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Analytical Services & Consulting

LEIS Characterisation of Diffusion Barriers

TAS-AN-L2E

Moore's law predicts that in the near future diffusion barrier layers in semiconductor devices will be measured in atomic layers rather than in nanometers. This development is leading to a gradual replacement of traditionally used deposition methods, like physical vapour deposition (PVD) or chemical vapour deposition (CVD), by atomic layer deposition (ALD). This is due to the excellent thickness control and layer uniformity that ALD provides. The closeness and homogeneity of dielectric films or diffusion barriers produced by ALD is essential for the quality of the final device. Low Energy Ion Scattering (LEIS) has developed into an indispensable tool for the characterisation and optimisation of ALD processes introduced in the 45 and 32 nm node technology.

In LEIS, the sample surface is bombarded with noble gas ions of some keV energy. Due to scattering with top surface atoms a specific energy loss of the projectiles is observed that allows a quantitative determination of the elemental surface composition. Additionally, information on the layer thickness can be gained when projectiles undergo scatter processes in the subsurface.[1]

These unique properties make LEIS an ideal tool for the analysis of ALD processes. It can be used to determine the growth rate even for the first ALD cycle, to minimise the number of cycles for a pin hole-free layer closure and to evaluate the thickness variation within a deposited film.

In a project with ASM, a specialist in ALD, LEIS has been used to control the deposition process in order to grow a pin hole-free ultrathin WN_xC_y layer on silicon. Some spectra from a series of LEIS spectra obtained after different numbers of reaction cycles are given in figure 1.

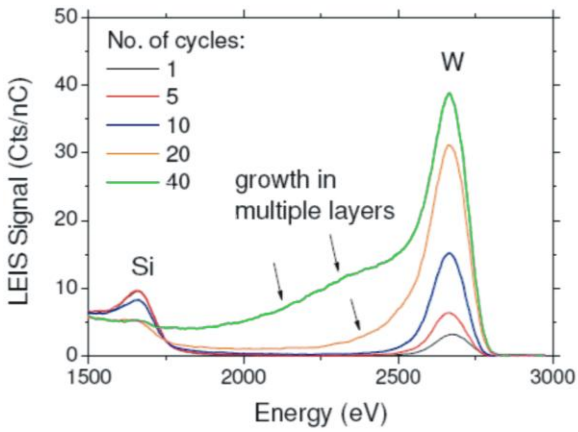

Figure 1: LEIS spectra for WN_xC_y layers grown with various numbers of reaction cycles. [1]

The areas of the detected peaks can be used to derive their atomic concentrations in the outermost atomic layer. After a number of cycles the W peak develops a low energy tail. This results from the growth of multiple layers. The intensity and width of the tail is a direct measure for the thickness distribution of the WN_xC_y layer. The asymmetry of the W peak becomes clearly visible between the 10^{th} and 20^{th} cycle. This indicates that a significant fraction of the surface is covered by multiple layers (islands) henceforward. This island formation appears long before full monolayer coverage with WN_xC_y is reached, because even after 40 ALD cycles a weak Si surface signal is observed. In addition, the surface fraction of W is still increasing between 20 and 40 cycles, as can be seen from the increase in the W peak intensity. Figure 2 shows a schematic of the film growth as derived from the LEIS experiments.

For the used process conditions the WN_xC_y layer thickness after 40 cycles can be calculated from the peak shape to vary between 0 and 3 nm (see figures 1 and 2). A detailed evaluation of the Si and W surface coverage derived from the data is presented in figure 3. The rate at which the substrate is covered can be followed precisely. For instance it can be seen that the WN_xC_y surface coverage after 40 cycles is 93 %.

[1] For more details about LEIS see our Technical notes.

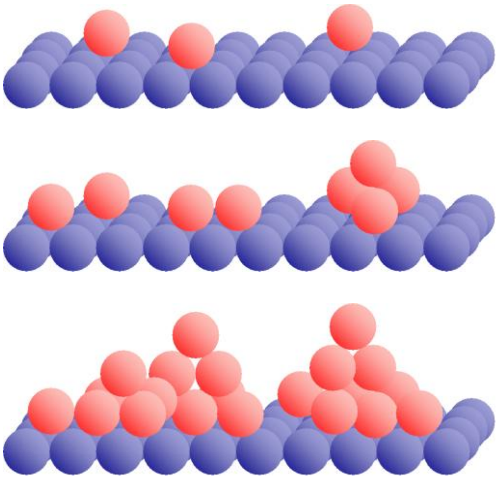

Figure 2: Principle of island formation corresponding to 1 (top), 20 (middle) and 40 (bottom) ALD cycles.

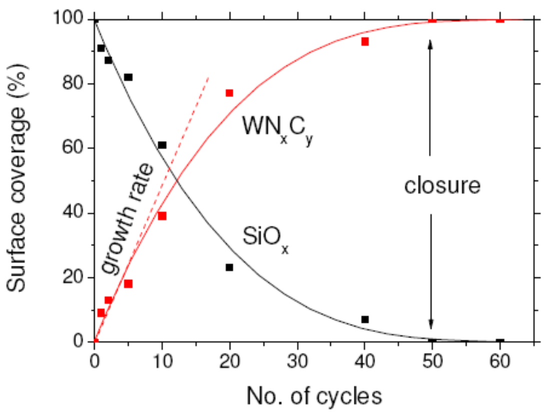

Figure 3: WN_xC_y and SiO_x coverage as a function of the number of reaction cycles.

For the applied process conditions a layer growth of 0.08 nm per ALD cycle can be observed once the coverage is complete. After 50 cycles of WN_xC_y deposition the Si peak has disappeared completely, while the W peak has reached its maximum. This indicates that the silica is covered with a complete, pin hole-free WN_xC_y layer.

The analytical results indicate that the studied ALD processes are already suited to obtain effective diffusion barriers for the 45 nm node technology.

For more information on LEIS studies on ALD systems see:

- LEIS study of ALD WN_xC_y growth on dielectric layers, M.S.H. Stokhof et al., 208th ECS Meeting, October 16 – 21, 2005. Los Angeles, CA, USA; published in ECS Transactions 1 (2006), 10, p.71 - 77.
- Atomic layer deposition of hafnium oxide on germanium substrates, A. Delabie et al., J. Appl. Phys. 97 (2005), p. 64104-110.