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# Radiation damage of Si wafers modified by means of thin layer ion assisted deposition

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**Abstract**

Development of the damage and structure of metal-based-film–Si structures' constructions formed by ion-beam-assisted deposition (IBAD) of thin films onto silicon, using a method in which the metal deposition is accompanied by bombardment by the same metal ions, is considered. The analysis was carried out using the RBS/channeling and TEM methods. The films are found to have uniform thickness, they are amorphous in the interface region and include low scale (~5–10 nm) inserts of metal. It is estimated that concentration of silicon atoms displaced during the IBAD process in the interface region decreases 1.7–3.7 times when a thin layer on the silicon wafer is deposited by physical evaporation before the IBAD process.


*Keywords:* Self-ion assisted deposition; Silicon; Deposited energy density; Thin film



## 1. Introduction

Transition and refractory metal–silicon interactions using the ion-beam techniques have been investigated intensively for the last 15 years because of their great importance for fabrication of semiconductor devices [1,2]. Ion-beam-assisted deposition (IBAD) of metal layers is a promising method for silicide creation because it enables us to perform silicidation directly in a single metal deposition step. The silicidation reaction in this situation, can be considered as a thermal activated process because of the effect of thermal spikes, which is associated with the microscopic temperature within a collision cascade of about 1500–2000 K [3].

In our work, we have fabricated the Me–Si structures by self-ion-assisted deposition (SIAD), and have investigated intermixing of components in the interface region between silicon and metal phases and the structure of the modified surface. It is known that various effects (e.g. ballistic mixing, radiation enhanced diffusion, thermal

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spike effects, chemical reactions, sputtering) may contribute to the rate of Me–Si interaction [4–7]; therefore, we investigated the dependence of Me–Si interaction on the SIAD process parameters. We have examined the influence of energy density deposited in the collision cascade (DED) and the procedure of Me–Si structure preparation on intermixing of components, to clarify the role of the above-mentioned processes in the desired structure construction.

## 2. Experimental techniques

Cobalt, zirconium, molybdenum and tungsten layers were deposited on (1 0 0)-oriented silicon wafers by means of SIAD. Deposition experiments were performed using a resonance vacuum arc ion source. Such kind of ion source provides deposition of a thin metal film on a target with ion irradiation. But instead of noble gas ions that are usually used in IBAD, our technique made use of self-ion-irradiation condition. It means that irradiation is carried out using ions of the same species as those used for the deposition on the target. Thus, no noble gases are introduced into the target. The second salient feature of the SIAD method is the increase of the DED under the influence of often heavier than argon metal ions up to 10 or even more electronvolt per atom inside the collision cascade.

The vacuum in the target chamber was about $10^{-2}$ Pa during SIAD of a thin metal film on the silicon. Silicon samples were floated to a negative potential with respect to the source of 5, 7, 15, 20 kV to accelerate the ion species. Thin film deposition rates were between 0.4 and 1.9 nm/min; ion/atom ratios were between 0.02–0.45. Sigmund's approximation [8] was used for the estimation of the DED in the ion beam mixing (IBM) experiments.

The Rutherford backscattering/channeling (RBS/C) technique was employed for the investigation of the target composition and for the study of silicon structure damage. The energy of $He^+$ ions was 1.5 MeV, the scattering angle $\Theta = 110°$, and the angles of the entry and escape were $\Theta_1 = 0°$ and $\Theta_2 = 70°$, correspondingly. The energy resolution of the analyzing system was 15 keV. TEM analysis was performed on a JEOL 3010 electron microscope, and applied to the samples prepared by hand tools using a small angle cleavage technique [9].

## 3. Results and discussion

RBS/C spectra of W-deposited and ion-irradiated samples are shown in Fig. 1. The level of the residual damage in the SIAD-treated samples was extracted from the aligned spectra of backscattered ions number 1–4. Since ions that are channeled can only be scattered by atoms that are displaced from the lattice site, the aligned spectra essentially replicate the profile of the interstitially displaced atoms (we neglect a flux peaking effect for two reasons: firstly, very thin layers are analyzed, and secondly, sufficient severely damaged crystals are investigated). Increase in the yield in the aligned spectrum corresponds to an increase in the damage or the number of displaced atoms. In our experiment, we observe that the damage increases with the accelerating voltage from 7 to 20 kV, (curves 1–3 in Fig. 1). This fact could be expected, but the most peculiar phenomenon observed here is the increase of yield of the aligned spectra behind the damage peak under the influence of ion energy,

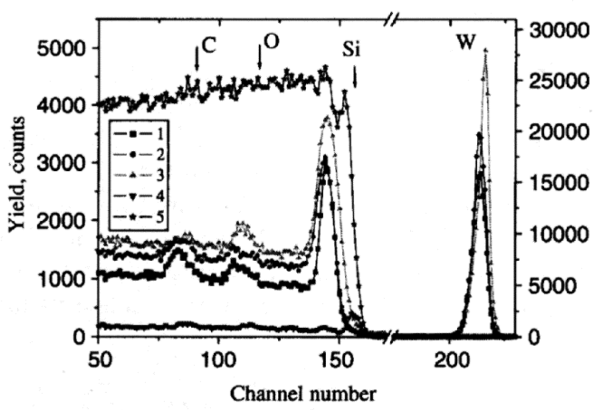


Fig. 1. RBS/C spectra of W–(1 0 0) Si samples constructed by means of SIAD at accelerating voltages: 1—7 kV, 2—15 kV, 3—20 kV, 4—virgin Si, 5—random Si.

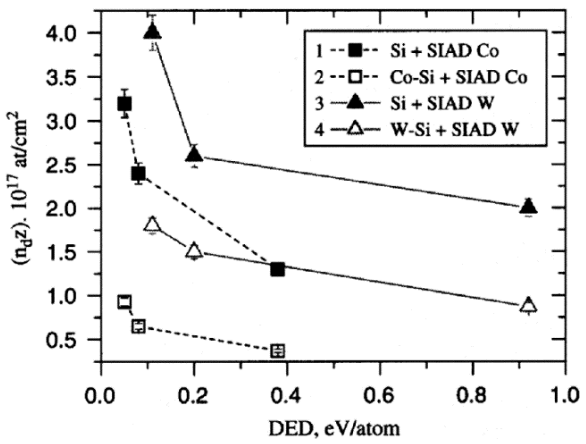


Fig. 2. Defect concentration in metal–(Si with a thin film) and metal–Si structures constructed by means of SIAD in dependence on DED.

leading to an increase of the dechanneling rate as a function of the DED. This suggests that different types of damage in silicon can be created so that the lattice strain produced by these defects can have influence on the rate of dechanneling. The damage in the RBS/C spectra reflects the fact, that the structure of silicon is damaged only in an initial instant of time of modifying of a Si sample, when the thickness of a deposit film is less than the projective range of assisting ions in a coating material. It is observed that a level of the dechanneling rate behind the damage peak increases with the energy of $W^+$ ions and decreases with the energy of $Co^+$ and $Mo^+$ ions.

It is revealed that defect concentration in the metal–Si structures depends on DED. Fig. 2 shows that the SIAD coats on the thin film evaporated previously on silicon by physical deposition, are characterized by low concentrations of defects in silicon, which decreases 1.7–3.7 times as compared with only the SIAD process. This means the vacuum deposition of a thin film on silicon masks its surface, and the structure of silicon is damaged less on further modifying the sample by means of SIAD.

In Fig. 3, the structure of Zr coating deposited on wafer (1 0 0) Si using the SIAD technique is demonstrated. The defects in silicon (Fig. 3a) near the thin film and Si substrate interface are

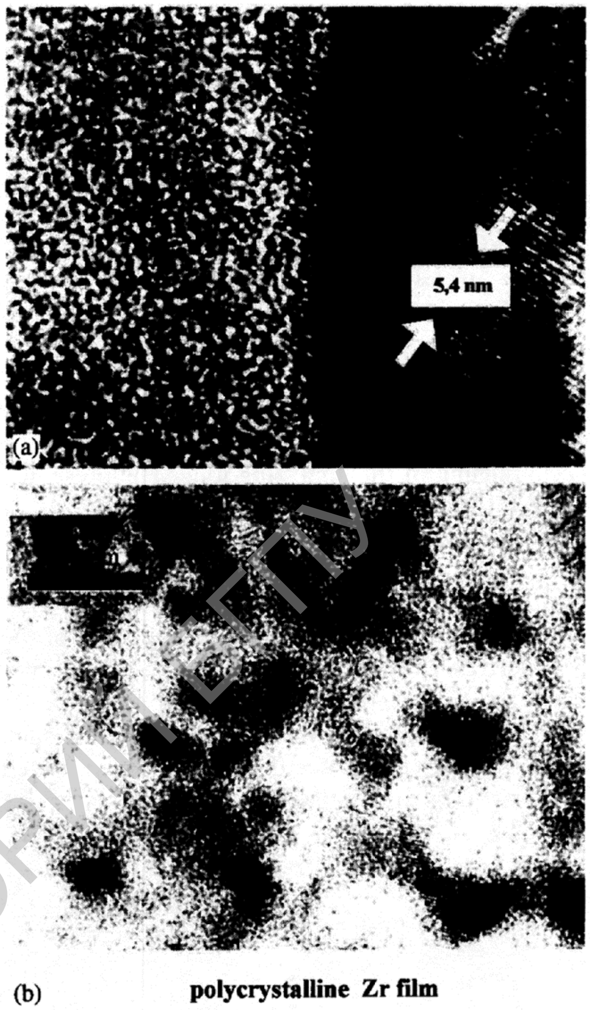


Fig. 3. TEM cross section of (1 0 0) Si sample with SIAD constructed Zr–Si structure; accelerating voltage of 5 kV. (a) Image of the interface area of the Zr film and Si substrate; (b) image of the central area of the film.

generated by irradiation of (1 0 0) Si wafer with $Zr^+$ ions at the initial stage of the coating deposition. The change in contrast near the boundary between the substrate and coating, Fig. 3a, results from intermixing of components causing elastic stress in the silicon. The structure of the coating comprises an amorphous layer of 12–15 nm thickness near the Si interface and a layer containing polycrystalline regions of Zr of 5–10 nm size, Fig. 3b. The density of the low-scale Zr inserts is estimated as $\sim 1.7 \times 10^{15}\,m^{-2}$.

## 4. Summary and conclusions

The influence of deposited energy density, and the procedure of metal coating deposition onto silicon using SIAD, on the damage of silicon structure has been investigated. Whereas the thickness of metal–Si intermixed layers increases with the increase of the DED, the damage or the amount of displaced atoms in silicon decreases. The silicide formation model using thermal spike, which activates the atom mixing processes, suggests that vacancy clusters or dislocation loops are nucleated within a high-density cascade of atomic collisions. That must lead to the increase of the dechanneling of the analyzing ions. The presented experimental data confirm the important role of cascade effects in the processes of atomic mixing and damage formation. It has been established by means of Rutherford backscattering in combination with channeling, that the concentration of the displaced silicon atoms decreases 1.7–3.7 times when the SIAD process is applied to the samples with a previously evaporated thin film. In such circumstances, the lattice defects are concentrated in a very thin surface layer of substrate.

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