High Precision Thin Metal Film Measurement by Optical Transmission

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ABSTRACT

Recent development of new products has given rise to stringent requirements for precision deposition control of thin metal films. Our enhancement mode (E-mode) pHEMT devices require a very thin layer of platinum (Pt) in the range of 25A to 200A to form the base of our gate metal. Furthermore, the ohmic metal needs to have each of the constituent layers deposited precisely. Successful transfer of the process from a development evaporator to multiple production tools demands the metal stacks to be duplicated as authentically as possible. In these applications, a thickness variation of as little as 5A will result in detectable device performance shift and probe yield loss. A typical E-beam evaporator employs a crystal monitor for deposition control and the film thickness is measured using a profilometer. The accuracy of the step height measurement diminishes with decreasing thickness below about 300A. It has become clear that a new metrology technique is needed to quantify film thickness in the tens of Angstroms range. This paper described how we applied optical transmission to measure thin metal films. The optical technique enabled us to match the coating thickness of two evaporators to within 3A. FIB/STEM analysis and electrical parametric data confirmed the accuracy of the final thickness. The procedure described in this paper has facilitated quick development of the deposition process and ensured a prompt transition to production.

INTRODUCTION

The profilometer is the most commonly used metrology tool for measuring metal film thickness. It is favored by most semiconductor fabrication facilities. The instrument utilizes a stylus that travels over a metal film step on a substrate. The stylus movement is transferred to a Linear Variable Differential Transformer (LVDT) or a variable capacitor calibrated to produce a precise step height reading. Being a physical measurement, the result is influenced by many factors. When measuring a very thin film on the order of tens of Angstroms, the profilometer has reached the precision limit as the measurement is increasingly drowned out by noise due to substrate roughness and other factors.

Deposition of a typical production evaporator is controlled by a crystal monitor. The tooling factor for each material is expressed in percentage by comparing the crystal monitor reading against the actual measured film thickness.

The limitation of the profilometer is not an issue until we have to transfer the E-mode product to production tools. Despite our meticulous effort to calibrate the tooling factors, there was always a parametric difference between different tools. Any delay in the opening or closing of the evaporator shutter will change the final film thickness by up to a few tens of Angstroms. These variations will not be captured or detected in the standard tooling factor calibration process.

Our E-mode pHEMT employs a platinum buried gate to fulfill the positive threshold needed for a normally off state operation. Data have shown that device threshold voltage (V_t) could vary by 60mV with a 5A change in Pt thickness. Typical E-mode device has a V_t in the range of 0.15V to 0.40V. 60mV is, therefore, a considerable variation and will affect V_t control. In order to have consistent probe yield, the production deposition tools must be able to control better than tens of Angstroms and we need to have a metrology technique to resolve film thickness close to one atomic layer (~2.7A).

A Woollam Alpha SE ellipsometer, which can operate in transmission mode, was used for this work. We use soda lime glass 620um thick cut into 100mm semi-standard wafer dimension. A jig is machined to hold the glass wafer vertically during measurement so that the light beam incident angle is at 90 degrees to the wafer.

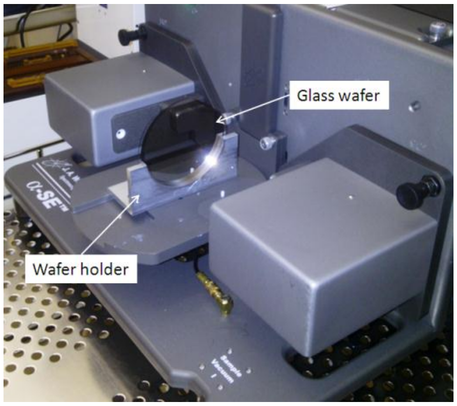

Figure 1 Woollam Alpha SE in transmission mode with wafer holder

Our tooling factor calibration procedure involved many 2000A run on blank wafers. After each run, the wafer was measured at 15 sites. Tooling factor was adjusted based on the measured film thickness using equation [1].

Tooling factor = measured thickness / crystal monitor thickness x old tooling factor

Once the tooling factor calibration was completed, a 50A nickel film was deposited in both the development tool and one of the production tools. Despite the fact that all the tools were meticulously calibrated using the same procedure, transmission measurement results showed a difference in the final thickness with the production tool having a higher thickness compared to the development tool. See fig 2.

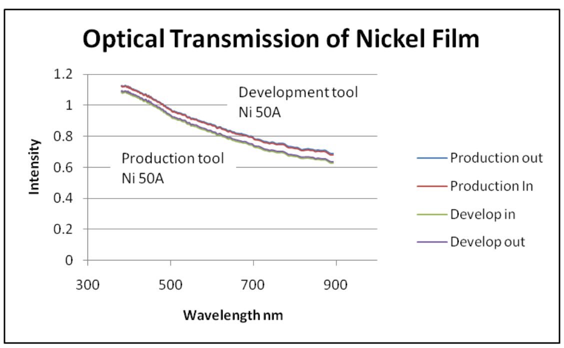

Figure 2 Optical transmission of Ni film (50A)

Based on the optical transmission spectra, we made a 3A reduction to the production tool and repeated the transmission measurement. The production tool transmission spectrum moved closer to the standard but it was not perfectly matching yet.

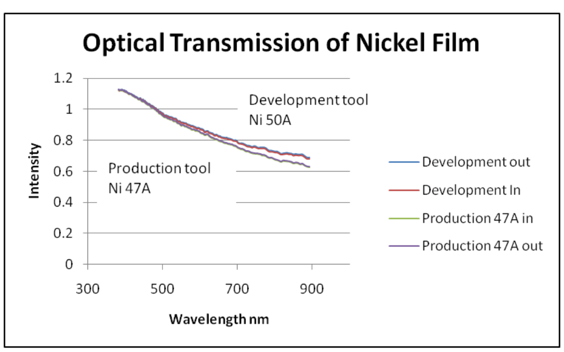

Figure 3 Optical transmission of Ni films (47A and 50A)

After studying the optical transmission data of the 50A and 47A films, we made another 3A adjustment to the production tool and the resulting spectra overlapped indicating perfect matching of the two tools.

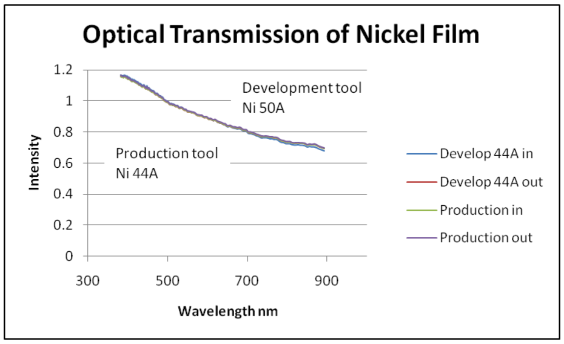

Figure 4 Optical transmission of 44A film in the production tool perfectly matching the development tool

CONCLUSION

Optical transmission is a precise metrology to measure thin metal films of up to about 1,000A thick. This technique fills the gap of standard profilometry where it is best suited to measure film thickness of greater than 1,000A. By combining these metrology techniques, we can match the thickness of production tools to the development tool to better than 3A.