3. Surface Temperature Measurements

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Objective: To improve the accuracy of surface temperature measurements, with emphasis in the area of rapid thermal processing (RTP) of semiconductors.

Problem: The semiconductor manufacturing industry requires improved accuracy in measuring the temperature of silicon wafers during processing because accurate temperature measurements are critical to product quality and device performance. As a result, the industry has an uncertainty requirement of 2 °C at 1000 °C for RTP for the next generation of wafer patterning.

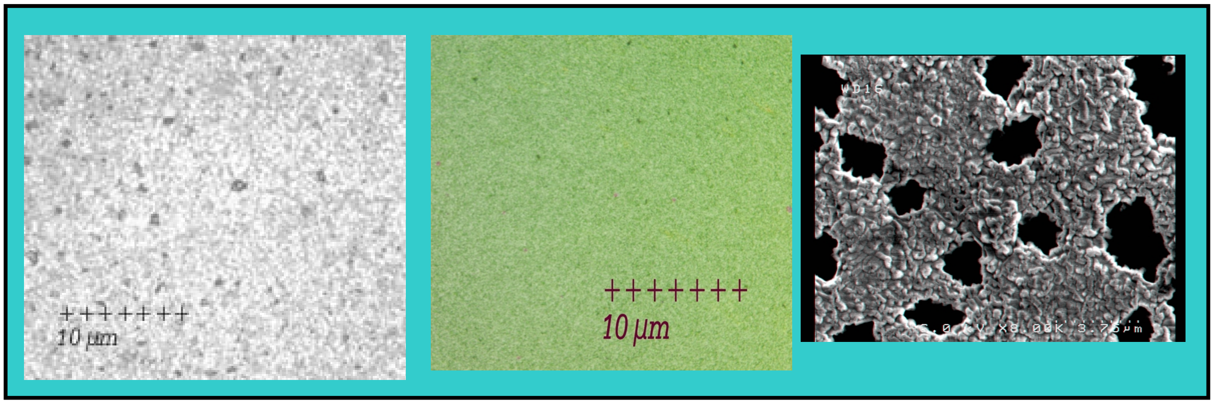
Approach: Light pipe radiation thermometers (LPRTs) are non-contacting and the sensor of choice in RTP. Thermocouple instrumented wafers are used to calibrate LPRTs in-situ. NIST efforts are based on combinations of stable thin-film and Pt/Pd wire thermocouples (TCs). The thin-film TCs (TFTCs) minimize errors from heat transfer present with other types of contact temperature sensors. This technique permits an expanded uncertainty of less that 1 °C when the wafer temperature is uniform to within 10 °C. Additionally, the effect of the environment of an LPRT on the temperature it measures was investigated to determine the proper procedure for calibrating an LPRT.

Results and future plans: In the past we have reported on TFTCs that were useful up to 900 °C, but problems of SiO_2 electrical conductivity, coalescence of the thin films, and oxidation of the films have precluded their use at 1000 °C. During FY00 we found solutions to those problems consistent with maintaining a standard uncertainty target of 0.4 °C for the surface temperature measurement. We have found that it was necessary to increase the thickness of the thermal SiO_2 to 690 nm from the 310 nm previously used. In order to improve the stability of the Pt against coalescence and pore growth, we have made the traces thicker (>1 μm) and covered them with sputtered SiO_2. We also developed a method to calibrate the thin-film TCs on the wafer *in situ* in the RTP tool using Pt/Pd wire thermocouples; previously we could only calibrate the thin film TCs externally on separate coupons. The new method may be used to validate the previously used calibration technique or as a substitute.

We also have expanded our technology transfer activities. Our cooperative project with SEMATECH, University of Texas, and Sensarray Inc. has included both the design, fabrication, testing, calibration, and delivery of two thin-film calibration wafers. These will be used for their unique RTP instrumentation test bed, and advisory services on the design of the facility and measurement methods used at the University of Texas. Other industrial and academic technical transfer activities have included providing thin-film calibration wafers to Applied Materials and Vortek Industries for test and evaluation in commercial RTP tools. Results from these collaborations provide valuable feedback on performance characteristics of the NIST calibration wafer. The NIST patent on the “Temperature calibration wafer for rapid thermal processing using thin-film thermocouple” #6,037,645 was issued Mar. 14, 2000 and licensed to Watlow Gordon Inc. for commercial production.

Finally, we have performed experiments to study the environmental effects on the accuracy of LPRTs. The experiments demonstrated that the temperature of a light pipe and the radiation surroundings significantly affect the temperature displayed by the LPRT. The scaling of the data with temperature implies that the effect is the result of self-emission and of scattering of extraneous radiation by the light pipes. The measurement uncertainty due to environmental influence can be minimized by calibrating the LPRT in an environment similar to that in which it will be used. Some light pipes are less affected by their environment than others, suggesting that better manufacturing techniques for light pipes can also minimize the measurement uncertainty.

Future activities include a concentrated effort to establish the repeatability, durability, and stability of the calibration wafers especially as it relates to their uncertainty in temperature measurement. We are improving the design to reduce the uncertainty in temperature measurement between 700 °C and 1000 °C. Our cooperative projects with the semiconductor processing industries will be expanded to assure the suitability of the wafer for their *in situ* calibrations. In addition we are exploring the use of thin-film calibration wafers for improving the accuracy of temperature measurement in photoresist curing and have a cooperative research project with MIT and SVG Inc. on these measurements.



(a) (b) (c)

Figure 2. (a) Sputtered Pt (0.7 µm thick) on a Si wafer with thermal oxide after 2 h in N_2 at 1000 °C. The 1µm to 3 µm medium gray areas are pores reaching the Si wafer.
(b) Same specimen with 0.4 µm of sputtered SiO_2 coating. No observed change from the un-annealed specimen..
(c) SEM of sputtered Pt (0.7 µm thick) on Si wafer with thermal oxide (2 h / 1000 °C). 2 µm to 4 µm dark spots were identified as Si using X-ray analysis.