The application of energetic ions to modify the composition of multilayer components.

J. Verhoeven, M. Cilia and R. Schlatmann.
FOM Institute for Atomic and Molecular Physics, Kruislaan 407, 1098SJ Amsterdam, The Netherlands.

Energetic ions penetrating a solid lose their energy by nuclear interaction with one or more target atoms as well as by electronic excitation of the target atoms. Fundamental research revealed that ion beam mixing could not only be explained by ballistic effects, but that also thermodynamic and chemical effects play a role. These effects are expected to take place in the end of the cascade formation, when the average energy is smaller than 1 eV.

Our first experiments have been done on the Mo / Si system, where we intended to drive Mo into Si. After deposition by evaporation of an overlayer of 3 nm Mo on Si we removed the whole Mo overlayer by sputtering with 300 eV krypton ions. We expected the formation of a system with periodic graded diffractive index. However, from x-ray reflection and TEM we learned that one period consisted of 4 nm Si and 2 nm Mo_5Si_3. It is striking that the silicide layer thickness coincides with the penetration depth of the ions. Removing of a 7 nm Mo overlayer on a 20 nm Si layer by 800 eV krypton ions resulted in a residual silicide layer thickness of ≈ 3 nm. A preliminary explanation is based on a combination of chemical stabilisation and ballistic driving of molybdenum that has no chemical binding with silicon. Subsequent sputtering of the Mo_5Si_3 layer revealed that the overlayer thickness did not decrease linearly with the ion dose. According to our model the surface is enriched by molybdenum due to preferential sputtering of silicon. The excess of molybdenum is driven into the silicide layer and binds chemically with available free silicon at the interface. Even after removal of an extra 10 nm of the silicide layer a molybdenum concentration could still be observed by Auger Electron Spectroscopy.

We continued our experiments on the Ni / Si system, known to be chemical reactive. The experiments were directed to implantation of nitrogen into silicon to form Si_2N_3 as a spacer component and to intermixing nickel and silicon by energetic neon ions to form Ni_2Si as an absorber component. The reactivity of the system was clearly demonstrated by the formation of a 2 nm thick intermix layer after deposition of Ni on a freshly deposited Si layer. A gradation of the nickel content as a function of depth was observed. Intermixing by 300 eV neon ions did not result in a homogeneous silicide layer as observed for the Mo / Si combination. Deposition of silicon on top of a freshly deposited nickel layer resulted in an intermixed layer of only ≈ .5 nm. Neon ions of 300 eV induced considerable intermixing over a layer of > 2 nm.

A pre-treatment of a silicon layer by 300 eV nitrogen ions followed by deposition of a nickel overlayer revealed only the formation of an intermixed layer < .3 nm. The resulting problem to solve was whether implantation of nitrogen would cause further damage to the interface with nickel underneath. Auger Electron Spectroscopy suggested that the thickness (.5 nm) of the initial intermixed layer did not increase. From cross section TEM it became clear that extra intermixing did occur. We finally produced a stable ML system by combination of implantation by nitrogen into silicon and intermixing an overlayer of silicon on nickel by 300 eV neon ions. Cross section TEM revealed the formation of homogeneous intermixed layers with sharp interfaces. However, according to x-ray reflectivity simulations the system corresponded to a combination of NiSi / Si_2N with interface roughnesses of ≈ .3 nm. Errors in the period thickness were mainly to blame for deviation of the expected reflectivity.

It should be emphasised that all these processes of intermixing and implantation's included smoothing of surfaces.

We can conclude that we have demonstrated the possibility to use energetic ions to modify the composition of the components of a multilayer system. For a better control of the composition more fundamental experiments are required.