Category Title:

Emissivity Correcting Pyrometry of Semiconductor Growth

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Motivation—Temperature is a critical factor in the growth of thin films by either chemical vapor deposition (CVD) or molecular beam epitaxy (MBE). It is particularly important in compound semiconductor growth because one is often challenged to grow materials with specific chemical compositions in order to maintain stringent lattice-matching conditions or to achieve specified bandgap values. Optical pyrometry can be used to measure surface temperatures, but the thin film growth causes significant changes in the emissivity of the surface, leading to severe errors in the pyrometer measurement. To avoid these errors, emissivity changes must be measured and appropriate corrections made to extract an accurate surface temperature.

Accomplishment—We have developed an emissivity-correcting pyrometer tool that is specifically tailored to accurately measure surface temperatures during compound semiconductor growth. The data collection and analysis software has been named Thermogrow. It is currently being licensed to an original equipment manufacturer (OEM) for sale to semiconductor thin film equipment vendors.

The Thermogrow emissivity-correcting pyrometer system can measure reflectance and thermal emission at two independent wavelengths. The reflectance data is used in two ways. First, it is used to correct for emissivity changes during growth, allowing one to extract surface temperatures with 1 °C precision throughout a thin-film deposition run. Second, the reflectance is used with a previously-developed Sandia tool – Analysis of Deposition using Virtual Interfaces and Spectroscopic Optical Reflectance (ADVISOR) to perform in situ thin film growth rate measurements. This provides a user with real-time information on temperature, growth rate and composition.

In applying the emissivity-correcting method to compound semiconductor growth, we found it necessary to measure and correct for other errors that are unique to each deposition system. At low emissivity values, the effects of detector offsets, reflectance drift, signal scaling errors, and stray thermal emission can lead to large temperature errors. As an example, during the growth of 850 nm mirrors, the pyrometer would produce 40 °C temperature artifact errors even when emissivity correction was used. We developed a way to account for all the above errors by devising an *in situ* calibration method. Analysis of the calibration run allows one to extract a single empirical parameter that accounts for all the unique errors of a particular deposition system. This parameter is employed in a slightly modified pyrometer algorithm to make artifact-free *in situ* surface temperature measurements during growth. Temperature precision is 1 to 3 °C, even in regions with low (< 20%) emissivity.

Significance—The Thermogrow pyrometer method has allowed semiconductor crystal growers to maintain accurate control of temperature for a variety of applications, increasing the yield of device production and enabling more complex device structures to be grown. It has proved to be particularly useful in low-nitrogen InGaAsN alloys where the bandgap is very sensitive to deposition temperature. A joint patent with EMCORE Corporation has been filed and the technology is being transferred to the commercial sector.

Sponsors for various phases of this work include: CRADA, BES

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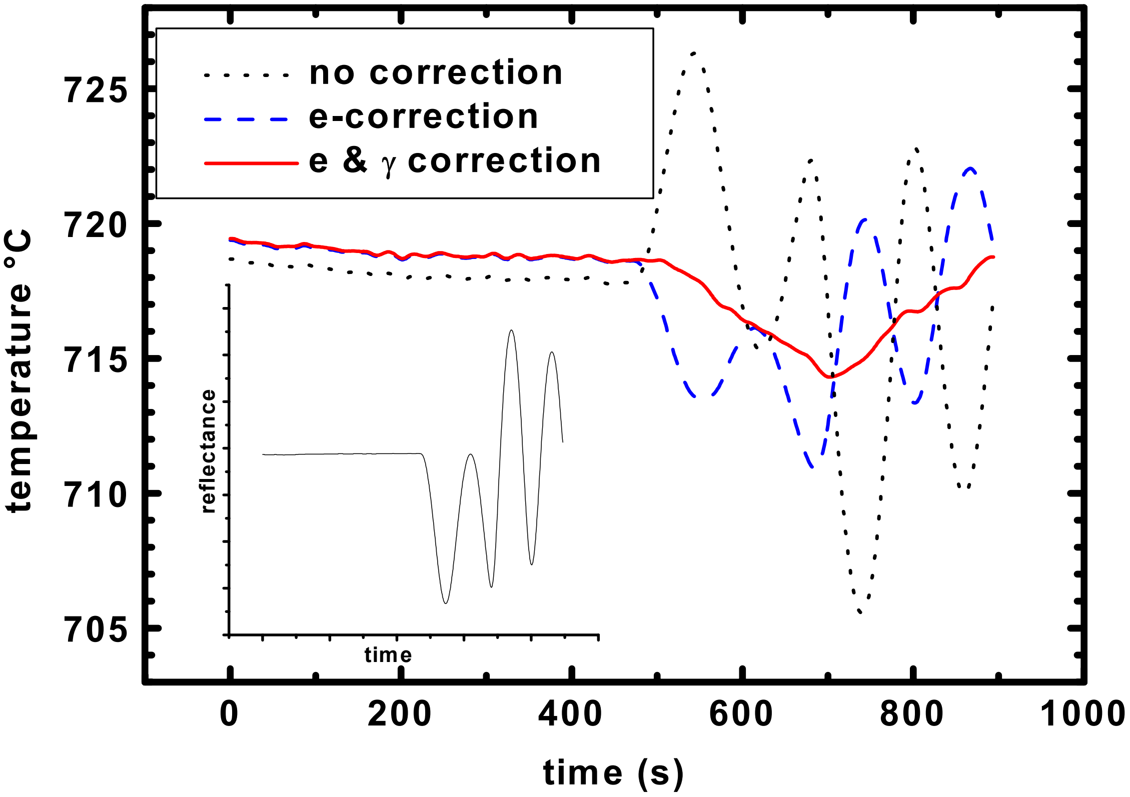

Example of the improvements in temperature measurement achieved by the Theromogrow method. The dotted curve shows the pyrometer temperature that is measured during the growth of an AlAs film followed by a GaAs film on a GaAs substrate. The large changes in reflectance from thin-film interference effects (shown in inset) cause large changes in the wafer emissivity. Compensating for the emissivity gives the dashed curve. Although the artifacts caused by emissivity changes are reduced, deposition-chamber specific factors lead to overcompensation errors. Thermogrow uses an *in situ* calibration method which measures a single empirical parameter that can correct for five deposition chamber errors. The result of this additional correction is shown with the solid curve. Subtle temperature changes caused by different materials on the wafer surface can now be resolved.