Finite element modeling of the heat transfer during the heating of a semiconductor wafer in a vacuum chamber

B. Gsib*, R. Arès
Laboratoire d'Épitaxie Avancée, Université de Sherbrooke, Sherbrooke, QC, Canada.

The epitaxial process is used for depositing thin, crystalline semiconductor films on a substrate. During the deposition process, the substrate must be heated to high temperatures so that the necessary chemical reactions can take place. Typical deposition temperatures range from about 300 °C to 600 °C for ultra high vacuum (U.H.V.) based epitaxial techniques. In the past, problems have being experienced in being able to maintain good temperature uniformity across the wafer. The endeavor is especially difficult in vacuum, where convection is inexistent. Any meaningful attempt to address this problem must rest on a solid understanding of the basic heat transfer happening within the oven/wafer configuration.

We have devised a model for a standard 100 mm, resistive element oven in a U.H.V. chamber. The substrate used for the simulations was made of GaAs. The model used thermal and radiative parameters taken from literature. The modeling technique was the finite elements method, using the COMSOL™ software package.

Many factors can influence the unwanted repartition of temperature on the wafer. One of them is the hemispherical coefficient of absorption which is about 0.2 for GaAs [1]. Such a low value means that a high fraction of the incident energy is not absorbed but reflected or transmitted through the wafer without contributing any heat to it.

The model takes into account the radiative heat transfer between the heating element and the wafer, as well as the conduction between the wafer and its holder. Thermal properties of all components must be known and included in the model. This is especially important for the hemispherical radiative coefficients. The main assumption of the model is an equal semiconductor wafer's hemispherical coefficients of absorption and emission. This kind of assumptions is common in thermal enclosure studies [2].

The actual temperature distribution of a heated GaAs wafer was measured using an infrared enhanced CCD camera. The wafer was heated to a typical deposition temperature and a series of wafer images were recorded. The images were then post-processed to remove unwanted signals from parasitic reflections in the optical setup. A full wafer map of the temperature is then obtained. Figure 1 shows a typical result for a wafer heated to a center-point temperature of about 574°C.

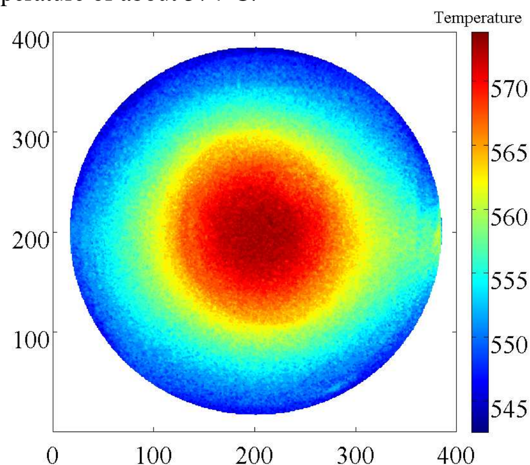

Fig. 1: Temperature map of the GaAs wafer (x y in pixels).

The experimental results are then compared with the predicted values given by the numerical model. Fig. 2 shows the comparison for the conditions given above. Excellent agreement is observed with a maximum difference of 5°C between the simulation and the measured data.

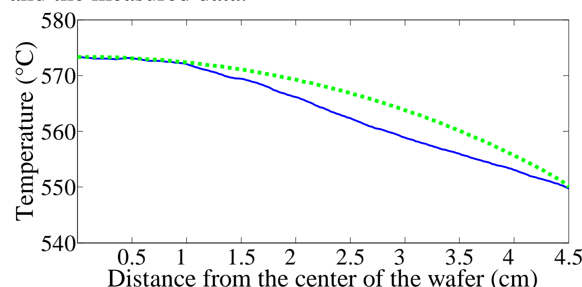

Fig. 2: Radial temperature of the GaAs wafer (dashed line from the model, solid line from the experience)

[1] P.J. Timans et al., J. Appl. Phys., p.26, April, 1992

[2] R. Siegel et al., THERMAL RADIATION HEAT TRANSFER, fourth edition, Taylor & Francis, p. 295, 2002

* Email: Badii.Gsib@usherbrooke.ca