

Ion Irradiation Induced Frustrated Non-collinear Magnetism in Tetragonally Distorted Cobalt Manganites: Insights from X-ray Magnetic Circular Dichroism

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The rapid advancement of multifunctional devices has stimulated considerable interest in materials whose physical properties can be precisely tuned through external perturbations. Among these, spinel oxides represent an exceptional class due to the strong coupling among lattice, charge, spin, and orbital degrees of freedom. Such intricate interactions often give rise to competing ground states, magnetic frustration, and non-collinear spin configurations, making spinel magnetic structure highly sensitive to external stimuli including magnetic fields, chemical substitution, pressure, and irradiation [1-5]. Consequently, they provide an ideal platform for investigating defect-property correlations in strongly correlated systems. In this context, swift heavy ion (SHI) irradiation has emerged as a powerful non-equilibrium approach for tailoring the structural, electronic, and magnetic properties of complex oxides via controlled defect engineering. By carefully tuning irradiation parameters such as ion beam species, energy, and fluence, SHI processing enables access to metastable defect configurations that are difficult to achieve through conventional chemical doping or thermal treatments. In the SHI regime, energy loss occurs predominantly through electronic stopping, producing intense electronic excitation along the ion trajectory. In complex oxides, this process can induce localized lattice modification, defect generation, and cation redistribution, thereby strongly influencing structural and functional characteristics [6-8].

To quantify these effects in tetragonal CoMn_2O_4 under 100 MeV ^{107}Ag ion irradiation, comprehensive structural, electronic, and magnetic characterizations were performed using complementary diffraction, magnetometry, and element-selective x-ray spectroscopic techniques, supported by SRIM-TRIM Monte Carlo simulations. The combined influence of SHI irradiation and cumulative fluence leads to a pronounced increase in oxygen-vacancy concentration, accompanied by associated cation vacancies, because electronic stopping dominates nuclear stopping by approximately two orders of magnitude in the beam scattering process in CoMn_2O_4 target. Structural analyses reveal that although the $I4_1/amd$ crystal framework is preserved, irradiation introduces substantial lattice strain, local symmetry distortions, and cation redistribution. Magnetic measurements demonstrate defect-driven responses characterized by field-aligned moments and short-range correlations indicative of superparamagnetic-like behavior. X-ray absorption spectroscopy confirms that Mn and Co oxidation states remain largely unchanged, whereas x-ray magnetic circular dichroism reveals modified spin polarization with antiparallel dichroic signatures, evidencing inter-sublattice antiferromagnetic coupling. Concurrently, O K-edge spectra show a redistribution of spectral weight between t_{2g} and e_g -derived states, signifying irradiation-induced tuning of metal-oxygen hybridization. Overall, these results demonstrate that lattice-induced electronic reconstruction and defect-modified exchange pathways govern the magnetic behavior, establishing ion irradiation as a versatile tool for tailoring functional responses in frustrated correlated oxides.

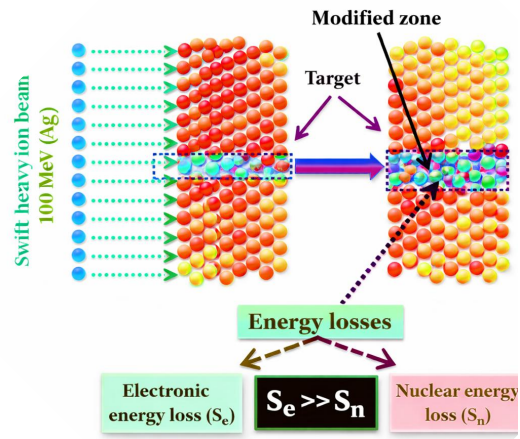


FIGURE 1. The Schematic illustrations of swift heavy ion beam interaction with matter.

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