SIMULATION OF SEMICONDUCTOR DEVICES AND PROCESSES Vol. 6
Edited by H. Ryssel, P. Pichler - September 1995

Modeling the Wafer Temperature in a LPCVD Furnace

A. Kersch[a], M. Schäfer[b]

[a]SIEMENS AG, Corporate Research and Development
Otto-Hahn-Ring 6, 81730 Munich, GERMANY
[b]Fraunhofer-Institut für Integrierte Schaltungen,
Schottkystrasse 10, 91058 Erlangen, GERMANY

Abstract

In the paper the application of a newly developed radiation model to the modeling of a batch furnace is shown. The model includes multi-band spectral dependence and the treatment of semitransparent materials The results are compared with experimental data.

1. Introduction

Batch processing with large diameter wafers requires a new generation of optimized furnaces. The challenge of the equipment simulation is to provide a sufficiently accurate radiation model for the description of the heat transfer. In the past, radiation models for the complex multiwafer geometry have been developed based on the diffuse, grey approximation [1][2]. In this paper we present results obtained from first principles with a new radiation model based on the diffuse approximation with multi-band spectral dependence and allowing for semitransparent materials. The results are compared with experimental data. The radiation model is included in the CFD-simulator PHOENICS-CVD [3].

2. The Model

In a discretization of the surfaces of the enclosure into N surface elements

$$F^l_{ij} = \frac{1}{Area(j)} \int_j \int_i t^l_{ij} \frac{|n(y) \cdot r||n(x) \cdot r|}{\pi \, r^2} dy dx$$

is the generalized viewfactor in the presence of semi-transparent surfaces. t^l_{ij} is the transmittance from j to i in the $l-th$ band of the spectrum, $r = y - x$ the distance between x and y and $n(x)$ and $n(y)$ the surface normals. The radiative flux from j to i is calculated in the diffuse approximation with the help of the Gebhard factors

$$G^l_{ij} = a^l_i(T_0) \sum_{m=1,N} \left(\delta_{im} - F^l_{im} r^l_m\right)^{-1} F^l_{mj}$$

taking into account direct and multiply reflected radiation, r_m^l the reflectivity. The net flux in the $l-th$ band from j to i is then described by the matrix

$$R_{ij}^l = \left(G_{ij}^l - \delta_{ij}\right) e_j^l(T_0) Area(j) P_j^l(T_0)$$

and with

$$P_j^l(T_0) = \frac{1}{\sigma T_0^4} \int_{\nu_l}^{\nu_{l+1}} \frac{c_1 \nu^3}{e^{c_2 \nu / T} - 1} ,$$

is the fraction of black body radiation in the band l. The total radiation into i is then

$$Q_i = \sum_{j=1,N} \left(\sum_{l=1,L} R_{ij}^l \right) T_j^4$$

where T is the actual surface temperature during the iteration. The matrix R is calculated with an initial estimate T_0 of the surface temperature and coupled into PHOENICS-CVD.

Figure 1 shows an example of optical properties in the banded approximation.

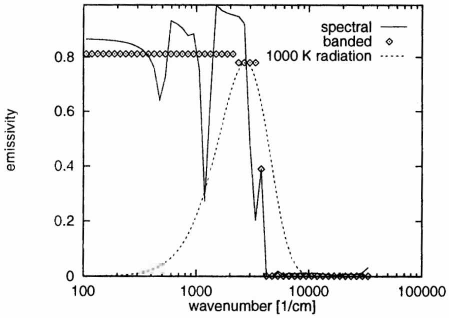

Figure 1: The hemispherical emissivity of fused quartz in the banded model in comparison with the spectral emissivity. Also shown is the black body radiation energy distribution at 1000°K.

3. The Simulation

The geometry of the batch furnace with three heating elements in an axisymmetric simplification is shown in Figure 2.

The semitransparent quartz tube extends to the outside of the heater, the tube ends are cooled steel and constitute a radiative sink. The batch of 68 wafers was resolved into 31 wafer in a first simulation. The paddle constitutes the only deviation from axial symmetry. In one simulation the paddle was neglected, in another represented effectively as two cylindrical regions in back and front of the batch. The surfaces were discretized into about $N = 350$ radiative zones, the computation time for R was about $2hr$ on a $HP750$.

The temperature drop at the back and front end of the batch is caused on the one hand by the radiative heat loss of the first and the last wafer to the cold inlet and outlet doors. On the other hand it is caused by the view of the wafers in the batch to the reactor tube with a temperature profile. To separate these both effects, the front and the back side of the wafer batch was represented as a perfectly reflecting

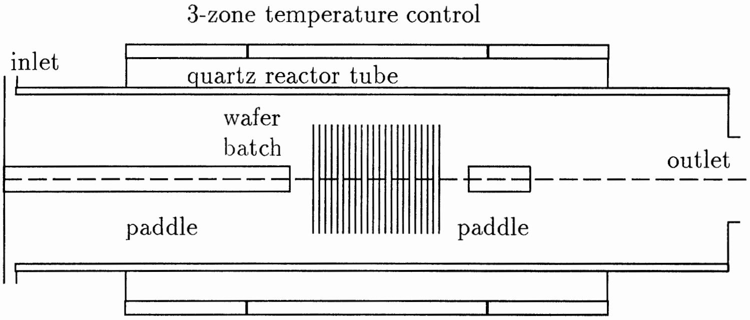

Figure 2: Geometry of the LPCVD furnace with three heating zones. For the heating zone a constant emissivity of 0.85 was assumed; for the quartz, the silicon and the silicon carbide paddle the emissivity was taken in the banded approximation.

mirror to eliminate the heat loss to the doors, The results in Figure 3 show, that the dominant effect is the view to the doors. Furthermore, the results show a simulation with an effective representation of the paddle as cylindrical surfaces. This additional radiative interaction of the front and back side wafers diminish the temperature drop.

Figure 4 shows the comparison of the axial temperature profile with data obtained at FhG IIS-B. The quantitative agreement is good. A further comparison is made in Figure 5 with the maximal temperature difference on the wafer. The agreement is good. The experimental inhomogeneity in the center should be close to the error of the measurement.

The potential of the model to perform optimization is furthermore shown in Figure 6. The improved axial temperature profile was obtained after increasing the power of the back and front heating elements.

Figure 7 finally shows the temperature distribution in the reactor. Clearly visible is the increased temperature drop of the batch towards the inlet side with the black opening.

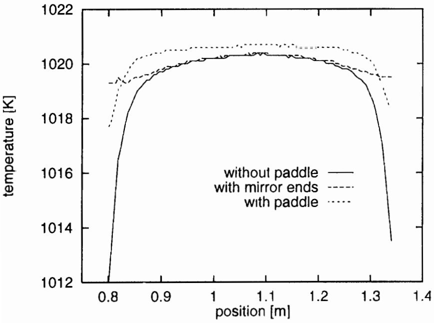

Figure 3: Temperature profile in the center of the batch (a) without paddle, (b) with mirrors at end of batch and (c) with effective representation of paddle.

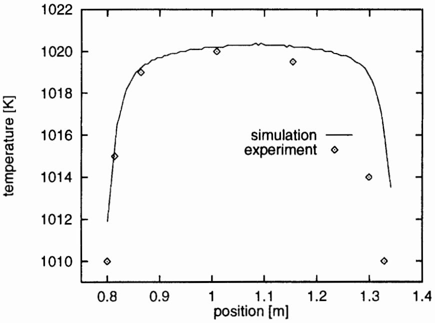

Figure 4: Temperature profile in the batch from the simulation without paddle in comparison with data.

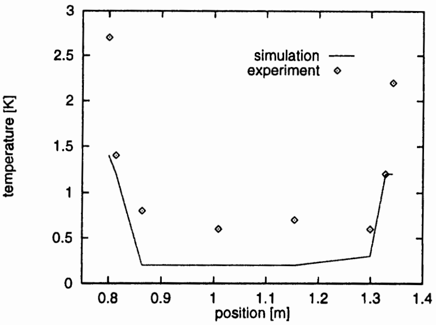

Figure 5: Radial nonuniformity of the wafers from the simulation in comparison with data.

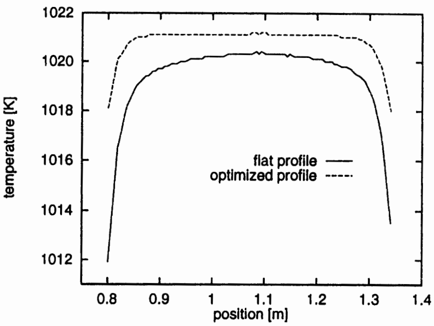

Figure 6: Optimized temperature profile in the batch with the temperatures in the heat zones set to $T_1 = 1063°K$, $T_2 = 1023°K$ and $T_3 = 1073°K$ instead of a constant $T = 1023°K$.

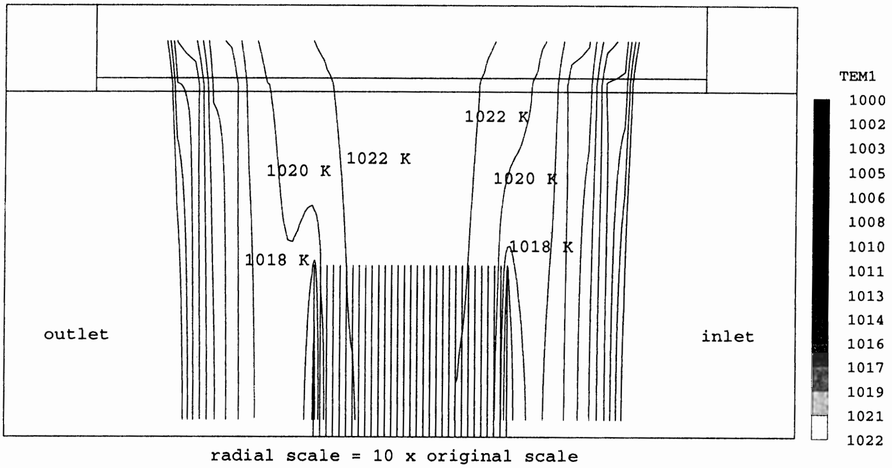

Figure 7: The temperature distribution in the reactor. Visible is the reduced temperature of the batch at the side towards the inlet. The inlet front is steel with an optical black opening of $30mm$ radius. The outlet front side is entirely steel.

References

[1] H. De Waardt and W. L. De Koning, *Automatica*, vol.28, p.243, 1982

[2] T. A. Badgwell, I. Trachtenberg and T. F. Edgar, "Modeling the Wafer Temperature Profile in a Multiwafer LPCVD Furnace", *J. Electrochem. Soc.*, vol 141, p.161, 1994

[3] PHOENICS-CVD, CHAM, Wimbledon, 1995