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In Situ Si Wafer Surface Temperature Measurement during Flash Lamp Annealing

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1. Introduction

For improved process controllability of the rapid thermal treatment by flash lamp annealing (FLA), top side surface temperature measurement of the Si wafer under treatment is essential. However, such a measurement by radiation thermometry is hindered by blindingly intense background radiation from the heating Xe arc lamps and by the unknown emissivity of the wafer surface, as well as by multiple reflection of the radiation on the metallic chamber wall. We report on radiation thermometry overcoming these difficulties, which was successfully tested on an FLA proto-type system.

2. Measurement principle

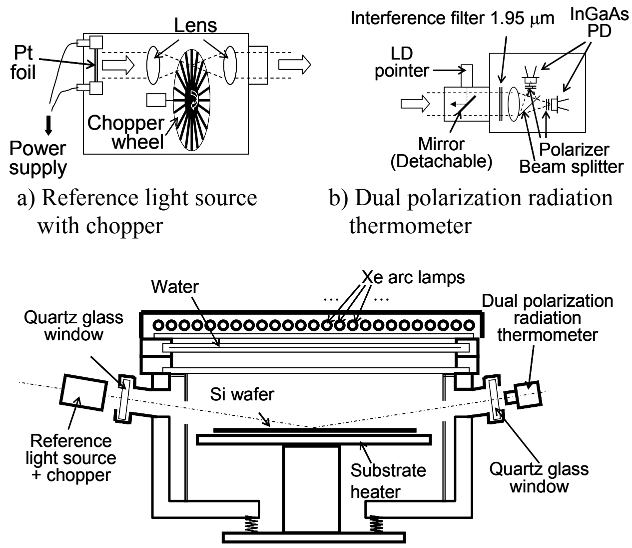
The system employs a classical automatic emissivity-compensated radiation thermometry technique [1]. In this method the radiation thermometer views the object at an inclined angle, while a reference light source is placed so that the thermometer detects radiation originating from this light source reflected on the measurement object surface, superimposed on the thermal radiation from this object. From the detected radiations at two orthogonal polarizations with the source ON and OFF, the blackbody radiance can be determined. Off-line investigation to verify the accuracy of the principle applied to Si wafer has shown that the temperature obtained by this method agrees with a reference radiation thermometer by better than 10 ^{o}C at above 1000 ^{o}C [2].

3. Measurement system

To suppress the intense background radiation from the Xe lamps, the radiation thermometer detects radiation at the absorption band of water at 1.95 μm for polarizations perpendicular to the wafer normal (p-polarization) and its orthogonal (s-polarization). Radiance signals from the two channels are recorded on a digital data logger.

The reference light source is a strip of platinum foil, which is resistively heated. A chopper unit realizes intermittent ON and OFF conditions at a rate of 5 kHz. The source viewed by the thermometer is a uniform and non-polarized source of diameter sufficiently larger than the target size of the thermometer, with radiance temperature of approximately 900 ^{o}C.

The thermometer and the reference light source are mounted on opposing sides of the FLA system, as depicted in Fig. 1. A steady flow of distilled water between quartz glass plates placed below the Xe arc lamp unit acts as an optical filter to eliminate background radiation from the lamp unit at the detecting wavelength of the thermometer.



a) Reference light source with chopper

b) Dual polarization radiation thermometer

c) Installation on an FLA system

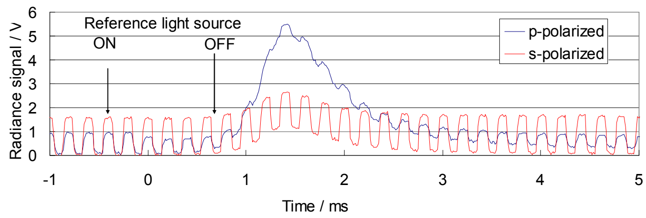
Fig. 1 Measurement system

4. Measurement results

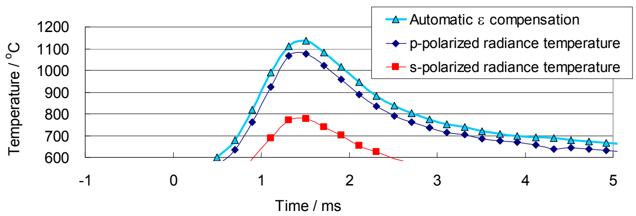
Initial check with the substrate heater off showed no detected signal, verifying that background radiation was sufficiently suppressed. Measurements were then conducted with various heater settings on bare, SiN deposited, and patterned wafers and the obtained peak temperature values were compared with sheet resistance measured after treatment.

By sampling the signal of Fig. 2a) synchronized to the chopper, the reference source ON/OFF radiance signals are obtained for each polarization. Subtracting OFF- from the ON-signal and taking the ratio gives the reflected radiance ratio. From this the blackbody radiance can be obtained. The derived emissivity compensated measured temperature profile is shown in Fig.2b) along with radiance temperature profiles for p- and s-polarizations before the compensation.

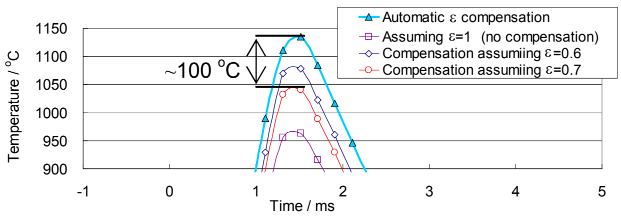
The effectiveness of the *in situ* emissivity compensation is demonstrated in Fig 2c): non-polarized detection with compensation assuming a fixed emissivity of 0.7 for SiN results in a temperature reading lower by almost 100 °C. Emissivity depends on wavelength, polarization, surface condition, as well as angle of view, making application of a fixed emissivity value to radiation thermometry impractical for high precision process control.



a) Detected p- and s-polarized radiance signals



b) Thermal profile before and after emissivity compensation

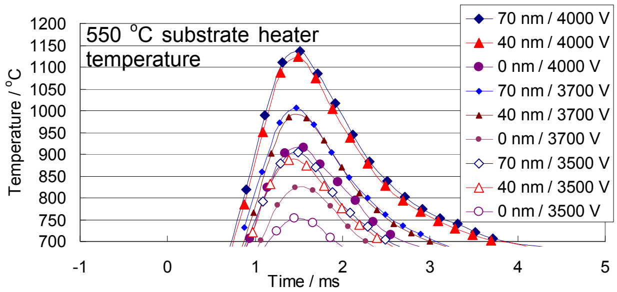


c) Thermal profile with automatic and non-automatic emissivity compensations

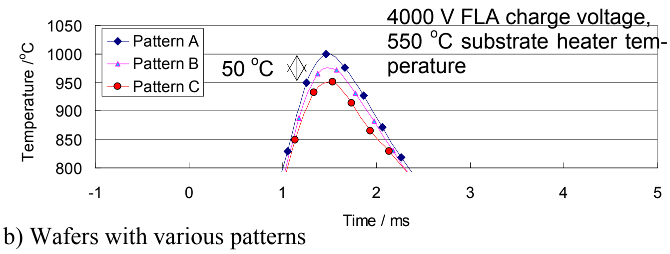
Fig. 2 Derivation of the emissivity compensated thermal profile SiN (70 nm) deposited wafer

Fig. 3a) shows that wafer surface emissivity differences can lead to large differences in peak temperature. Fig. 3b) tells us that for real Si wafers this can amount to 50 °C difference in peak temperatures among different patterns even for the same operating condition of the FLA system, indicating the benefit of *in situ* temperature measurement.

The measured peak temperatures of Fig. 3a) are plotted against sheet resistance measured after treatment in Fig. 4a). Good correlation is seen irrespective of the emissivity difference due to different SiN layer thickness. Similar plot for bare wafers treated under various FLA operation conditions also shows good correlation, verifying the validity of the automatic emissivity compensation (Fig 4b)). Here, conditions such as flash lamp duration and peak power, lamp power temporal profile, as well as substrate heater temperature are varied.

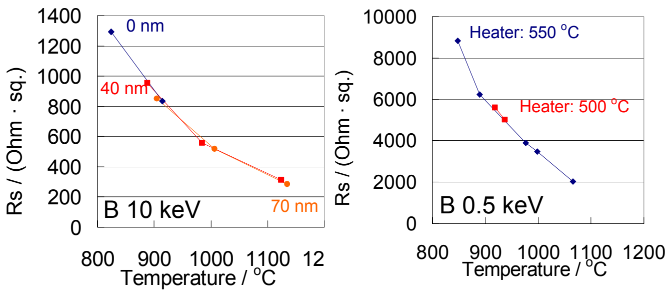


a) SiN deposited wafers of various deposition layer thicknesses treated under various FLA charge voltage



b) Wafers with various patterns

Fig. 3 Thermal profiles obtained for various wafers and operating conditions



a) SiN deposited Wafers b) Bare wafers

Fig. 4 Correlation of measured peak temperature with sheet resistance

5. Conclusions

Automatic emissivity compensating radiation thermometer was applied to *in situ* measurement of Si-wafer top-surface temperature in the FLA process. The measured peak temperatures showed good correlation with sheet resistance measured off-line, verifying the reliability of the obtained temperature. No dependence was seen on operation condition of the lamp annealing or on the wafer surface condition. Sensitivity of the measured temperature on the emissivity has also been shown, demonstrating the advantage of *in situ* automatic emissivity compensation.

References

[1] C. Tingwaldt, *Z. f.. Metallkunde*, **51** Vol.2 (1960) pp.116-119.

[2] K. Hiraka, T. Shimizu, Y. Yamada and J. Ishii, *Proc. SICE Sensing Forum* (2009), to be submitted (in Japanese).