The effect of low-energy Ar^+ ion irradiation parameters on the structure and properties of Ni/Cu/Cr thin films

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Introduction

Ion bombardment is a widely used tool for the modification of crystalline structure and defectiveness, surface roughness, stress state, phase and chemical composition, optical and mechanical properties of thin solid films. The application of low-energy ion beams (<3 keV) is also widely employed for ion etching in various experimental techniques of surface analysis such as AES, SIMS, and XPS.

By varying the parameters of ion beam in the low-energy interval, it becomes possible to control effectively different properties of deposited layers. In our recent study we reported that some low-energy ion modes provide reduction of impurities amount through the whole Ni/Cu/Cr thin film stack without diffusion intermixing between main components [1]. Effect of O and C impurity atoms removal through the whole depth of Ni/Cu/Cr layer stack after several modes of low-energy ion-plasma treatment was also revealed earlier in [2].

In present study, the influence of such parameters as irradiation energy (400-1400 eV), ion beam current density (4-8.5 mkA/cm^2) and treatment duration (20-40 minutes) on the development of oxidation-reduction processes, impurity and structural effects is investigated in layered Ni/Cu/Cr films.

Methods and Objects

Ni/Cu/Cr trilayers with 25 nm thickness of each layer were deposited by dc magnetron sputtering at RT from high-purity Ni (99.995 at.%), Cu (99.99 at.%) and Cr (99.95 at.%) targets onto Si(001) single-crystal substrates. Low-energy ion bombardment of thin films was performed on OMI-0010 ion source with various beam parameters: irradiation energy (400-1400 eV), ion beam current density (4-8.5 mkA/cm2) and treatment duration (20-40 minutes).

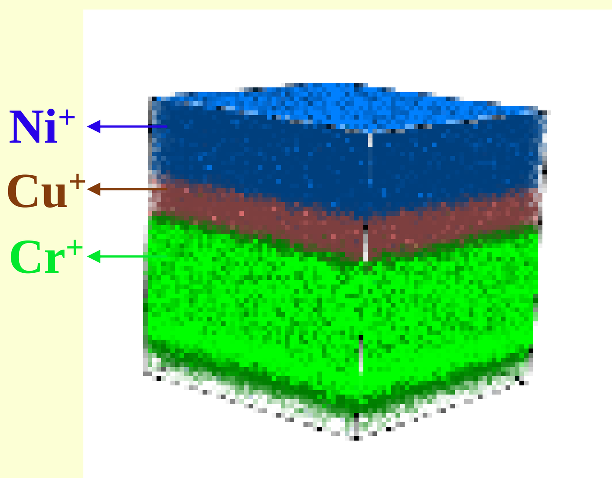
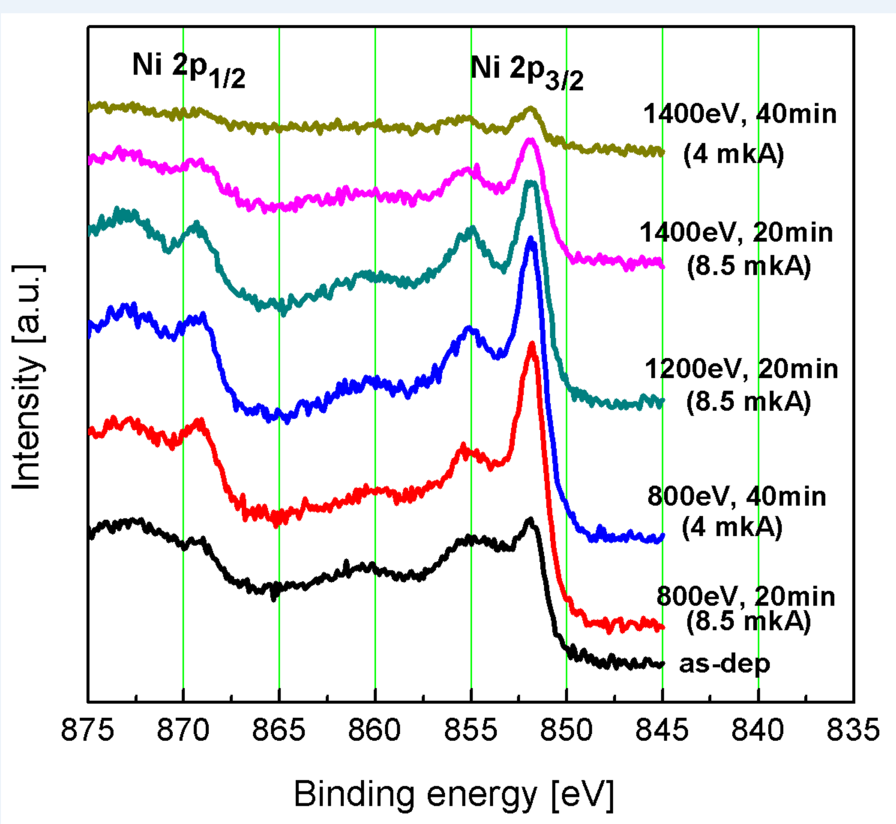


Figure 1. 3D visualization of SIMS analysis of secondary ions distribution in the as-deposited Ni/Cu/Cr trilayer.

Modification of the films under various ion bombardment parameters was studied by synchrotron radiation X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES) and scanning electron microscopy (SEM).

Results



It is established, that the competition of two processes on surface: (a) re-deposition and (b) sputtering of atoms determines the final properties and composition, depending on the ionic current density.

Figure 2. XPS surface spectra of Ni/Cu/Cr trilayers in as-deposited state and after various irradiation modes..

Results

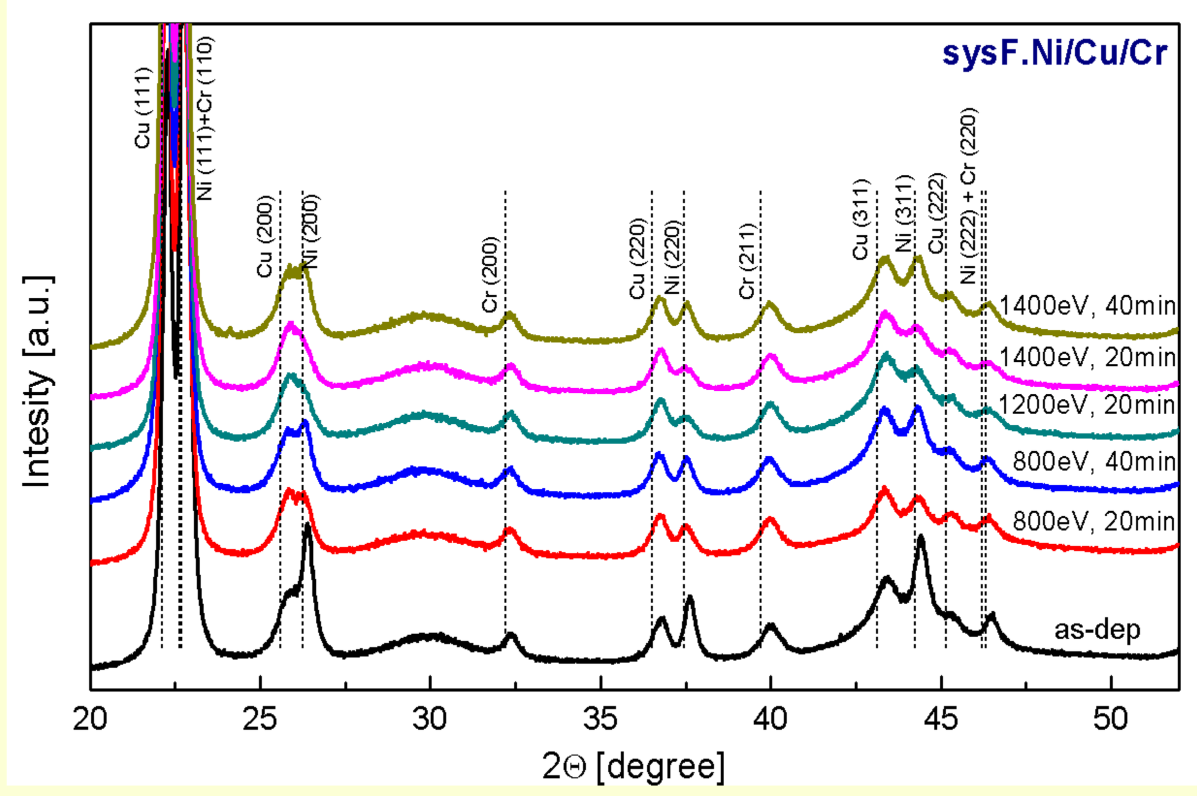
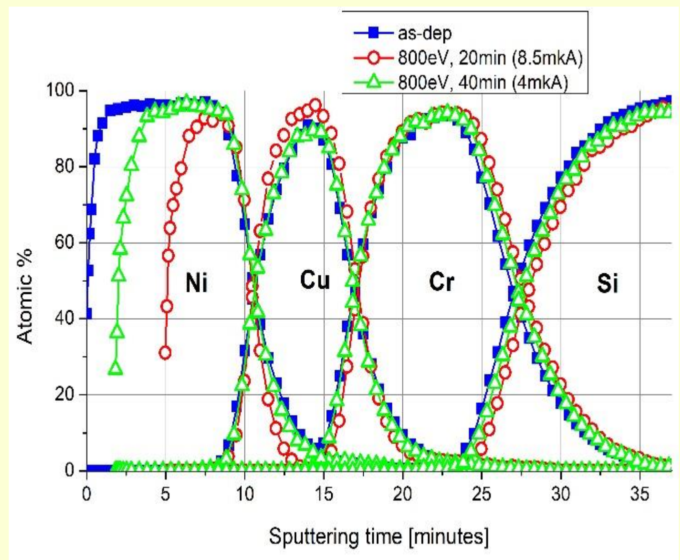


Figure 3. GIWAXS scans obtained from Ni/Cu/Cr trilayers in as-deposited state and after io irradiation with different ion beam parameters.



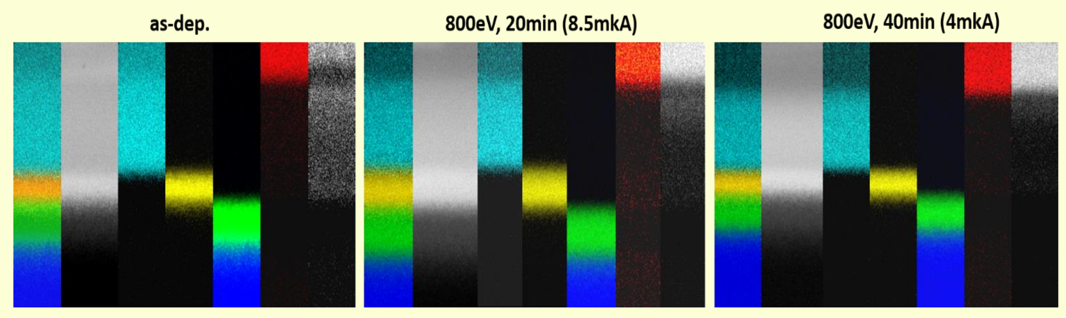


Figure 4. AES profiling data (left) and chemical maps in Auger electrons (right) of Ni/Cu/Cr trilayer in as-deposited state and after ion irradiation with two different modes at 800eV beam energy.

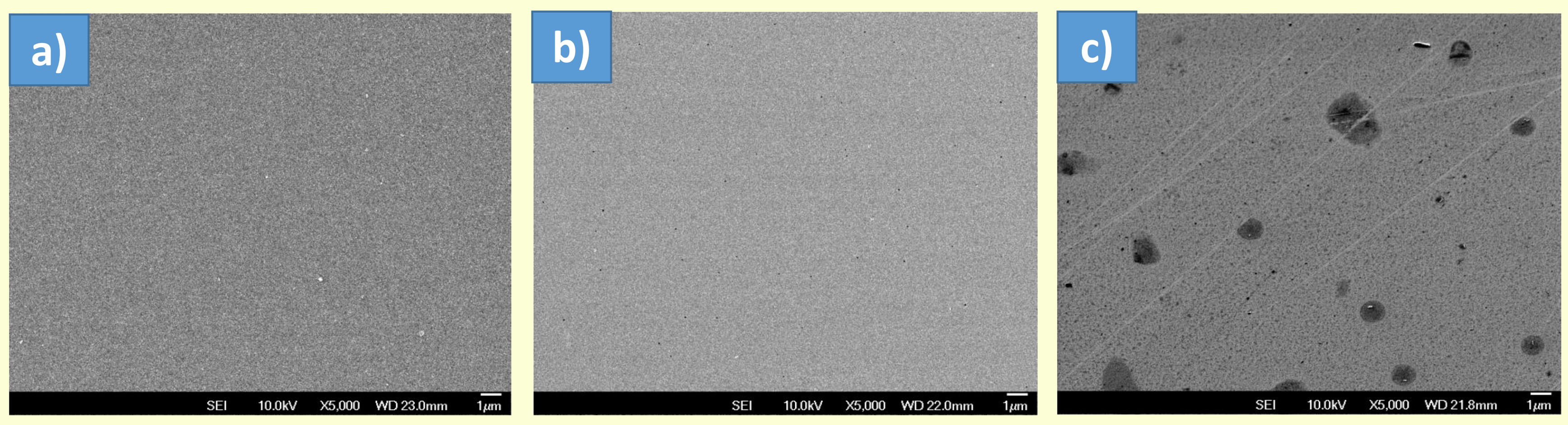


Figure 4. SEM images of the Ni/Cu/Cr trilayer surface after deposition (a), after ion irradiation with 800 eV (b) and 1400 eV energy.

Conclusions

The competition of re-deposition and sputtering of surface atoms determines the final properties, depending on the ionic current density. Re-deposition processes predominate when the lowest current density of 4 mkA/cm^2 is applied, even in case of the longest exposure, causing the formation of a non-conductive amorphous layer on the surface. Simultaneously, the saturation of the stack by impurities is observed, which significantly reduces the crystal structure perfection of Cu layer. However, when the ion current density is increased to 8.5 mkA/cm^2, the surface sputtering processes become dominant. As a result, the content of impurities, especially O, through the film depth is decreased due to the reduction of oxidized sublayers at the interfaces and grain boundaries. Additionally, increasing the beam energy over 1000 eV causes the formation of macrodefects clusters on the surface, which can negatively affect the functional and technological properties of the studied thin films.

Acknowledgment

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References

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[2] Kruhlov *et al.* Mater. Res. Express 6 (2019) 126431.

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