This supplementary document provides supporting data and experimental details that are referenced in the main manuscript. It includes:

Figure S1, Thermogravimetric analysis (TGA) curve used to determine the calcination temperature.

Figure S2, Fouriertransform infrared (FTIR) spectrum of a representative sample.

Figure S3, Scanning electron microscopy (SEM) images and energydispersive Xray (EDX) spectra for all compositions.

Table S1, Quantitative EDX elemental composition.

1 THERMOGRAVIMETRIC ANALYSIS

The calcination temperature of 550°C was selected based on TGA of the precursor gel for pure and doped NiO. Figure S1 shows the TGA curve recorded from room temperature to 800°C under air atmosphere at a heating rate of 10°C·min^{-1}. A major weight loss (~45%) occurs between 250°C and 500°C, corresponding to the decomposition of the metal–EDTA complex and removal of organic residues. Above 500°C, the weight becomes stable, confirming complete conversion to the oxide phase. Therefore, 550°C was chosen as the calcination temperature for all samples. The thermogravimetric analyzer TG 209F1 Libra (NETZSCH Co., Germany) was used at Kamal A. Shair Central Research Science Laboratory KAS CRSL at the American University of Beirut AUB, Beirut, Lebanon.

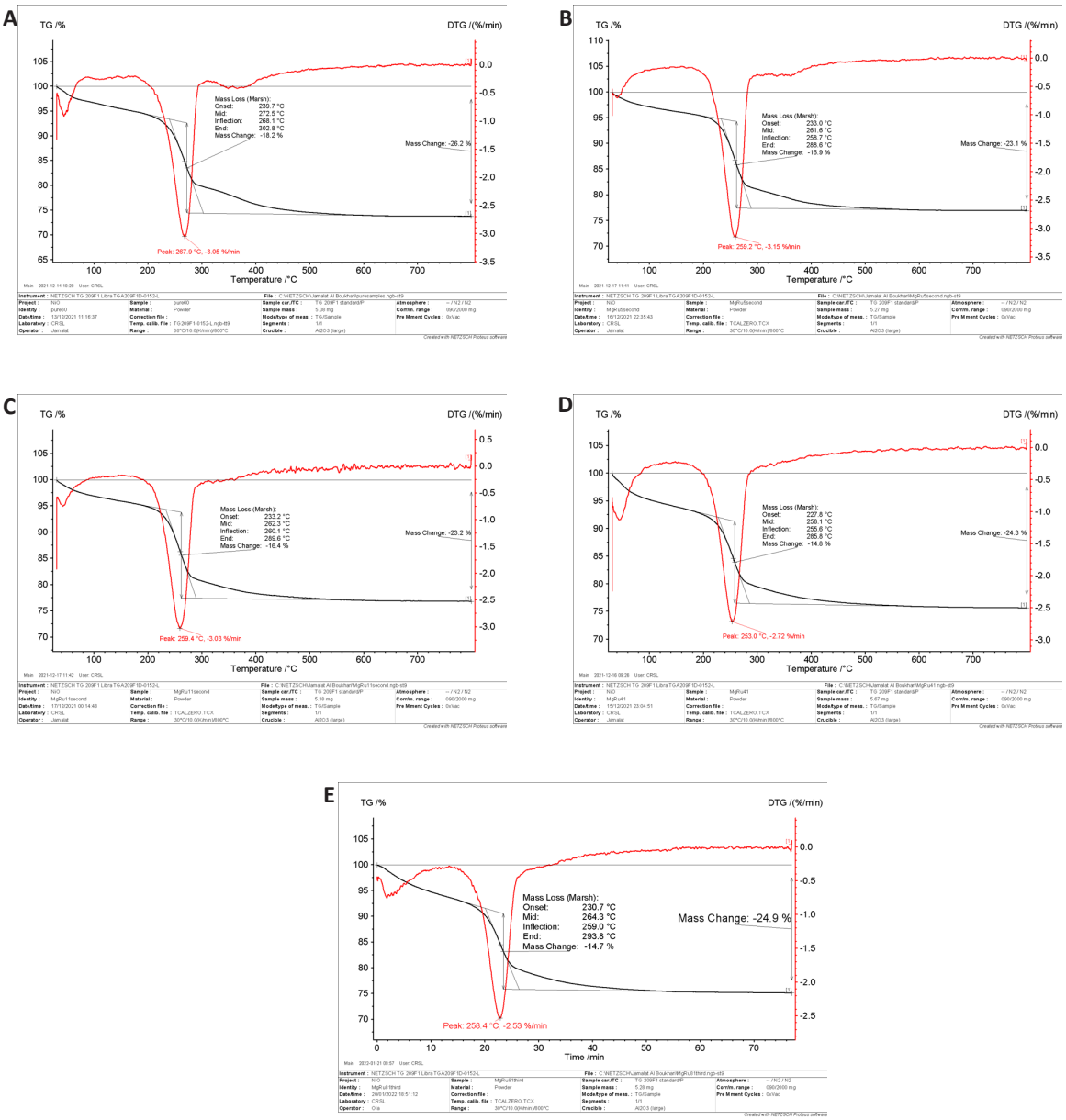


Figure S1. TGA Curves for Pure and Doped NiO.

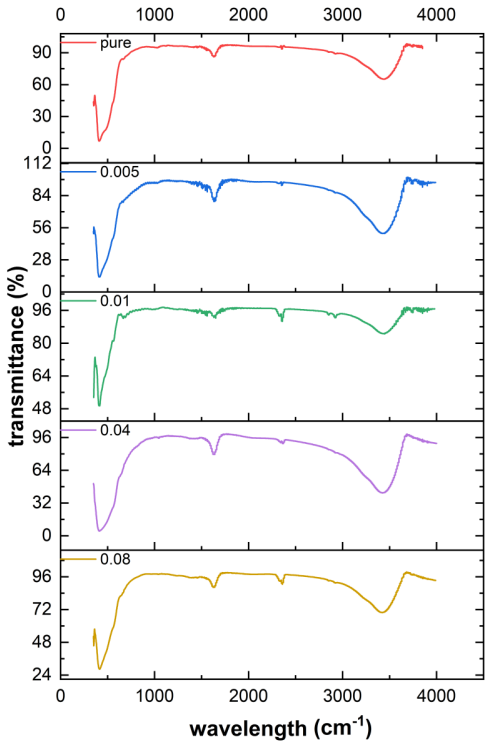


Figure S2. FTIR Spectra for Pure and Doped NiO.

2 FOURIERTRANSFORM INFRARED SPECTROSCOPY

Figure S2 presents the FTIR spectrum of a representative $Ni_{1-2x}Mg_xRu_xO$ nanoparticle sample (x=0.04) in the range 400-4000cm^{-1}. The spectrum was recorded using the FTIR spectrometer Nicolet iS5 (ThermoFisher Scientific Co., US) was used at the Faculty of Science, Beirut Arab University BAU, Debbieh, Lebanon. A strong broad band centred at ~450cm^{-1} is attributed to the Ni–O stretching vibration in the rocksalt lattice. No additional bands from organic residues or other impurities are observed. The absence of significant band shifts upon Mg and Ru codoping indicates that the dopants are incorporated into the NiO lattice without disrupting the primary oxide framework.

3 SCANNING ELECTRON MICROSCOPY AND ENERGYDISPERSIVE XRAY ANALYSIS

3.1 Morphology SEM

Figures S3(A1–E1) show SEM images of $Ni_{1-2x}Mg_xRu_xO$ nanoparticles for x=0, 0.005, 0.01, 0.04, and 0.08 (the same order as in the main manuscript). The scanning electron microscope MIRA3 LMU (TESCAN Co., Czechia) was used at Kamal A. Shair Central Research Science Laboratory KAS CRSL at the American University of Beirut AUB, Beirut, Lebanon. No significant morphological change is observed with increasing dopant concentration, confirming that the synthesis method yields stable, phasepure nanoparticles up to x=0.08 despite the appearance of a secondary RuO_2 phase at $x \geq 0.04$ (as discussed in the main manuscript).

3.2 Elemental Composition EDX

Figure S3(A2–E2) present the corresponding EDX spectra collected from the same regions shown in the SEM images. Table S1 summarizes the quantitative elemental compositions in weight percent (wt%). The data confirm the systematic decrease of Ni content with increasing x and the successful incorporation of Mg and Ru. For the lowest doping levels (x=0.005 and 0.01), Ru was not detected which can be attributed to that its concentration is below the EDX detection limit. For $x \geq 0.04$, Ru becomes clearly visible and its measured wt% increases with x, consistent with the nominal stoichiometry. The oxygen content remains stable, confirming the oxide nature of all samples. The energy dispersive X-ray detector X-Max SDD (Oxford instruments Co., UK), coupled with INCA software package at the American University of Beirut AUB, Beirut, Lebanon, was utilized for surface elemental analysis.

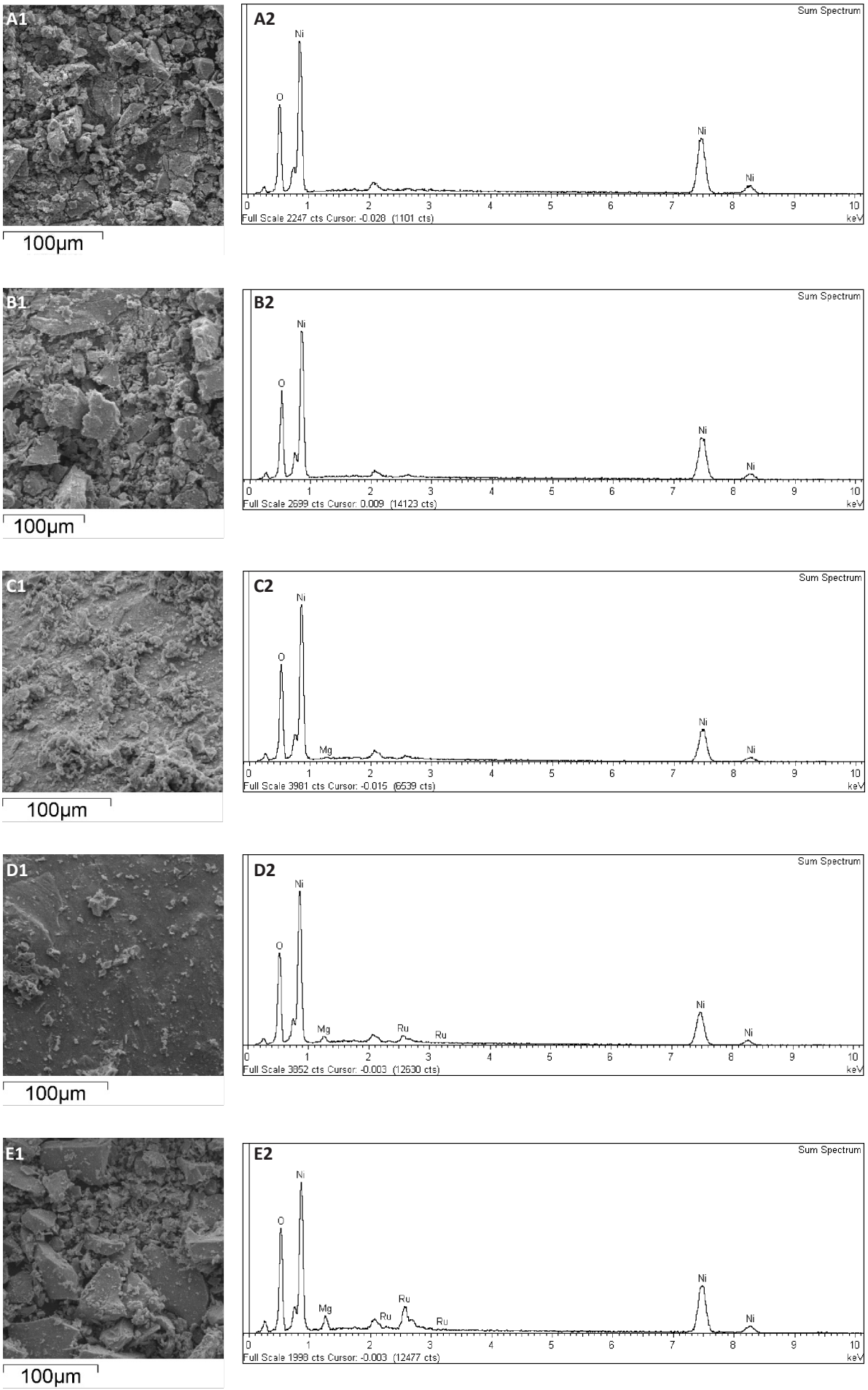


Figure S3. SEM Images and EDX Spectra. (A1) SEM of NiO, (A2) EDX of NiO; (B1) SEM of x=0.005, (B2) EDX of x=0.005; (C1) SEM of x=0.01, (C2) EDX of x=0.01; (D1) SEM of x=0.04, (D2) EDX of x=0.04; (E1) SEM of x=0.08, (E2) EDX of x=0.08.

Table S1. EDX Elemental Composition (wt%) of $Ni_{1-2x}Mg_xRu_xO$ Nanoparticles

Sample	x	Ni (wt%)	Mg (wt%)	Ru (wt%)	O (wt%)
NiO	0.00	82.47	0.00	0.00	17.53
$Ni_{0.99}Mg_{0.005}Ru_{0.005}O$	0.005	79.45	0.00	0.00	20.55
$Ni_{0.98}Mg_{0.01}Ru_{0.01}O$	0.01	72.8	0.45	0.00	26.75
$Ni_{0.92}Mg_{0.04}Ru_{0.04}O$	0.04	68.5	1.59	3.45	26.46
$Ni_{0.84}Mg_{0.08}Ru_{0.08}O$	0.08	66.42	2.29	8.64	22.64