Center for surface analytical services

Application note

Process and quality control by HS-LEIS when growing ultra-thin diffusion barriers.

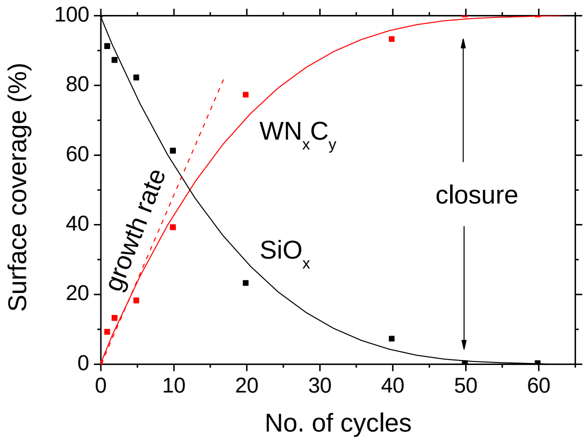
- Determination of the growth rate already for 1st cycle
- Minimization of the number of cycles for layer closure (pinhole free)
- Evaluation of the thickness variation.

Introduction

Moore's law predicts that in the near future barrier layers in semiconductor devices have to be measured in atomic layers rather than in nanometers. Atomic Layer Deposition (ALD) can be used to grow such layers, but device quality is critically dependent on whether the layers are pinhole-free. Only LEIS is capable of providing both chemical and thickness information in a single measurement for the top atomic layer. This note explains that LEIS will be an indispensable tool for process - and quality control when ALD is introduced in the 45- and 32 nm nodes in the semiconductor industry.

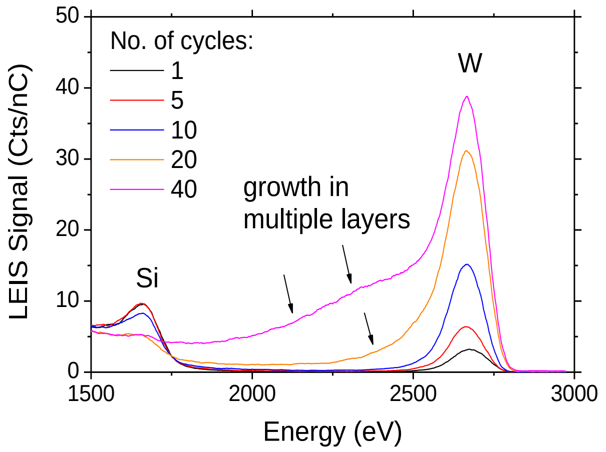
Growth of pinhole-free barrier layers

In a project with ASM, a specialist in ALD, LEIS has been used to control the deposition process in order to grow a pinhole-free ultra thin WN_xC_y layers on silica. Since LEIS is sensitive to the outer atomic layer it provides a direct figure for the surface coverage by WN_xC_y.



The figure shows how the WN_xC_y and SiO_x coverages increase and decrease, respectively, with increasing number of reaction cycles.

The sensitivity of the Calipso LEIS makes it already possible to quantitatively determine the WN_xC_y coverage after the first cycle. The rate at which the substrate is covered can be followed precisely. At 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 WN_xC_y layer is closed. The surface is covered with at least one monolayer of WN_xC_y.



The figure shows the LEIS spectra for WN_xC_y layers grown with various numbers of reaction cycles.

The peaks in the spectra give the 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 are a direct measure for the thickness distribution of the WN_xC_y layer. Since the asymmetry of the W peak becomes clearly visible between the 10th and 20th cycle, this indicates that, from that point on, a significant fraction of the surface becomes covered by multiple layers (islands). This is long before full coverage is reached.

For the used process conditions the thickness variation after 40 cycles is 0 – 3 nm, while the WN_xC_y coverage is 93 %. Once the coverage is complete, the layer grows with 0.08 nm/cycle. This demonstrates that the process parameters are already suited to obtain effective diffusion barriers for the 45 nm node. Further developments and more advanced applications seem possible.

Conclusion

Combination of LEIS and ALD yields a powerful method to deposit ultra thin, homogeneous barrier layers for future generations of semiconductor devices. With LEIS we have been able to measure both the initial growth rate and the moment of complete closure of the barrier layer, a critical parameter in the deposition process control. We have demonstrated that LEIS is not only suited to contribute to optimizing process parameters during the development phase but also to determine device quality at the production stage.

For more information on LEIS studies on ALD-systems:

- LEIS study on ALD of WN_xC_y growth on dielectric layers, M.S.H. Stokhof, W.-M. Li, M. de Ridder, H. Sprey, S. Haukka, H.H. Brongersma, 208th ECS Meeting, October 16 – 21, 2005. Los Angeles, CA, USA. To be published: Journal of Electrochemical Society, April 2006.
- Atomic layer deposition of hafnium oxide on germanium substrates, A. Delabie, R.L. Puurunen, B. Brijs, M. Caymax, T. Conard, O. Richard, W. Vandervorst, C. Zhao, M.M. Heyns, M. Meuris, M.M. Viitanen, H.H. Brongersma and M. de Ridder, L.V. Goncharova, E. Garfunkel, T. Gustafsson, W. Tsai, J. Appl. Phys. **97** (2005) 64104-1-10