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IN-SITU INVESTIGATION OF ION IMPLANTATION EFFECTS OF RADIATION-
INDUCED SEGREGATION IN Ni-Al ALLOYS

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IN-SITU INVESTIGATION OF ION IMPLANTATION EFFECTS ON RADIATION-INDUCED SEGREGATION IN Ni-AL ALLOYS

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In-situ experiments using the HVEM (high voltage electron microscope)/Tandem accelerator facility at Argonne National Laboratory were performed to determine the effects of 400-keV Zr⁺ and 75-keV Ne⁺ implantation on electron radiation-induced segregation (RIS) in Ni-9at.%Al at 550°C and 450°C, respectively. The alteration of RIS kinetics by Ne implantation was studied at two different doses. A highly-focused 900-keV electron beam, which produces a radial defect flux away from the beam center, was used to induce segregation of Al atoms in the opposite direction via the inverse-Kirkendall effect. Within the irradiated zone, Al enrichment drives the formation of γ' -Ni₃Al precipitates, and the radial segregation rate of Al was monitored by measuring the growth of the precipitate zone.

When a thin film is subject to a focused, electron beam, a non uniform defect distribution is produced [1]. The effective beam diameter, D_0 , is defined by $I_T = I_0(\pi D_0/2)^2$ where I_T is the total electron current and I_0 is the peak electron flux. For a beam with a Gaussian profile, D_0 is related to the standard deviation, σ , by $D_0 = 2\sqrt{2} \sigma$. Previous HVEM irradiations in Ni-Al alloys [1-5] have shown the segregation of Al against the vacancy flux, resulting in Al enrichment at the beam center. When the solubility limit is reached, nucleation and subsequent growth of a γ' -Ni₃Al zone occur, which provides a direct measure of the segregation rate.

Two types of irradiation were conducted: (i) electrons only and (ii) ion implantation followed by electron irradiation. In case (ii), small γ' -Ni₃Al zones were pre-formed by electron irradiation before ion implantation to act as reference markers during and after ion bombardment. The ion energies were chosen so that all incident ions were implanted in the observation zone (1800Å). The electron beams in this investigation were elliptical in nature and, therefore, assumed to possess a bi-gaussian shape described by $I(x,y) = I_0 \exp\{-(x/a_0)^2 - (y/b_0)^2\}$ where $a_0 = \sqrt{2} \sigma_a$ and $b_0 = \sqrt{2} \sigma_b$ (σ_a and σ_b are defined as the standard deviation of the beam profile along the major and minor axes, respectively). The dimensions of the precipitate zones were normalized to a_0 and b_0 along these axes and can thus be displayed on the same scale.

Typical micrographs of γ' -Ni₃Al zones in both (i) and (ii) types of irradiation are given in Figure 1. The effect of 400-keV Zr⁺ implantation on RIS at 550°C is demonstrated in Figure 2. After Zr implantation to a dose of 10^{15} Zr/cm², γ' -Ni₃Al precipitate growth was similar to the standard irradiation with electrons only. The effects of 2.5 and 4.2×10^{15} Ne/cm² on Al segregation are shown in Figure 3, and the results indicate that increasing Ne implantation fluence results in decreased γ' -Ni₃Al precipitate growth.

It has been previously reported that Zr, much like Ti, acts as a strong vacancy trapping site in the reduction of void swelling in austenitic stainless steels [6,7]. The results from Zr implantation here contradict the suggestion that it acts as a strong vacancy trapping site, since the radial segregation of Al was not changed by the presence of 10^{15} Zr/cm². Hence, an undetermined mechanism may be responsible for the suppression of void swelling in Zr doped steels. The presence of Ne in Ni-9at.%Al, on the other hand, altered RIS kinetics, gradually reducing the precipitate growth with increasing Ne implantation dose. This effect suggests that Ne atoms may act as strong defect trapping sites, reducing the number of defects free to participate in RIS.

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Fig. 1a γ -Ni₃Al zone after electron irradiation at 550°C to 2.18 dpa.

Fig. 1b γ -Ni₃Al zone after implantation of 10^{15} Zr/cm² and electron irradiation at 550°C to 1.67 dpa.

Fig. 2 γ -Ni₃Al growth curves for 900-keV electron and pre-implanted 400-keV Zr⁺ ion/900-keV electron irradiations at 550°C. Peak electron damage rates ranged from 5.68 - 7.24×10^{-4} dpa/s.

Fig. 3 γ -Ni₃Al growth curves for 900-keV electron and pre-implanted 75-keV Ne⁺ ion/900-keV electron irradiations at 450°C. Peak electron damage rates ranged from 5.68 - 6.03×10^{-4} dpa/s.