Recent Developments in Real-Time Thickness Control of Plasma Deposited Thin Film Dielectrics Using Optical Emission Interferometry

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A key technical goal in III-V and III-N compound semiconductor manufacturing is to achieve and maintain consistent product device performance. Control of not only the composition of the constituent layers in these devices but also the thicknesses of the individual layers is one of several critical requirements necessary to meet this goal. This also applies to the Si-based dielectric films such as silicon nitride (SiN_x), silicon dioxide (SiO_2), and silicon oxynitride (SiO_yN_x) prepared by plasma-enhanced chemical vapor deposition (PECVD) that are incorporated into many of these device structures[1]. For both control purposes and device design rules, repeatable wafer-to-wafer film thickness within ±1 % of the target is often desired. Due to small but significant variations in the deposition rate of these films caused by short and long term fluctuations in process conditions, the fixed time deposition approach is not sufficient to reliably maintain control within this limit.

To overcome the limitations of the fixed time approach, we presented in a previous publication[2], a non-invasive automated technique to monitor in real-time the thickness of the depositing film and terminate, or endpoint, the process when the target thickness has been achieved. This technique is based on optical emission interferometry (OEI). The plasma emission reflected from the wafer is monitored through one of the gas introduction holes in the upper electrode of the PECVD reactor. As the film thickness increases, the reflected intensity undergoes a cyclical variation due to interference effects. The film thickness change for one complete cycle is known from the values of the wavelength and the refractive index of the film. The number of interference cycles, including fractional cycles is counted and the film thickness calculated in real time as the film is deposited.

The previously reported OEI technique is capable of reliable and repeatable control down to the minimum thickness that corresponds to the first full optical interference cycle. For a typical PECVD process using a strong N_2 plasma emission line at 337.1nm, this technique is capable of detecting and controlling processes for applications with SiN_x films greater than 800Å or SiO_2 films thicker than 1100Å. Unfortunately, for many compound semiconductor applications, there are requirements for films with thicknesses lower than these resolution limits. As an example, the SiN_x dielectric in metal-insulator-metal (MIM) capacitors is typically on the order of about 500Å. The capacitance and the film thickness are strongly interrelated. Therefore, in order to maintain necessary tight control of capacitance, tight control of thickness is also required. In this paper, we will present an extension of the OEI technique using a multi-wavelength approach to accurately target film thicknesses in this lower range. This approach exploits the presence of several additional N_2 plasma emission bands in the UV that are commonly present in all Si-based dielectric deposition plasmas.

To illustrate the advantage of the multi-wavelength approach, first consider the results presented in Figure 1 for the calculated SiN_x reflectance as a function of film thickness at different UV N_2 plasma emission wavelengths. At each of these wavelengths, there is a well-defined unique film thickness that occurs for each 1st reflectance minima. Therefore, by monitoring the reflected signal at these wavelengths during the deposition process, it is possible as shown by the experimental data for PECVD SiN_x presented in Figure 2 to determine precisely the thickness-time dependence for films in the 400 to 600Å regime. In the paper, repeatability data will also be presented on thickness control for a 500Å SiN_x film.

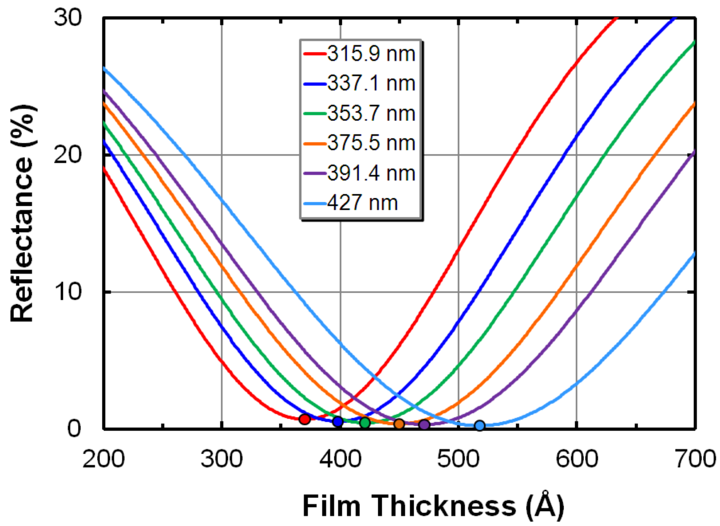

Figure 1. Calculated reflectance of a SiN_x film deposited on Si as function of film thickness at the indicated UV N_2 plasma emission wavelengths. The symbols, (●) denote the unique film thickness at each 1st reflectance minima.

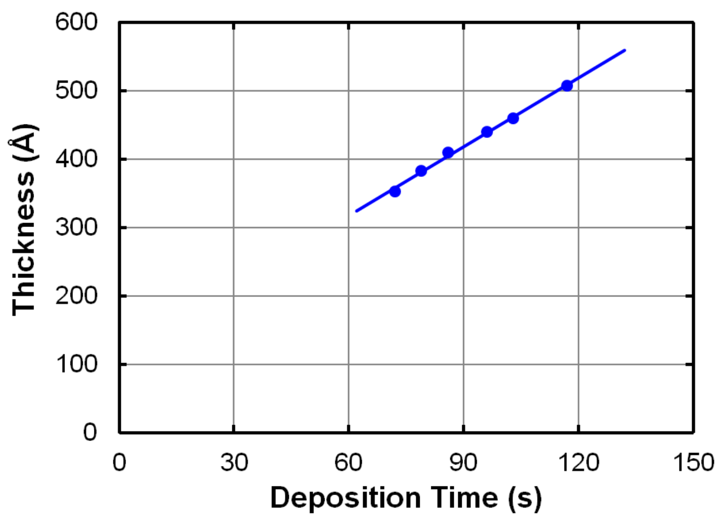

Figure 2. Measured PECVD SiN_x film thickness *versus* deposition time dependence derived from the location of 1st reflectance minima from the monitored multiple UV N_2 plasma emission bands.

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