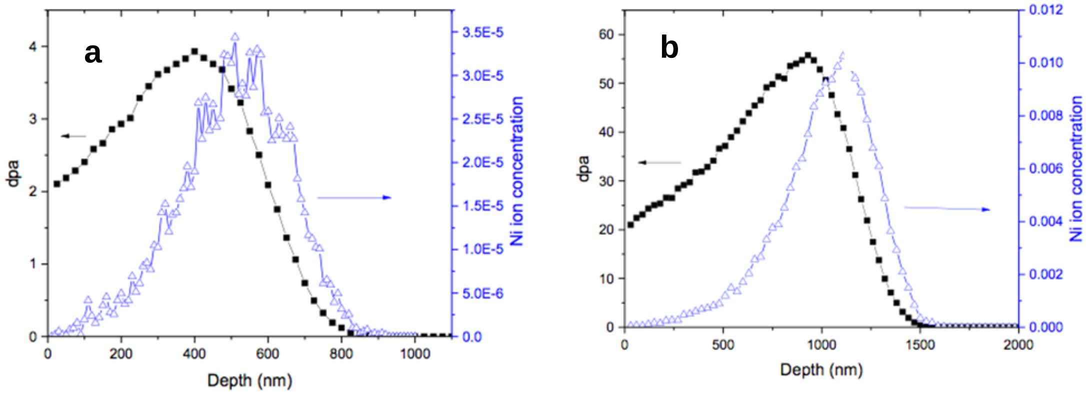
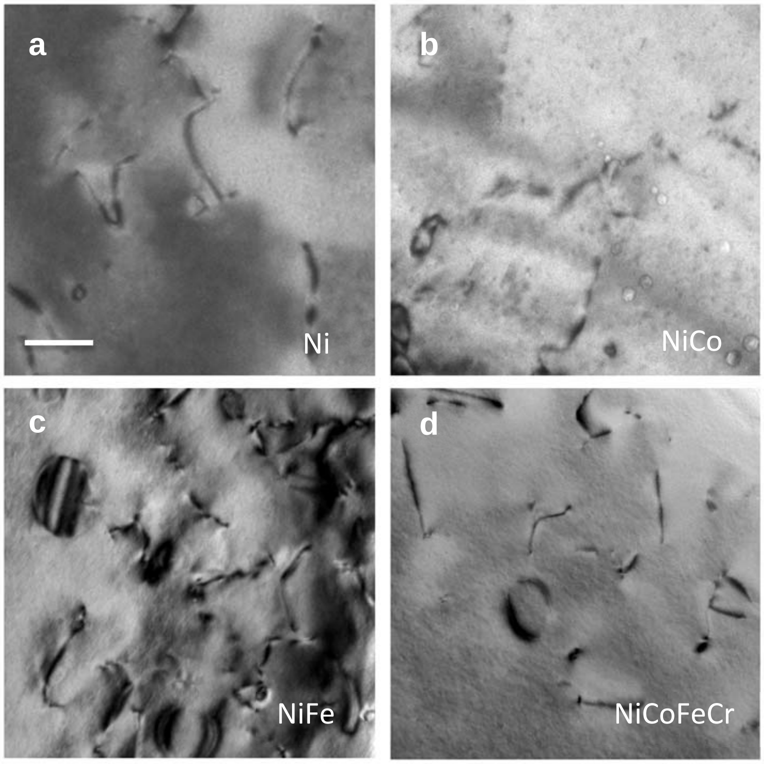
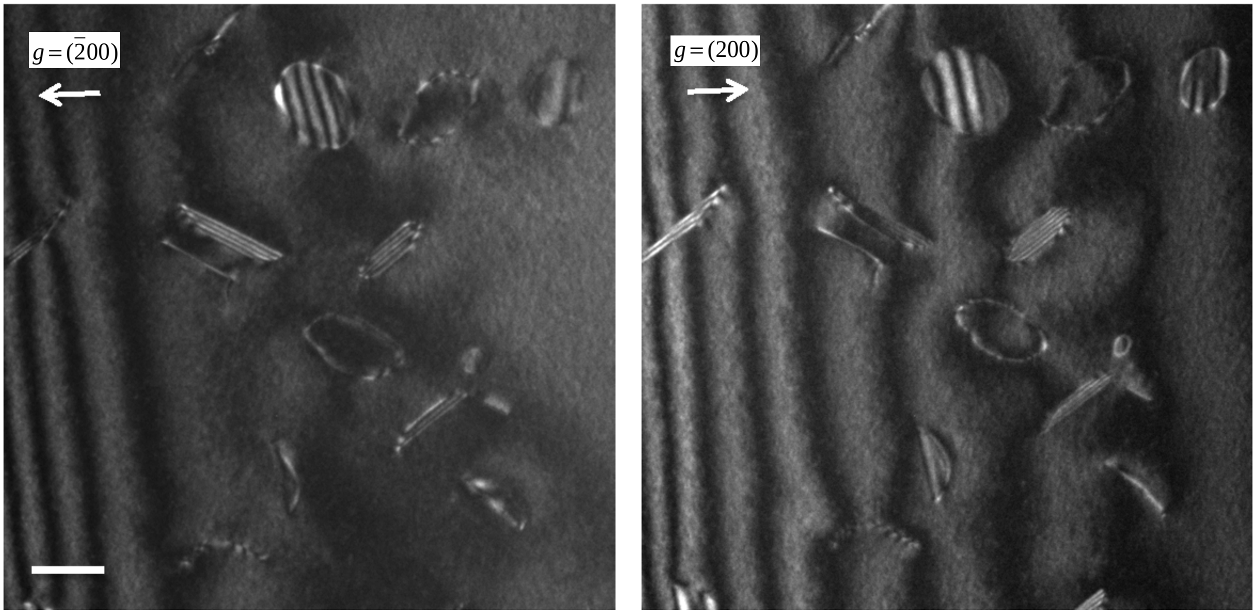


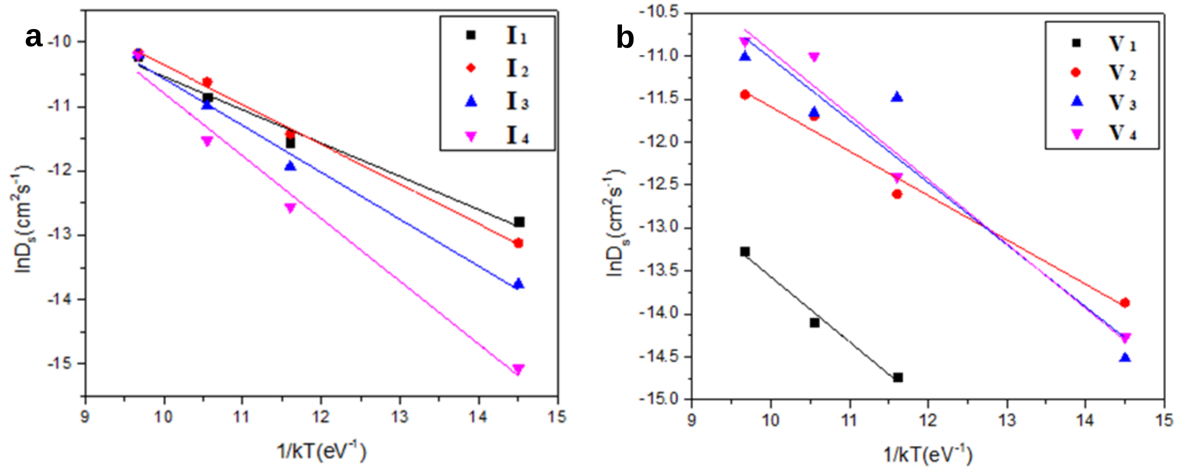
Supplementary Figure 1 | SRIM prediction profile of depth distribution of displacement damage and implanted ions (**a**) 1.5 MeV Ni^+ ions to 3×10^{15} cm^{-2}, (**b**) 3 MeV Ni^+ ions to 5×10^{16} cm^{-2}.



Supplementary Figure 2 | Dislocation structures in nickel, NiCo, NiFe and NiCoFeCr irradiated with 1.5 MeV Ni^{+} ions to 3×10^{15} cm^{-2} at 773 K. (**a**) nickel, (**b**) NiCo, (**c**) NiFe, (**d**) NiCoFeCr. The scale bar is 100 nm.



Supplementary Figure 3 | Characterization of the nature of dislocation loops by inside-outside method in NiCoFeCr irradiated with 1.5 MeV^{+} ions to 3×10^{15} cm^{-2} at 773 K. Weak-beam dark field images are recorded using different **g** vectors at (**g**, 4**g**), with specimen oriented close to [011] zone axis. The dislocations are all identified as interstitial type. The scale bar is 50 nm.



Supplementary Figure 4 | Self-diffusion coefficients of (**a**) interstitials and (**b**) vacancies in NiFe as a function of reciprocal temperature. The lines are drawn as a guide for the eyes. The values for the effective migration barriers and the pre-exponential factors are given in Table 1.

Note 1: Fundamental theory of defect evolution

In the fundamental level, displacement cascades produce interstitials and vacancies, and the concentrations of these defects under irradiation can be simply described by[1]

$$\frac{\partial C_v}{\partial t} = K_0 - K_{iv}C_iC_v - \sum K_{vs}C_vC_s$$

$$\frac{\partial C_i}{\partial t} = K_0 - K_{iv}C_iC_v - \sum K_{is}C_iC_s$$

where C_v is vacancy concentration, C_i interstitial concentration, K_0 defect production rate, K_{iv} vacancy-interstitial recombination rate constant, K_{vs} vacancy sink strength and K_{is} interstitial sink strength. Here, we consider only single phase crystal without sinks (such as GBs, dislocations and precipitates), and thus, $C_s = 0$. K_{iv} is proportional to the interstitial and vacancy diffusion coefficients, D_i and D_v. In metals, D_i is much larger than D_v and thus, interstitial migration controls the microstructural evolution under irradiation. For example, the D_i is 7.3×10^{-5} cm^2s^{-1} at 800 K in nickel, which is four orders magnitude larger than the D_v (2.2×10^{-9} cm^2s^{-1}) [2] and the interstitials migrate very fast either to free surface or forming interstitial type dislocation loops.

Supplementary References

1. Was, G. S. *Fundamentals of radiation materials science: metals and alloys* (Springer, New York, 2007).
2. Zhao, L., Najafabadi, R. & Srolovitz, D. J. Determination of vacancy and atomic diffusivities in solid solution alloys. *Acta Mater*. **44,** 2737–2749 (1996).