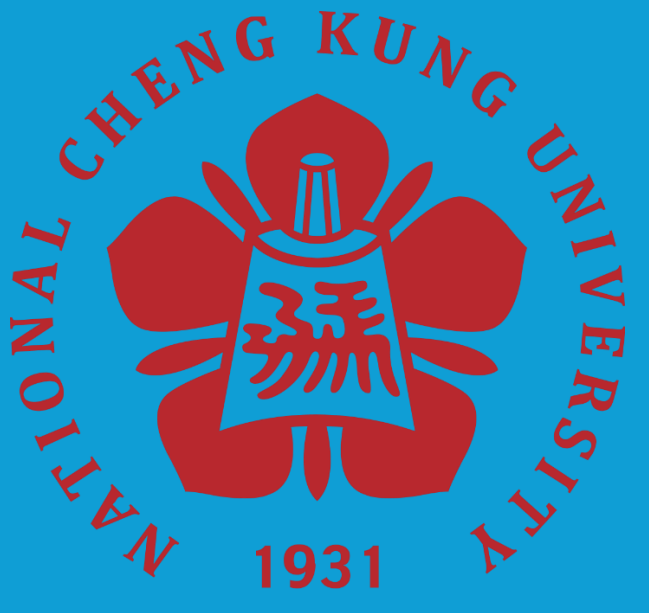


Research on Reduction-Resistant Low-Temperature Sintered Ni-Zn Ferrite Applied to Copper Electrode Multilayer Wafer Inductors



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1、Introduction

Research Background

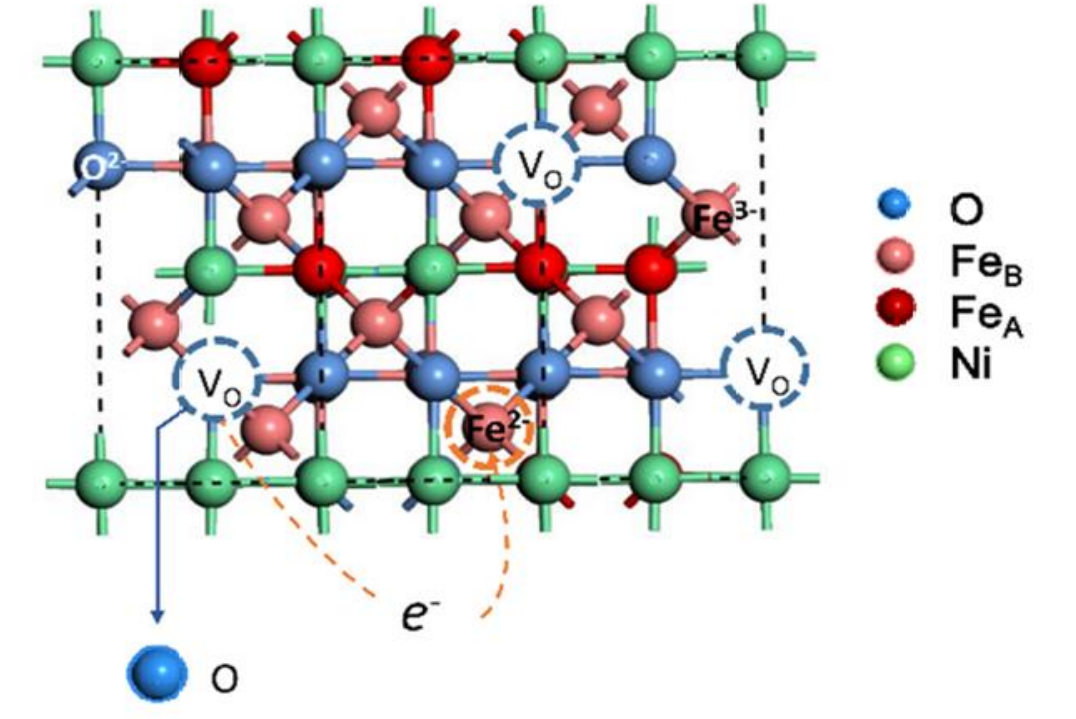
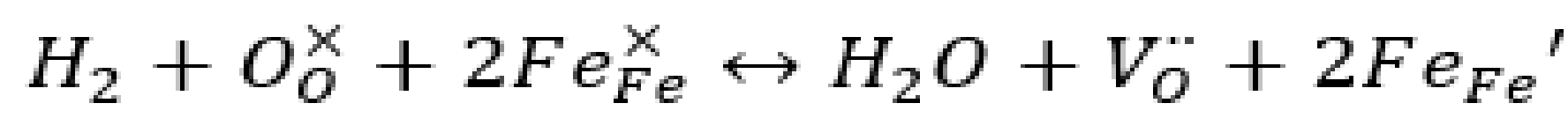
- 5G and automotive miniaturization is driving Ag → Cu electrode transition in MLCIs
- Cu co-firing requires a **low-pO₂ reducing atmosphere**
- Reducing atmosphere triggers **oxygen vacancy formation (V_O^{••})** and forces **Fe³⁺ → Fe²⁺ reduction**. He et al. [1] and Priesse et al. [2]
- Result: **electron-hopping degrades insulation resistance** and **worsens high-frequency eddy current loss**

Strategy

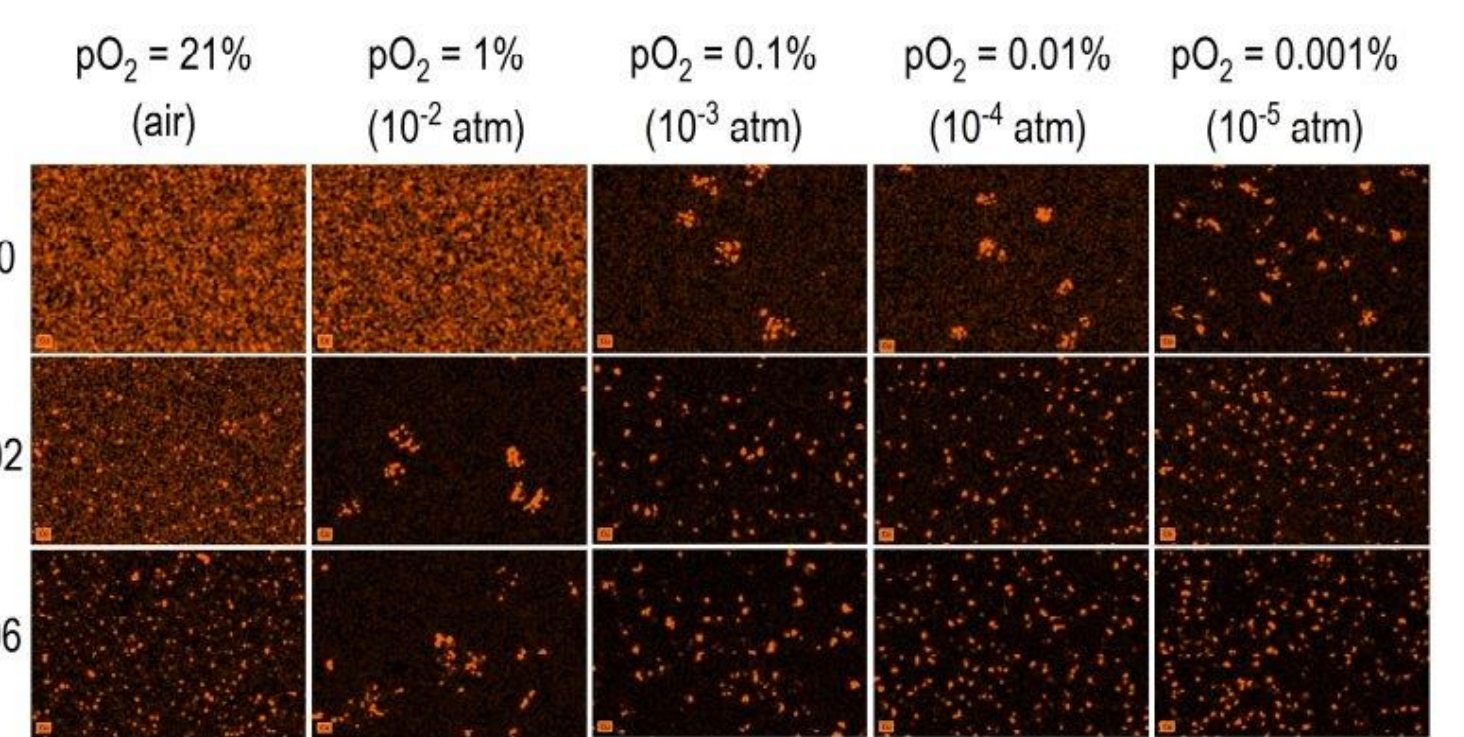
- Ti⁴⁺ stabilizes the spinel structure via **high-energy Ti-O bonds**. He et al. [3]
- Mn^{3+/2+} acts as a **sacrificial element**, absorbing oxygen vacancies and **suppressing Fe³⁺ reduction**. Yamada et al. [4]
- ZBO promotes **low-temperature** sintering densification through liquid phase. Hsiang et al. [5]

Results

- Secondary-phase-free pure spinel structure achieved at **950°C**
- High initial permeability (μ_i) maintained while resonance frequency shifted significantly higher
- Massive **increase** in volume resistivity via blocked electron-hopping paths

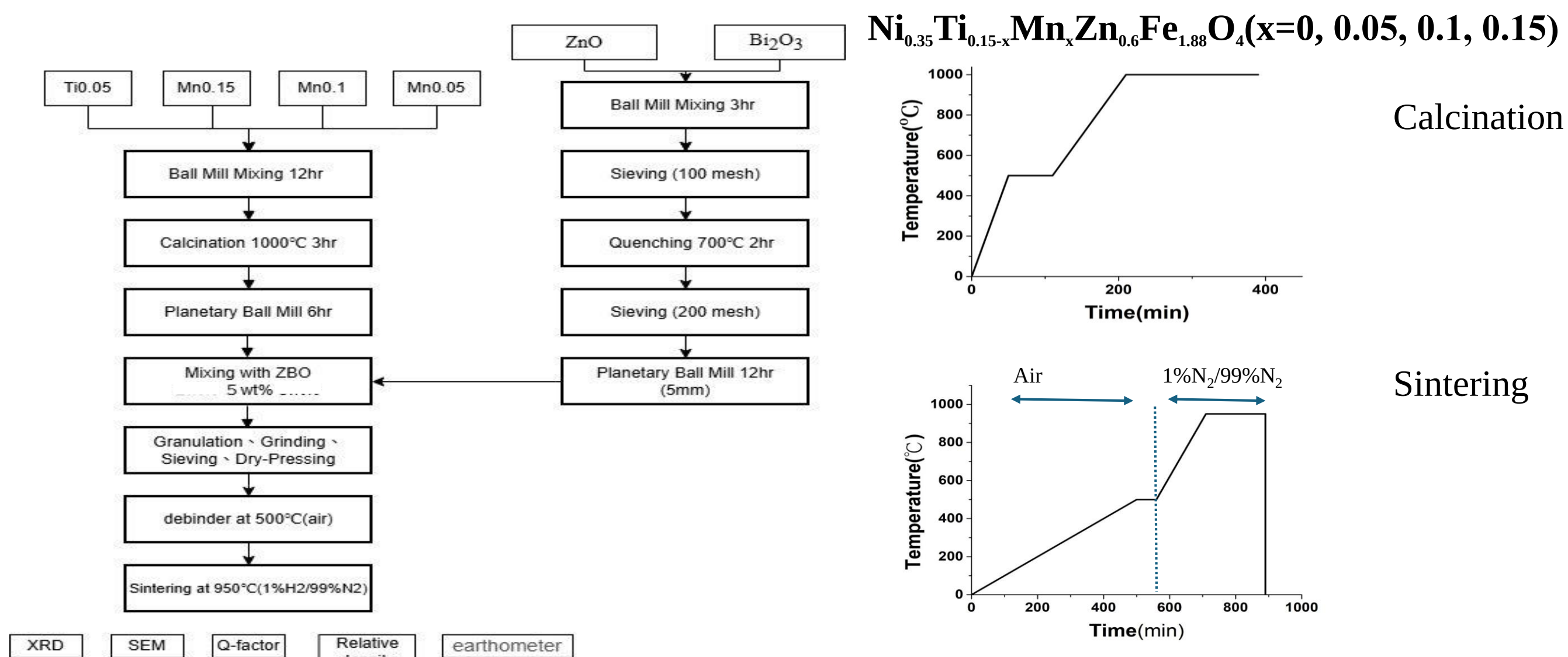


Y. He, L. Zhang, H.W. Xiong, X. Kang, J. Alloys Compd. 917 (2022) 165494.

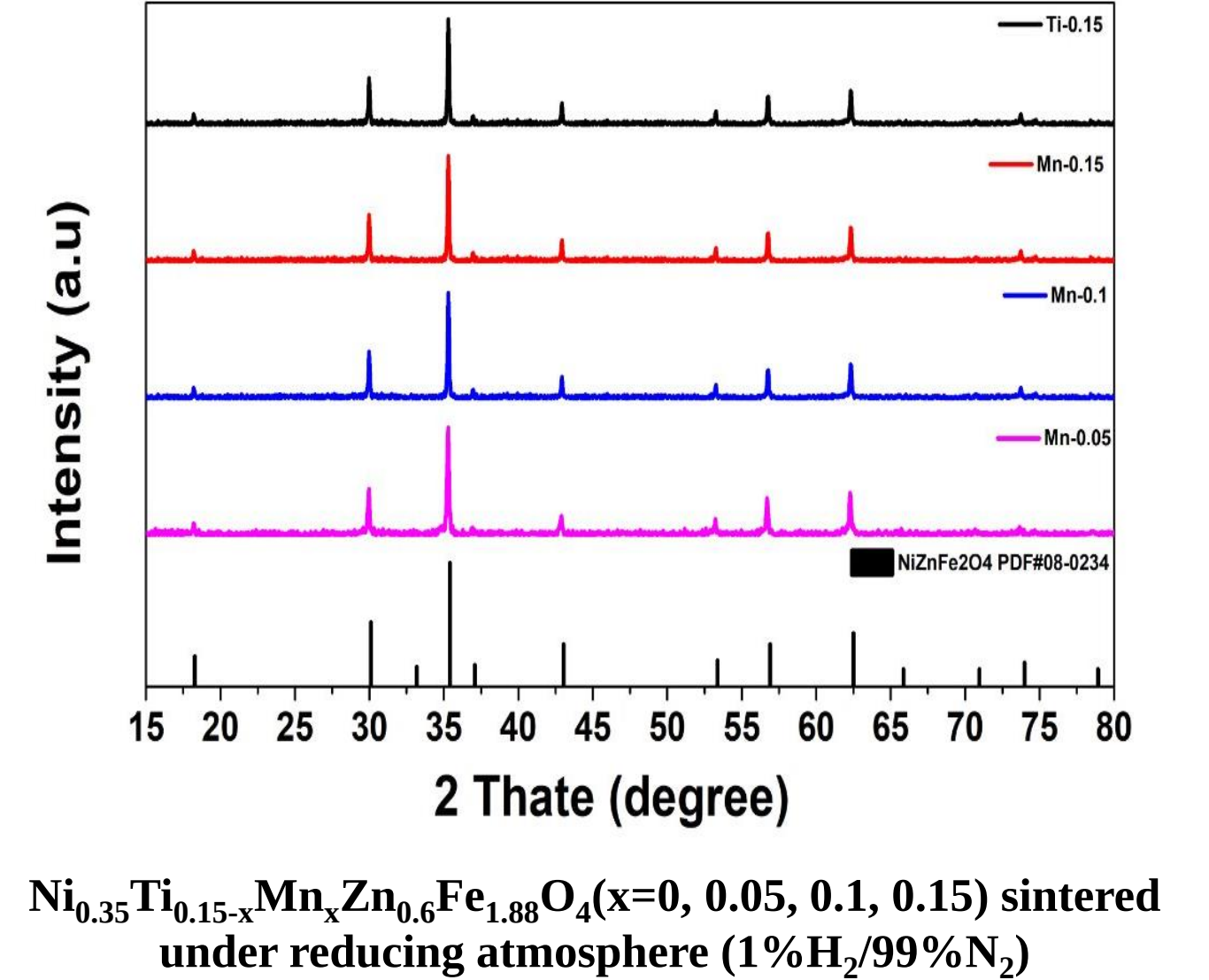
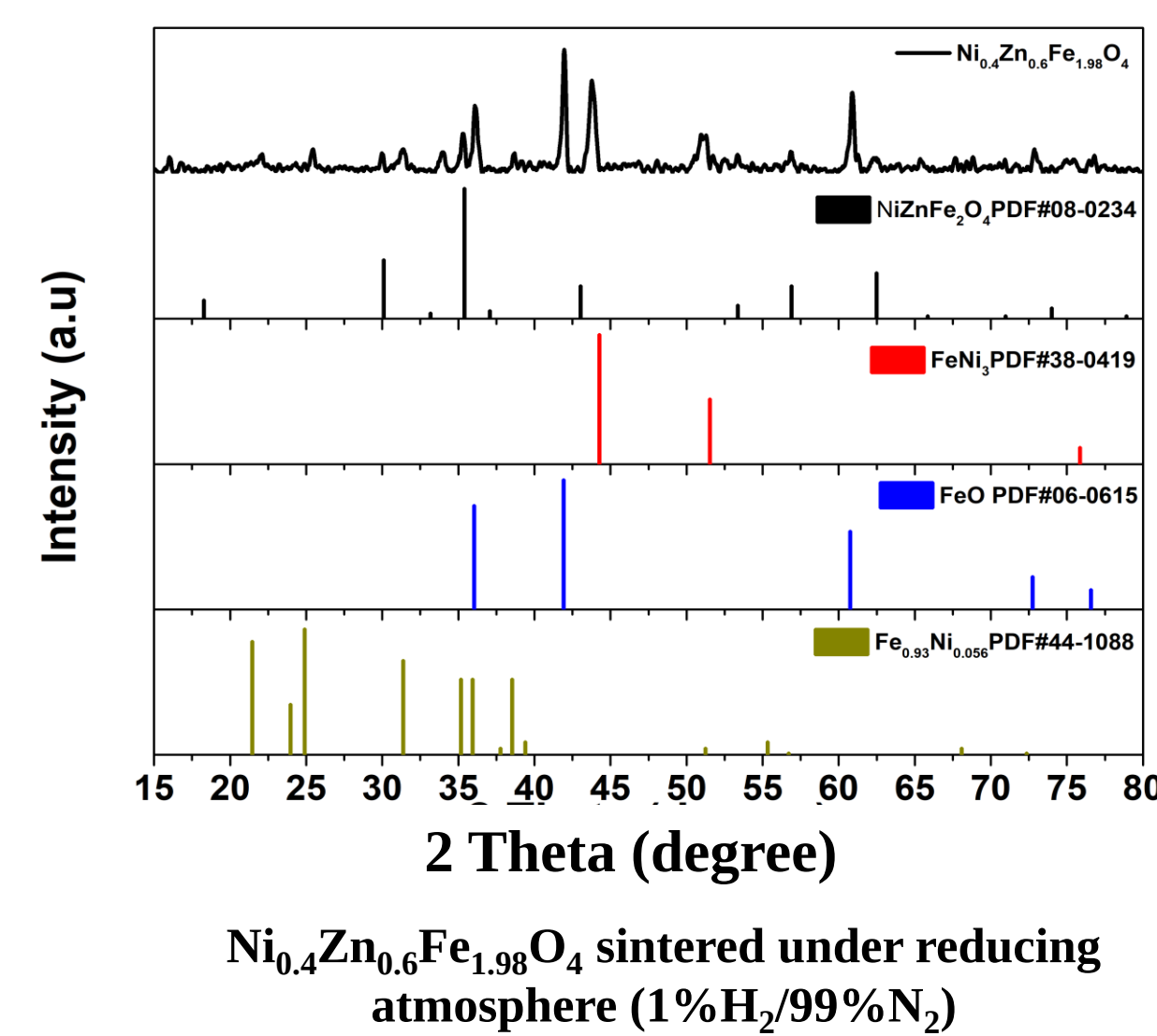


C. Priesse, J. Töpfer, Magnetochemistry 10 (2024) 97.

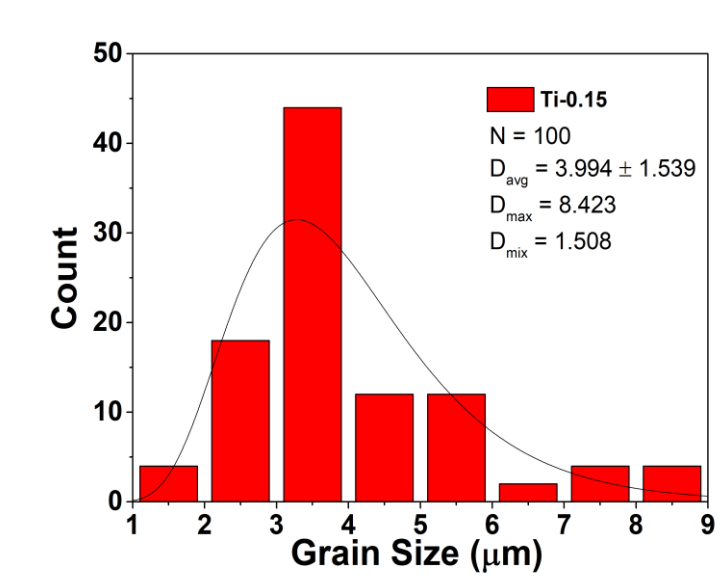
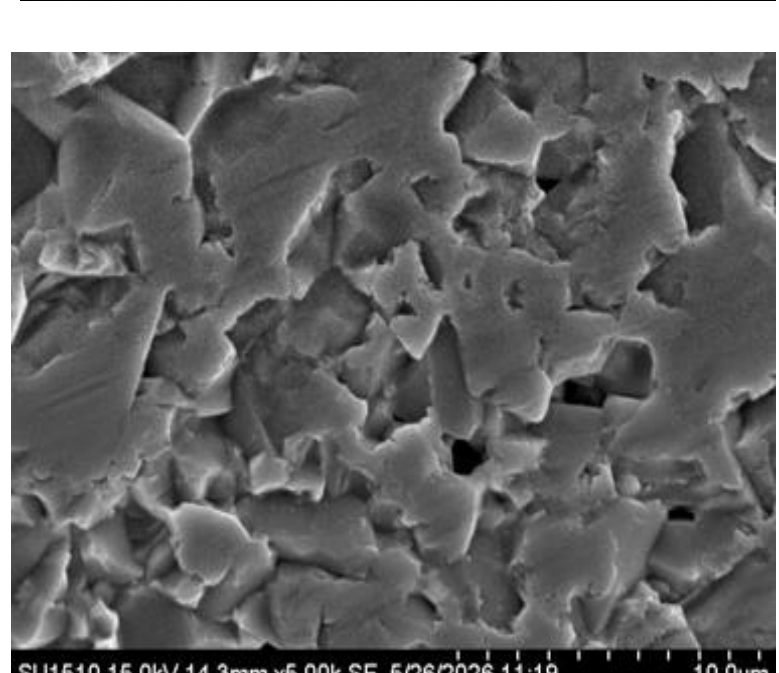
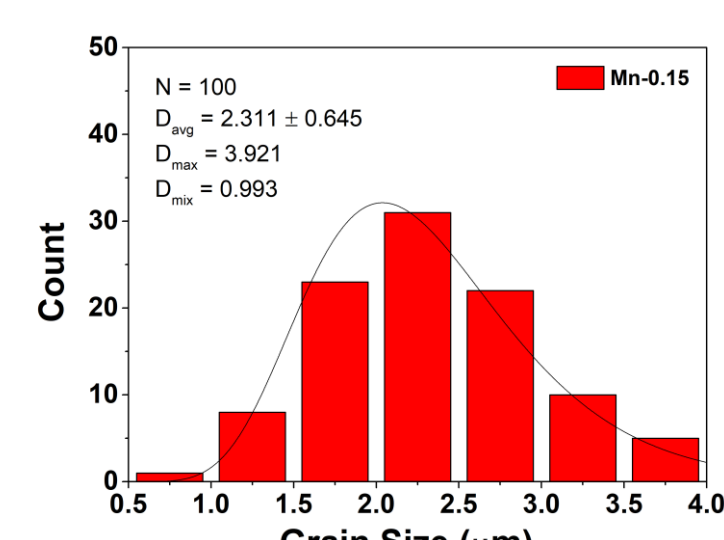
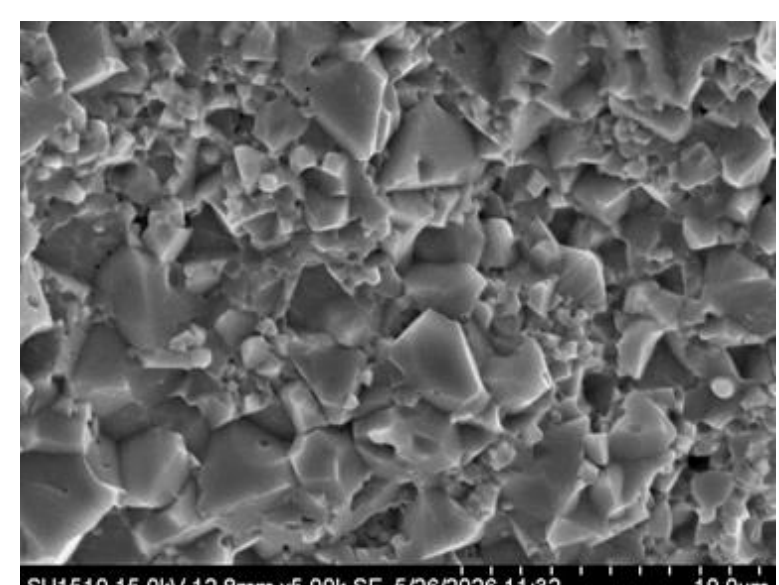
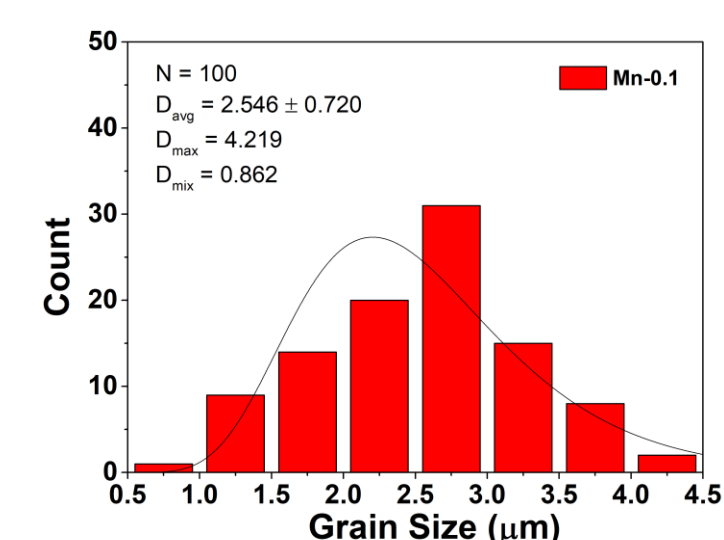
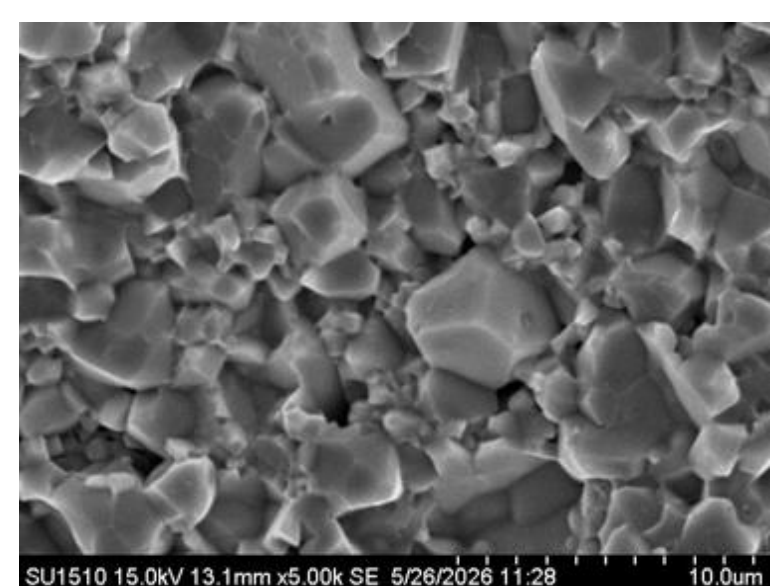
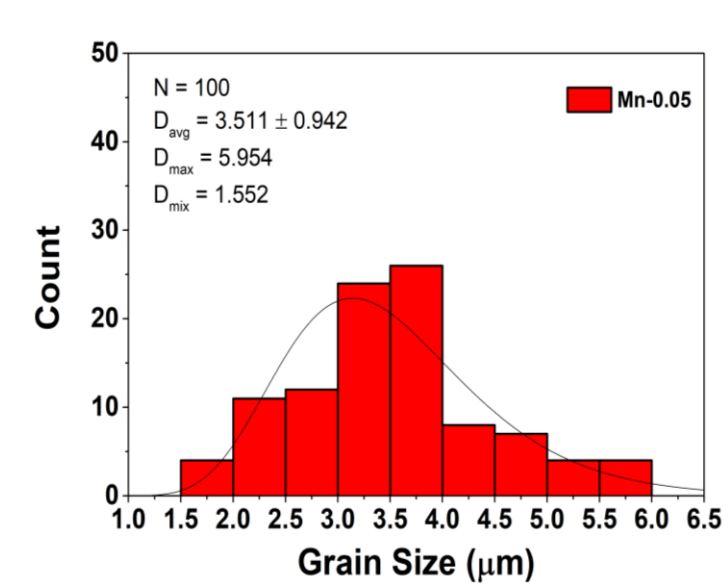
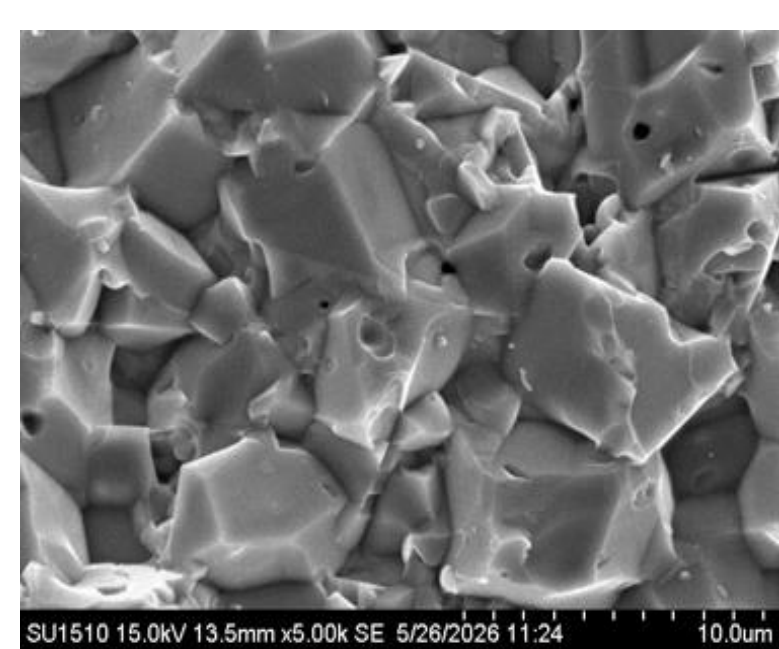
2、Experiment Design



3、Phase Analysis

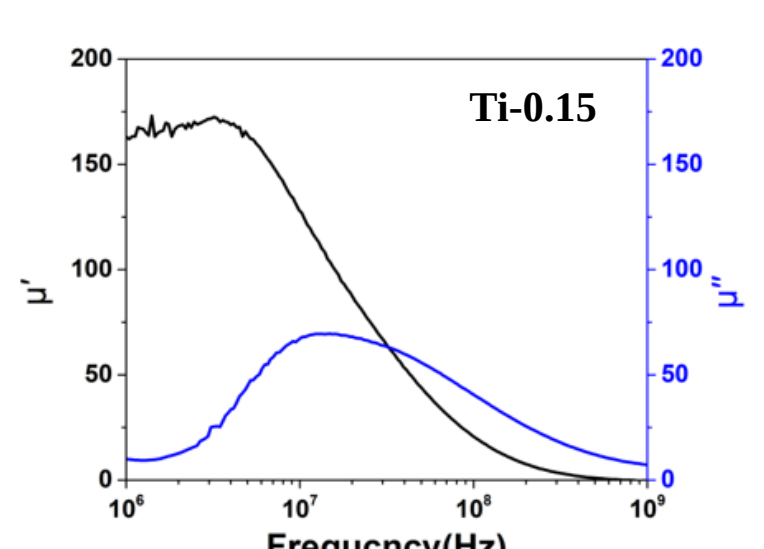
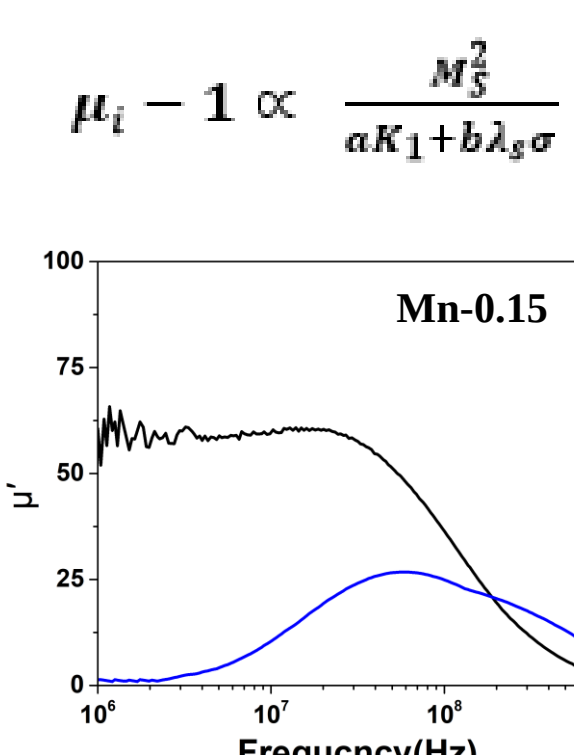
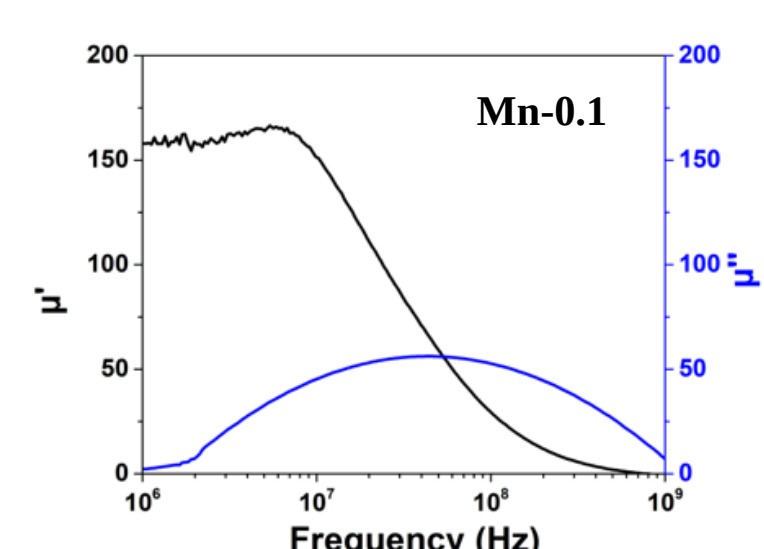
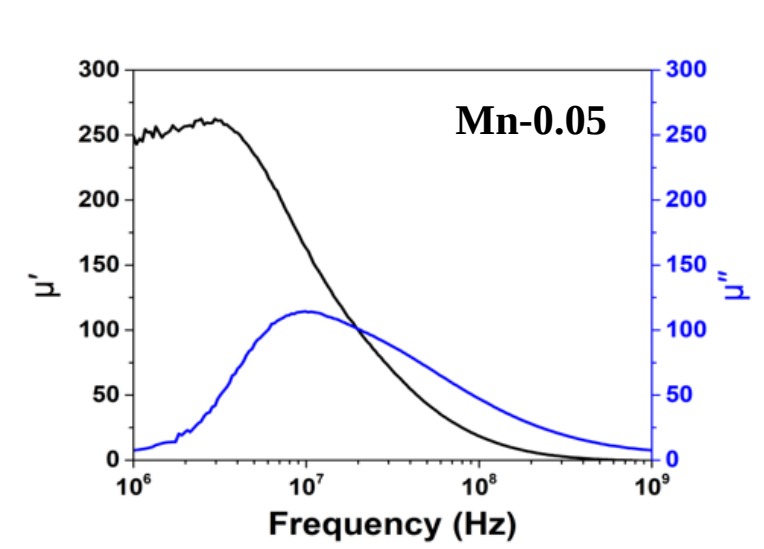


4、SEM



- Well-faceted polyhedral grains with a **narrow size distribution** — no abnormal grain growth across all Mn/Ti ratios.
- No macroscopic discrete second phase** was observed at SEM resolution.

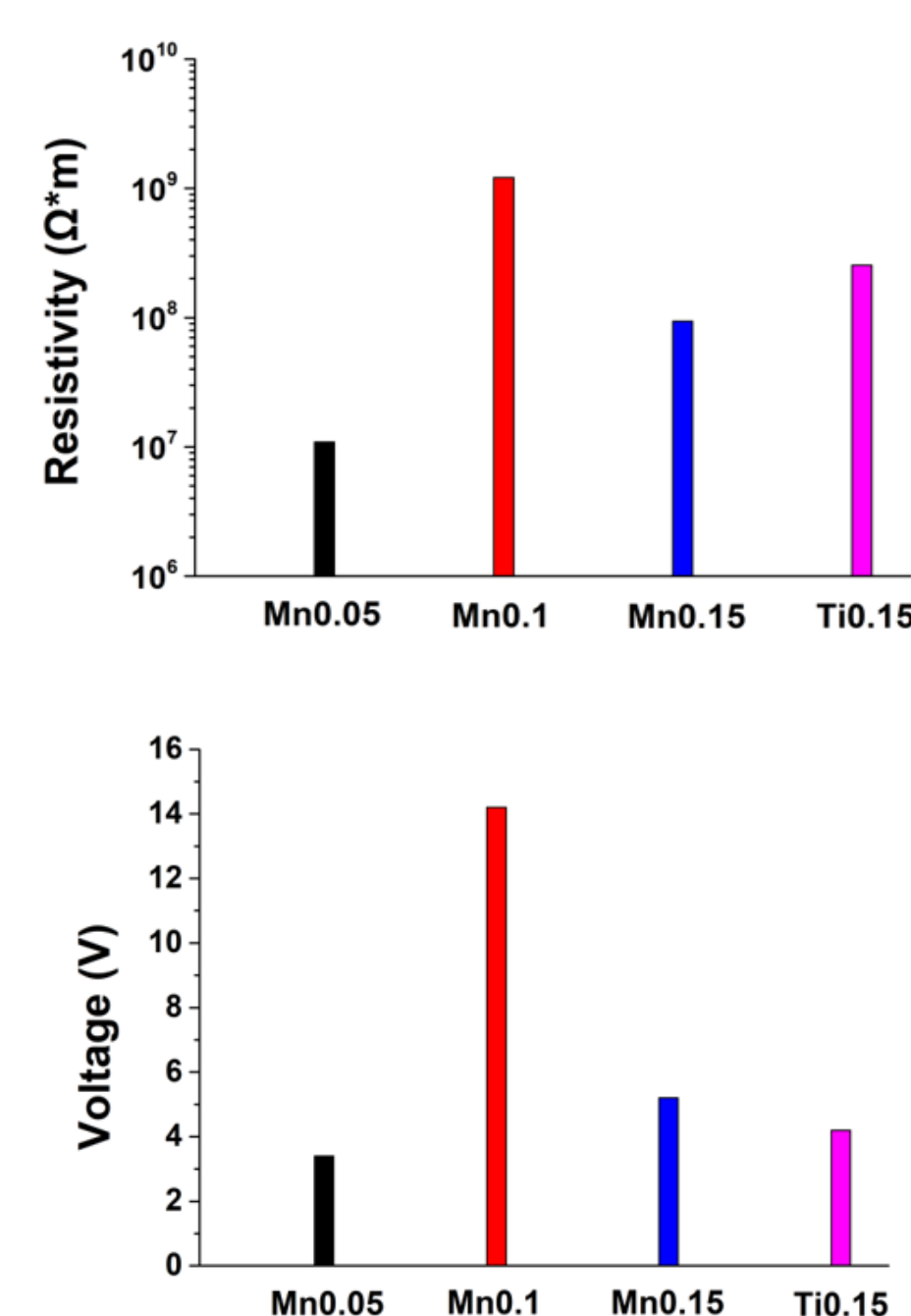
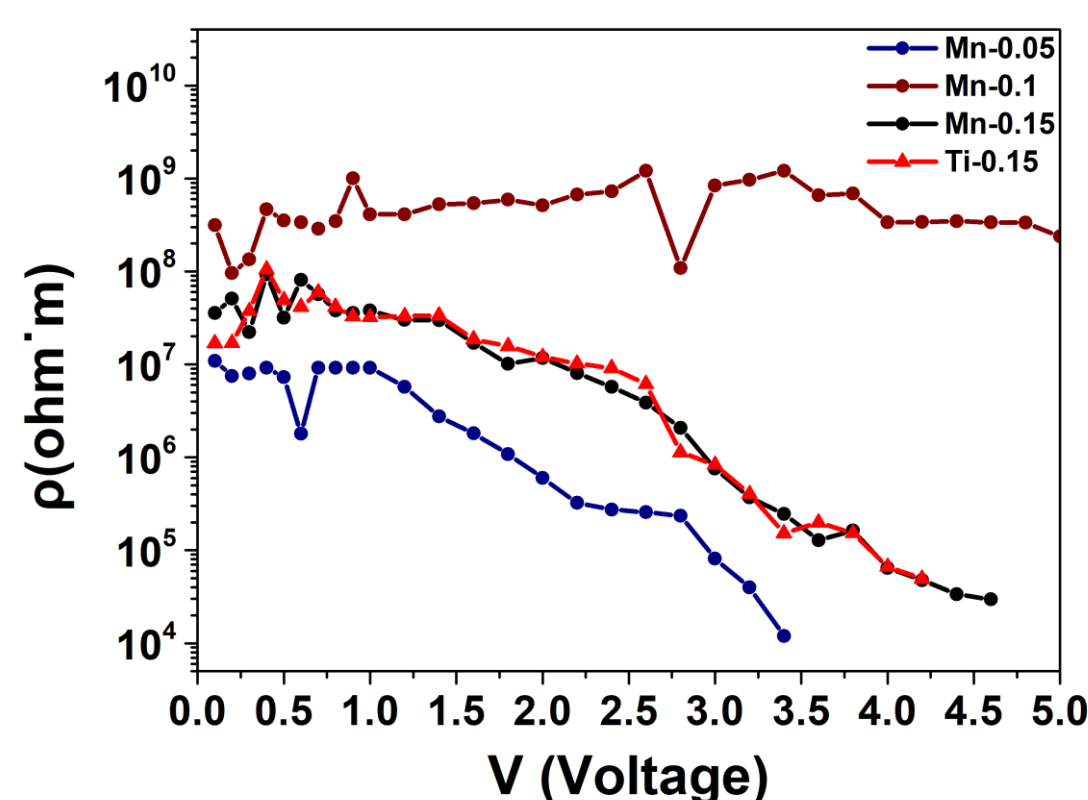
5、Permeability Analysis



	μ'	μ''	Resonance Frequency (MHz)
Mn-0.05	262.4	41.7	9.63
Mn-0.1	165.3	21.3	28.0
Mn-0.15	60.5	15.5	57.8
Ti-0.15	172.5	25.5	14.9

- Altering the Mn/Ti ratio changes the lattice distortion and internal anisotropy.
- Higher internal restoring force decreases μ_i but pushes f_r to a higher frequency band[6].

6、DC Resistance Tester



	Resistivity(Ω* m)	Voltage(V)
Mn0.05	1.09E+07	3.4
Mn0.1	1.21E+09	14.2
Mn0.15	9.38E+07	4.6
Ti0.15	2.54E+08	4.2

- The hopping between Fe²⁺ and Fe³⁺ is the primary mechanism for electrical conductivity.
- Highly diffusive Mn diffuses to the grain boundaries, acting as a sacrificial electron acceptor and sealing the conductive channels at the grain interfaces.
- Slowly moving Ti reduces oxygen vacancies within the grains, thus reducing the generation of free electrons.

7、Conclusion

- Ti/Mn co-doping successfully achieved resistance to reduction**
- Optimal High-Frequency Performance (Mn0.1):** The Ni_{0.35}Ti_{0.05}Mn_{0.1}Zn_{0.6}Fe_{1.98}O₄ formulation demonstrated the best overall properties for MLCI applications. It exhibited the highest bulk resistivity (1.21*10⁹Ω·m) and breakdown voltage 14.2 (V) to minimize eddy current losses. Furthermore, it maintained a high initial permeability (μ_i=165.3) while effectively shifting the resonance frequency up to 28.0 (MHz).

8、References

- [1] Y. He, L. Zhang, H.W. Xiong, X. Kang, J. Alloys Compd. 917 (2022) 165494.
- [2] C. Priesse, J. Töpfer, Magnetochemistry 10 (2024) 97.
- [3] Y. He et al., J. Alloys Compd., 917, 165494 (2022).
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- [5] H.I. Hsiang, C.C. Chen, C.C. Kao, Ceram. Inter. 49 (2022) 2244-2249.
- [6] 1948, Volume 14, Issue 4, Pages 207-217.