At higher NiO concentrations ($x \geq 0.08$), the samples exhibit almost complete loss of superconducting behavior, displaying predominantly resistive characteristics. This degradation is primarily due to the formation of insulating NiO phases at the grain boundaries, which disrupt intergranular coupling and act as scattering centers for charge carriers. The applied field variation (0.1–1.0 Oe) further confirms that flux-pinning and shielding capabilities are significantly weakened in the presence of NiO. Overall, the comparative analysis demonstrates that Ni substitution at the Y site has a milder effect on Tc and phase purity, while NiO addition severely suppresses superconductivity due to phase segregation and intergranular resistance.



(a)



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(b)

Figure 4. The real part of susceptibility for $(YBCO)_{1-x}(NiO)_x$ superconductor.

Discussion

The comparative study of Ni substitution and NiO addition in $YBa_2Cu_3O_7$-δ (YBCO) superconductors highlights how the method of nickel incorporation distinctly impacts the crystal structure, phase purity, and superconducting properties. When Ni is substituted at the yttrium site in Y(1-x)Ni$_x$Ba$_2$Cu$_3$O$_7$-δ, X-ray diffraction (XRD) analysis typically shows that the orthorhombic crystal structure characteristic of YBCO is preserved up to doping levels around x = 0.06. This preservation indicates successful incorporation of Ni into the lattice without causing major structural distortion, which is crucial for maintaining superconductivity. However, at higher concentrations ($x \geq 0.08$), XRD patterns reveal peak broadening and reduced intensity, suggesting increasing lattice strain and minor structural disorder. This is likely due to ionic size mismatch between Ni and Y and potential segregation of Ni, disrupting local lattice homogeneity (Chamekh, Bouabellou, Elerman, Kaya, & Dincer, 2017; Dzul-Kifli et al., 2022).

Such subtle lattice changes manifest in the superconducting behavior, where AC susceptibility studies show a gradual reduction in the critical temperature (Tc) as Ni concentration increases. This decline is attributed to distortion of the Cu–O planes and changes in the local electronic environment, affecting charge carrier density and pairing mechanisms necessary for superconductivity. The introduction of Ni also acts as scattering centers that can weaken the superconducting order parameter (Fawad et al., 2025). On the other hand, when Ni is introduced as NiO particles added physically to the YBCO matrix, forming $(YBCO)_{1-x}(NiO)_x$ composites, the effect on the crystal structure is less direct since NiO tends to segregate as a secondary phase rather than substitute within the lattice. NiO inclusions can serve as effective flux pinning centers by providing nanoscale defects that anchor magnetic vortices, potentially enhancing the critical current density (Jc) without drastically lowering Tc. However, excessive addition of NiO can lead to the formation of non-superconducting secondary phases that degrade connectivity between superconducting grains and reduce overall superconducting volume fraction (Lin et al., 1996; Somacescu et al., 2019).

Overall, nickel incorporation via substitution and via NiO addition presents different mechanisms for modifying YBCO superconductors. Atomic substitution impacts the intrinsic lattice and electronic structure, generally resulting in Tc suppression beyond certain doping levels, whereas NiO addition acts extrinsically, influencing flux pinning and microstructural properties while better preserving Tc at low concentrations. These findings emphasize the need to carefully control doping levels and methods to tailor superconducting properties for targeted applications, whether for improved flux pinning or optimized transition temperatures (Chamekh et al., 2017; Lin et al., 1996; Somacescu et al., 2019).

The reduction in critical temperature (Tc) observed with increasing nickel substitution in $YBa_2Cu_3O_7$-δ (YBCO) is primarily attributed to the magnetic pair-breaking effect of Ni^{2+} ions. In YBCO, superconductivity is strongly linked to charge carrier motion within the CuO_2 planes, where Cooper pairs form the superconducting condensate.

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The substitution of copper ions by magnetic nickel ions disrupts the local electronic environment, weakening the Cooper pairing and consequently suppressing Tc. Additionally, Ni substitution may induce oxygen deficiency or rearrangement within the Cu–O chains, reducing hole concentration, which is essential for superconductivity in YBCO. Such oxygen stoichiometry variations further contribute to Tc degradation. This mechanism aligns with numerous studies reporting similar Tc suppressions upon transition metal substitution, while maintaining overall structural stability at low doping levels (Maeno et al., 1987; Shams, Ranjbar, & Barzegar, 2012). Conversely, when Ni is added as NiO particles forming $(YBCO)_{1-x}(NiO)_x$ composites, X-ray diffraction patterns reveal distinct NiO phases that do not incorporate into the YBCO lattice but remain segregated. This phase separation results in the formation of grain boundary resistances and microstructural disorder as NiO particles accumulate at grain interfaces. At higher NiO concentrations ($x \geq 0.08$), the electrical transport through the sample shifts from superconducting to resistive due to disrupted percolation paths between superconducting grains. Therefore, while NiO additions can enhance flux pinning at low concentrations by acting as extrinsic pinning centers, excessive NiO inclusion deteriorates grain connectivity and superconducting coherence, reducing overall performance (Pęczkowski et al., 2021).

AC susceptibility measurements in $YBa_2Cu_3O_7$-δ (YBCO) doped with NiO composites provide critical insight into how NiO addition influences superconducting behavior, particularly concerning grain connectivity and flux pinning. Studies show that increasing NiO content leads to significant reduction in diamagnetic shielding, reflecting diminished superconducting volume and weaker magnetic response. The superconducting transition broadens noticeably with NiO doping, indicating gradual loss of long-range coherence (Buchkov, Galluzzi, Nazarova, & Polichetti, 2023; Hannachi, Almessiere, Slimani, Baykal, & Ben Azzouz, 2020). Near high NiO concentrations ($x = 0.10$), AC susceptibility reveals an almost complete loss of superconductivity. The real (χ') and imaginary (χ'') components show weak or absent transitions, suggesting ineffective flux pinning and poor intergranular coupling. This is consistent with NiO acting as an insulating barrier at grain boundaries, impeding superconducting current percolation and creating microstructural disorder. The grain boundary resistance caused by segregated NiO particles obstructs supercurrent flow between grains rather than disrupting the intrinsic superconducting lattice. Such grain decoupling results in a resistive state despite the presence of superconducting phases within grains (Hannachi et al., 2020; Silva & McHenry, 2001).

The comparative study of Ni substitution versus NiO addition in $YBa_2Cu_3O_7$-δ (YBCO) superconductors highlights the critical influence of the dopant incorporation mechanism on both structure and superconducting properties. Substitutional Ni, which replaces yttrium in the lattice, causes only slight modifications to superconducting parameters such as Tc while maintaining the integrity of the orthorhombic crystal framework. This form of doping gently alters the local electronic environment and oxygen distribution without inducing major structural inhomogeneities. Consequently, controlled Ni substitution can be a viable strategy to fine-tune the superconducting behavior of YBCO within a limited composition range, leveraging the chemical compatibility of Ni with the host lattice (Shams et al., 2012). In stark contrast, the physical addition of NiO nanoparticles results in the formation of

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secondary phases that remain segregated from the YBCO matrix. This leads to structural inhomogeneity, grain boundary disorder, and increased intergranular resistance. The insulating nature of NiO disrupts the connectivity between superconducting grains, severely impairing current flow and degrading overall superconducting performance. AC susceptibility data corroborate this, showing broadening and weakening of the superconducting transition and eventual loss of diamagnetic shielding with increased NiO content, reflective of poor flux pinning and weak intergranular coupling (Kandari, Dahiya, Faraz, & Khare, 2024).

Therefore, the influence of Ni doping in YBCO is not solely a matter of chemical substitution but is strongly governed by microstructural factors such as dopant distribution, phase compatibility, and interaction with grain boundaries. When Ni is incorporated within the lattice, it integrates into the crystal structure and electronic system, whereas NiO additions predominantly affect microstructural integrity. The balance between structural stability and superconducting functionality in these high-Tc cuprates is critically dependent on the solubility limit and phase behavior of the dopant species (Galeano-Cabral et al., 2024). Ni substitution offers a controlled pathway to modulate YBCO's superconducting properties without compromising crystallinity, making it promising for careful materials engineering. Conversely, NiO addition, while potentially beneficial as flux pinning centers at very low concentrations, generally leads to phase segregation and connectivity issues at higher levels. These findings underscore the importance of optimizing doping methods to achieve the desired superconducting performance in YBCO systems.

Conclusion

The comparative analysis of Ni substitution and NiO addition in $YBa_2Cu_3O_7$-δ (YBCO) superconductors reveals that the mechanism of dopant incorporation plays a decisive role in determining both structural integrity and superconducting behavior. Substitution of Ni at the yttrium site maintains the orthorhombic phase up to $x = 0.06$, introducing only minor lattice distortions while causing a gradual reduction in the critical temperature (Tc) due to magnetic pair-breaking effects and altered oxygen stoichiometry. In contrast, NiO addition introduces distinct secondary phases that segregate at grain boundaries, leading to reduced intergranular connectivity and eventual loss of superconductivity at higher concentrations ($x \geq 0.08$). AC susceptibility results corroborate these findings, indicating weaker diamagnetic shielding and broader transitions in NiO-added composites. Thus, while Ni substitution offers a controlled means to fine-tune superconducting parameters without compromising phase purity, NiO addition tends to degrade superconductivity through structural inhomogeneity and resistive grain boundary formation. Optimizing Ni doping concentration and incorporation method is therefore essential for enhancing YBCO's flux pinning and current-carrying capabilities in advanced superconducting applications.

References

Alotaibi, S., Slimani, Y., Hannachi, E., Almessiere, M., Yasin, G., Al-qwairi, F., . . . ben azzouz, F. (2021). Intergranular properties of polycrystalline YBa2Cu3O7-δ superconductor added with nanoparticles WO3 and BaTiO3 as

Online ISSN 3007-3197
Print ISSN 3007-3189

artificial pinning centers. Ceramics International, 47. doi:10.1016/j.ceramint.2021.08.336

Buchkov, K., Galluzzi, A., Nazarova, E., & Polichetti, M. (2023). Complex AC Magnetic Susceptibility as a Tool for Exploring Nonlinear Magnetic Phenomena and Pinning Properties in Superconductors. Materials (Basel), 16(14). doi:10.3390/ma16144896

Chamekh, S., Bouabellou, A., Elerman, Y., Kaya, M., & Dincer, I. (2017). Effects of Nickel Substitution on Crystalline Structure and Superconducting Properties of YBa2Cu3O7-δ Ceramics. Journal of New Technology and Materials, 7. doi:10.12816/0044599

Dzul-Kifli, N. A. C., Kechik, M. M. A., Baqiah, H., Shaari, A. H., Lim, K. P., Chen, S. K., . . . Shariff, K. K. M. (2022). Superconducting properties of YBa2Cu3O7- δ with a multiferroic addition synthesized by a capping agent-aided thermal treatment method. Nanomaterials, 12(22), 3958.

Fawad, M., Maqsood, N., Nawaz, A., Islam, B., Zaheer, M. D., & Skotnicová, K. (2025). Synthesis, Characterization, and Enhanced Optical and Dielectric Properties of Pure and Ni-Doped ZnO Nanoparticles for Advanced Electronic Applications. Results in Engineering, 26, 104824. doi:https://doi.org/10.1016/j.rineng.2025.104824

Galeano-Cabral, J., Schundelmier, B., Oladehin, O., Feng, K., Ordonez, J., Baumbach, R., & Wei, K. (2024). Effect of Ni Doping on the Thermoelectric Properties of YbCo2Zn20. Materials, 17, 1906. doi:10.3390/ma17081906

Gao, J., Luo, Y.-X., Liu, Z.-T., & Liu, Q.-J. (2024). Superconductivity and stability of the novel electron-doped H3S system under high pressure. Chinese Journal of Physics, 90, 364-371. doi:https://doi.org/10.1016/j.cjph.2024.02.025

Hadi-Sichani, B., Shakeripour, H., & Salamati, H. (2018). Structural investigation of Y1- xNixBa2Cu3O7- δ superconductor. Physica C: Superconductivity and its Applications, 550, 92-94.

Hannachi, E., Almessiere, M. A., Slimani, Y., Baykal, A., & Ben Azzouz, F. (2020). AC susceptibility investigation of YBCO superconductor added by carbon nanotubes. Journal of Alloys and Compounds, 812, 152150. doi:https://doi.org/10.1016/j.jallcom.2019.152150

Hussein, A., Hussein, A., & Hasan, N. (2023). Study of the Properties of YBCO Superconductor Compound in Various Preparation Methods: A Short Review. Journal of Applied Sciences and Nanotechnology, 3, 65-79. doi:10.53293/jasn.2022.4867.1156

Jeon, I., Yazici, D., White, B. D., Friedman, A. J., & Maple, M. B. (2014). Effect of yttrium substitution on the superconducting properties of ${\mathrm{La}}_{1\ensuremath{-}\mathit{x}}{\mathrm{Y}}_{\mathit{x}}{\mathrm{O}}_{0.5}{\mathrm{F}}_{0.5}{\mathrm{BiS}}_{2}$. Physical Review B, 90(5), 054510. doi:10.1103/PhysRevB.90.054510

Kandari, R., Dahiya, M., Faraz, M., & Khare, N. (2024). Effect of Magnetic NiO Nanoparticles on Pinning Properties of YBa2Cu3O7-x Superconductor. Journal of Superconductivity and Novel Magnetism, 38. doi:10.1007/s10948-024-06885-5

Online ISSN 3007-3197
Print ISSN 3007-3189

Khan, S., Alam, F., Azam, A., & Khan, A. (2012). Gold nanoparticles enhance methylene blue–induced photodynamic therapy: a novel therapeutic approach to inhibit Candida albicans biofilm. International Journal of Nanomedicine, 7, 3245-3257. doi:10.2147/IJN.S31219

Lin, J. Y., Gurvitch, M., Tolpygo, S. K., Bourdillon, A., Hou, S. Y., & Phillips, J. M. (1996). Flux pinning in $\mathrm{Ya}{\mathrm{Ba}}_{2}{\mathrm{Cu}}_{3}{\mathrm{O}}_{7\ensuremath{-}\ensuremath{\delta}}$ thin films with ordered arrays of columnar defects. Physical Review B, 54(18), R12717-R12720. doi:10.1103/PhysRevB.54.R12717

Maeda, H. (2016). Yttrium-Barium-Copper Oxide High-temperature Superconducting Magnet Technology. IEEJ Transactions on Power and Energy, 136, 797-800. doi:10.1541/ieejpes.136.797

Maeno, Y., Tomita, T., Kyogoku, M., Awaji, S., Aoki, Y., Hoshino, K., . . . Fujita, T. (1987). Substitution for copper in a high-Tc superconductor YBa2Cu3O7–δ. Nature, 328(6130), 512-514. doi:10.1038/328512a0

Pęczkowski, P., Zachariasz, P., Kowalik, M., Tokarz, W., Kumar Naik, S. P., Żukrowski, J., . . . Gondek, Ł. (2021). Iron diffusivity into superconducting YBa2Cu3O7-δ at oxygen-assisted sintering: structural, magnetic, and transport properties. Journal of the European Ceramic Society, 41(14), 7085-7097. doi:https://doi.org/10.1016/j.jeurceramsoc.2021.06.018

Sato, Y., Petrykin, V., Yasuoka, H., & Kakihana, M. (2012). Synthesis of high-purity YbBa2Cu3O7-d and LuBa2Cu3O7-d superconductors by polymerizable complex method. Journal of the Ceramic Society of Japan, 120, 503-508. doi:10.2109/jcersj2.120.503

Shams, G., Ranjbar, M., & Barzegar, F. (2012). The Effect of Critical Parameters of High Temperature Superconductor (YBCO) in Magnetic Levitation Trains.

Silva, C. C., & McHenry, M. E. (2001). Measurement and interpretation of AC susceptibility and loss in high-temperature superconductors. Journal of Magnetism and Magnetic Materials, 226-230, 311-313. doi:https://doi.org/10.1016/S0304-8853(00)01360-3

Somacescu, S., Cioatera, N., Osiceanu, P., Calderon-Moreno, J. M., Ghica, C., Neaţu, F., & Florea, M. (2019). Bimodal mesoporous NiO/CeO2-δ-YSZ with enhanced carbon tolerance in catalytic partial oxidation of methane—Potential IT-SOFCs anode. Applied Catalysis B: Environmental, 241, 393-406. doi:https://doi.org/10.1016/j.apcatb.2018.09.065

Terzioğlu, R., Kalkan, Y., Varilci, A., Öztürk, Ö., & Terzioglu, C. (2025). Magnetic properties of Au-doped YBCO superconductors studied by low field AC susceptibility. Journal of Materials Science: Materials in Electronics, 36. doi:10.1007/s10854-025-15561-w

Tolendiuly, S., Sovet, A., & Fomenko, S. (2023). Effect of Doping on Phase Formation in YBCO Composites. Journal of Composites Science, 7(12). doi:10.3390/jcs7120517