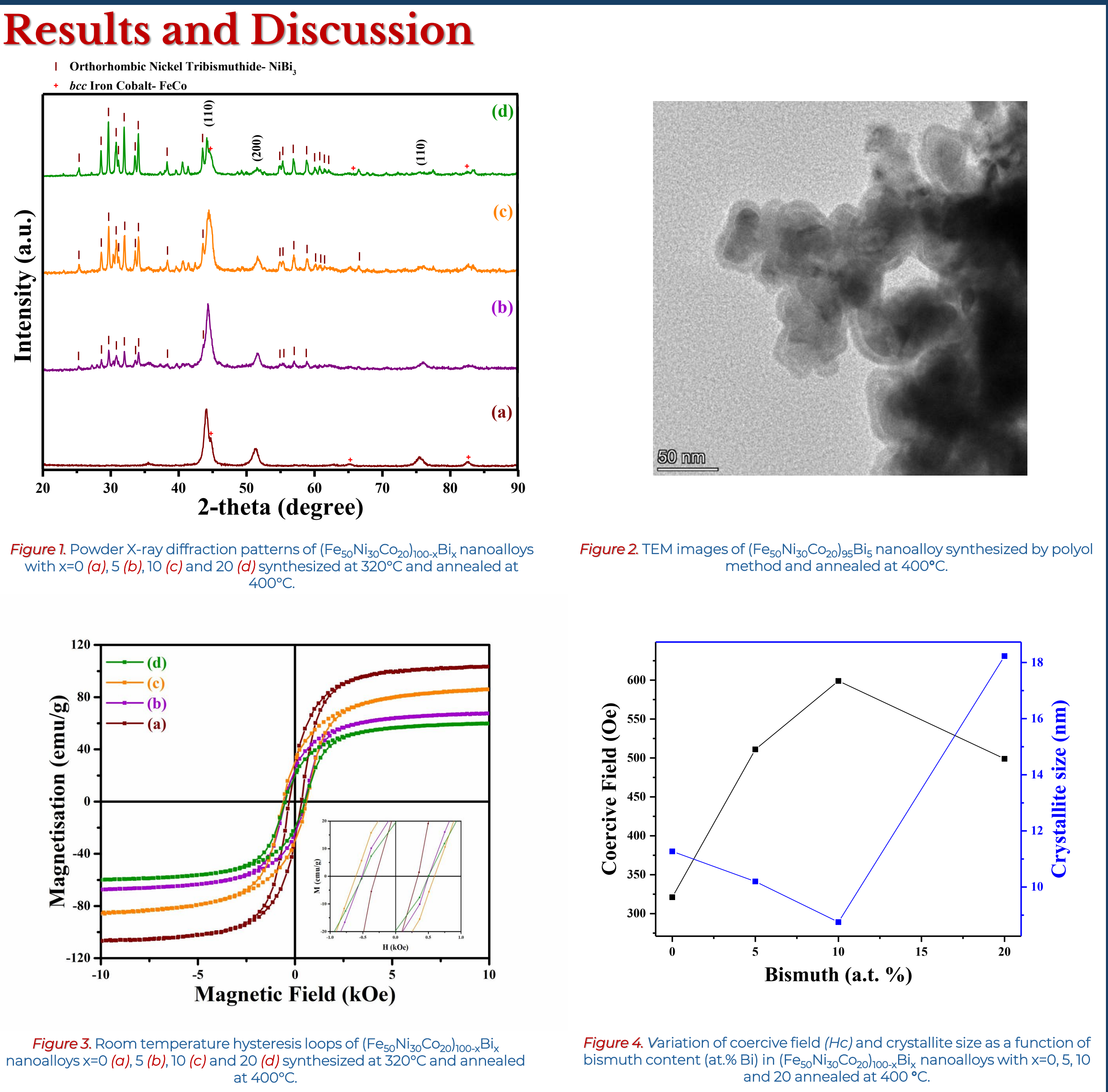
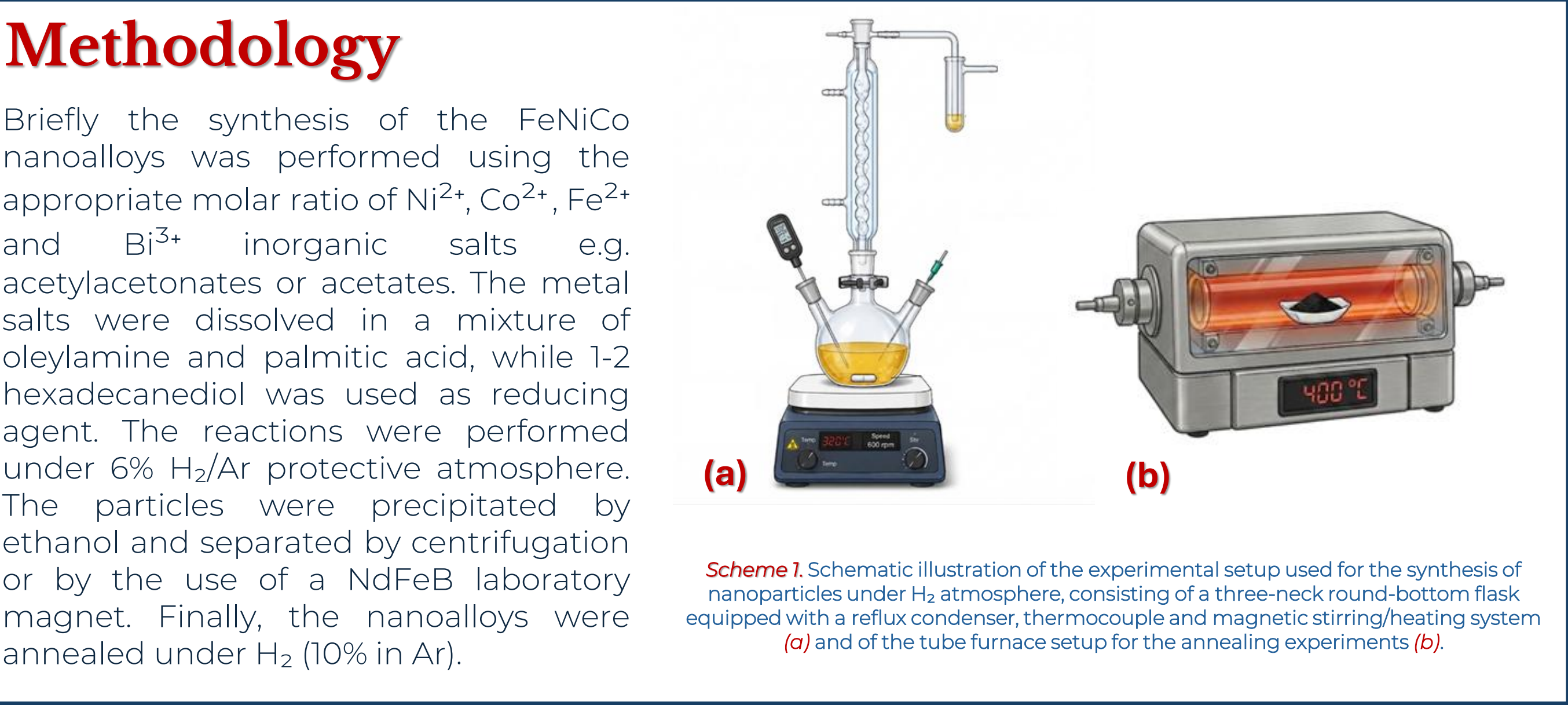


Abstract

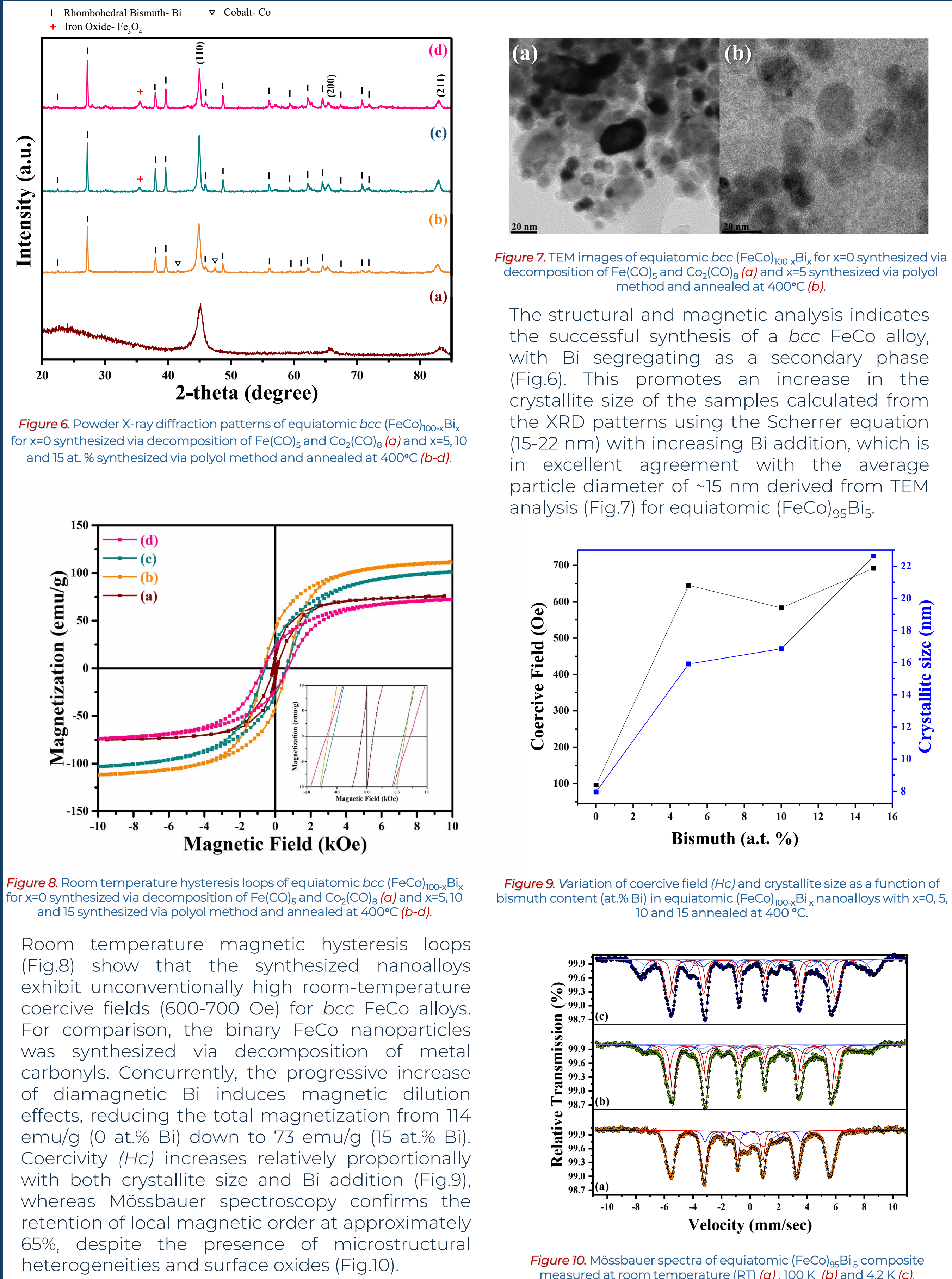
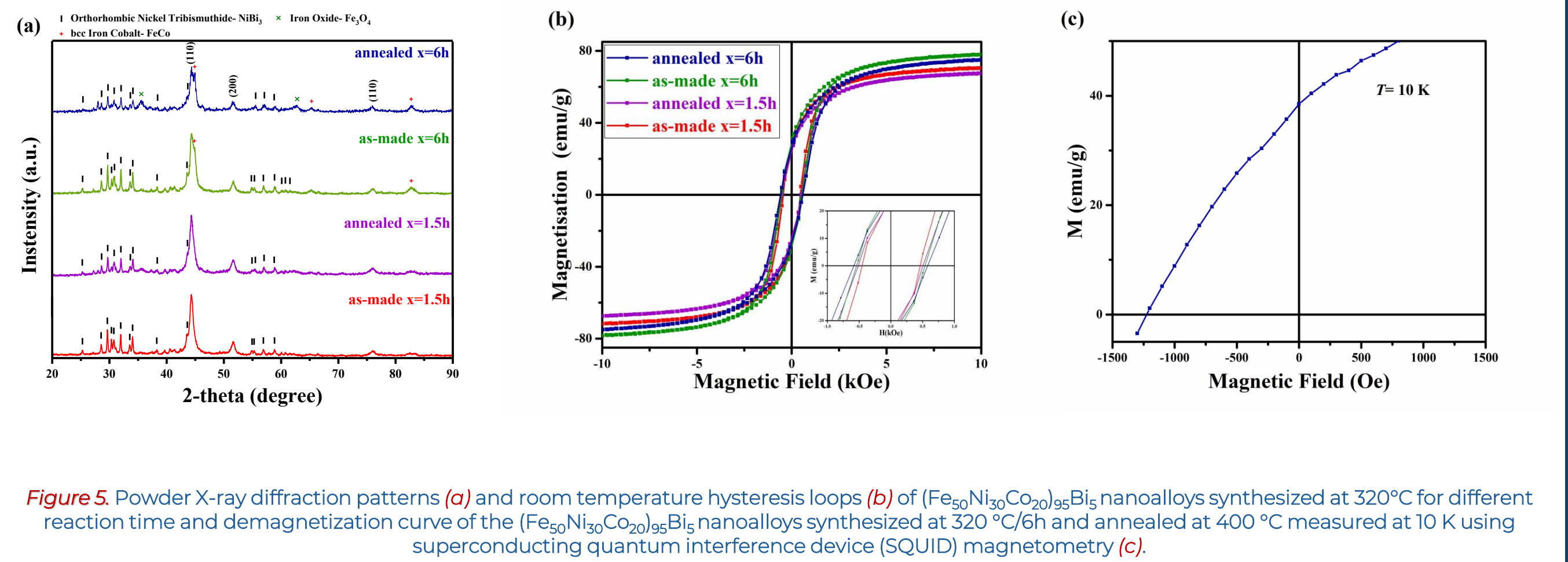
FeCoNi-based nanoalloys were prepared through a modified liquid-phase polyol method, and the influence of Bi addition was examined alongside chemical composition, elemental substitution, and post-synthesis annealing under a reducing atmosphere. Crystal structure and phase evolution were examined by X-ray diffraction, morphology and particle-size distribution by transmission electron microscopy (TEM), structural characterization by Mössbauer spectroscopy, and room-temperature magnetic properties by vibrating sample magnetometry (VSM). The results demonstrate the successful formation of nanoalloys with *bcc* and *fcc* structures and coercive fields higher than those typically expected for these phases. This work determines the effects of Bi addition while assessing the potential of this synthetic approach for tailoring FeCoNi-based magnetic nanoalloys.

Introduction

The growing demand for high-performance permanent magnets has intensified the search for magnetic materials that do not rely on rare-earth elements.^[1] Among the most promising candidates are tetragonally distorted FeCoNi-based alloys, which represent magnetic materials featuring high saturation magnetization along with substantial magnetocrystalline anisotropy approaching 0.84-1.3 MJ m⁻³ for FeNi^[2] and 10 MJ m⁻³ for FeCo^[3]. However, controlling the crystal structure and phase stability in bulk or powder form to achieve enhanced magnetic performance remains an ongoing challenge^[1]. Most experimental studies have therefore focused on thin films grown on metallic substrates, where lattice mismatch induces the required distortion. Template-assisted core-shell approaches have similarly used the phase transformation of nanostructures to impose interfacial strain on FeCoNi shells. Despite these advances, the synthesis of powder tetragonal FeCoNi remains an unresolved challenge. The introduction of a third element offers an alternative route for modifying the phase stability and magnetic anisotropy of FeCoNi-based materials. Additions of light elements, such as C and B, have been reported to induce lattice strain, stabilize tetragonal distortion, or alter the coercive behavior of FeCoNi films and nanostructures. In this context, Bi is of particular interest as an additive because its incorporation can modify atomic diffusion, lattice distortion, phase formation, and magnetic properties, as demonstrated in chemically synthesized L1₀-FePt nanostructures.^[4] Liquid-phase polyol synthesis provides a versatile platform for investigating these effects. The method enables the co-reduction of metallic precursors under controlled conditions and offers flexibility in composition, reaction temperature, reaction time, and surfactant chemistry. It can also produce nanoscale alloys at temperatures substantially lower than those commonly employed in conventional metallurgical processing.^[5] However, the relationships among elemental substitution, Bi addition, secondary-phase formation, oxidation, post-synthesis annealing, and the magnetic response of FeCoNi nanoalloys have not yet been fully established.



In the (Fe₅₀Ni₃₀Co₂₀)_{100-x}Bi_x system, the successful synthesis of an *fcc* FeNiCo alloy is observed, with the distinct feature that Bi reacts with Ni to form a secondary NiBi₃ phase, while a *bcc* FeCo-rich phase also develops in certain samples (Fig.1). The consumption of Ni during the formation of the non-magnetic NiBi₃ phase induces magnetic dilution effects and shifts the stoichiometry of the metallic phases, accounting for the overall, non-proportional reduction in magnetization (Fig.3). Bi addition suppresses crystallite growth, reducing the crystallite size from 11 down to 8 nm, up to a critical concentration of 10 at.% Bi (Fig.4), which enhances the coercive field (*H*_c up to 600 Oe). This coercivity enhancement is attributed to the reduced crystallite size, increased interfacial pinning, and exchange coupling between the *fcc* matrix and the more coercive *bcc* FeCo phase. There is an excellent agreement with the average particle diameter (~13 nm) determined by TEM (Fig.2), indicating that the nanoparticles are predominantly single-crystalline. Prolonging the synthesis duration to 6 hours improves the magnetic response due to the further development of the *bcc* phase (Fig.5. a-b), whereas low-temperature SQUID (Fig.5.c) measurements at 10 K (*H*_c=1223 Oe) confirm the magnetic anisotropy of the material.



Conclusion

In the FeNiCo-based alloys

- Bi addition and Co substitution enhance *H*_c (up to 600 Oe at 10 at.% Bi).
- H*_c enhancement is further supported by exchange coupling between *fcc* FeNiCo and secondary *bcc* FeCo-rich phases, reaching 1223 Oe at 10 K.
- Part of Bismuth reacts with Ni to form a secondary non-magnetic NiBi₃ phase alongside the FeNiCo ternary alloys.

In the FeCo-based alloys

- Although bismuth does not participate in the unit cell its presence suppress the formation of oxides.
- Enhance room temperature coercivity up to 700 Oe is driven by the presence methodology.
- The exact role of Bi is still under investigation and the enhanced magnetic properties may be due to tetragonality, spin orbit coupling and exchange phenomena.

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Website: <https://nanomag.gr/>

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