



## Heat transfer model of an iCVD reactor

R. Bakker<sup>\*</sup>, V. Verlaan, A.D. Verkerk, C.H.M. van der Werf, L. van Dijk, H. Rudolph, J.K. Rath, R.E.I. Schropp

Utrecht University, Faculty of Science, Debye Institute for Nanomaterials Science, Nanophotonics - Physics of Devices, P.O. Box 80.000, 3508 TA Utrecht, The Netherlands

### ARTICLE INFO

Available online 22 January 2009

#### Keywords:

Hot-wire CVD  
iCVD  
Heat transfer

### ABSTRACT

Contrary to conventional HWCVD, the power consumption in the iCVD process is dominated by heat conduction rather than radiation. This is due to the fact that while the typical wire temperature for HWCVD is about 1750–2200 °C, for iCVD the temperature is only 250–500 °C. Typical deposition pressures are in the transition regime between the collision free regime, where the conduction is pressure dependent, and the collision mediated regime, where the conduction is pressure independent. The power loss due to heat conductivities of molecular nitrogen, glycidyl methacrylate (GMA) and tert-butylperoxide (TBPO) gases have been determined experimentally for these pressure regimes. The necessary power input to the filaments can be explained to be due to mainly heat dissipation by radiation and by gas conduction. This means that the dissociation process requires only very little power, about 2% of the total power consumption in a typical iCVD process.

© 2009 Elsevier B.V. All rights reserved.

### 1. Introduction

Initiated chemical vapor deposition (iCVD) is a gas-phase technique for depositing polymer films without the use of a solution or plasma and it can quite easily be integrated in large-scale device production [1]. In the iCVD process, metal wires are resistively heated to a temperature of typically 250 °C, so that the initiator is decomposed into radicals. These radical species then initiate a free radical polymerization of monomers to form a film on a cooled substrate (<25 °C). One of the polymers that can be deposited using iCVD is poly-glycidyl methacrylate (PGMA) [2,3]. Because no plasma is involved and the process temperatures are very low, the occurrence of any unwanted side reaction is minimized, resulting in a high purity of the deposited polymer [3,4]. Furthermore, the iCVD process consumes very little energy, due to the relatively low process temperatures, which is an advantage for implementation in commercial production lines.

Although for typical HWCVD processes that use filament temperatures in the 1750–2200 °C range, several studies have been done to examine the consumed power [5–7], no studies have, to our knowledge, been done for iCVD. It is obvious that at high temperatures and low pressures of a typical HWCVD process, heat conduction by the process gases has only a minor influence on the consumed power, compared to radiation. This difference is mainly due to the fact that radiation power is proportional to the fourth power of the wire temperature ( $T_w^4$ ), whereas the temperature dependence of conduction is of a lower order. In this paper, the power consumption of an iCVD reactor is studied.

### 2. Experimental

The investigated iCVD system contains a nichrome wire (80% Ni, 20% Cr) mounted in a parallel array, 28 mm above the substrate in a home-built reactor (the PANDA), after a design by Prof. Gleason's laboratory at MIT. The reactor is cylindrically shaped and has an internal diameter of 25 cm and internal height of 5 cm. The monomer, GMA (97%, Aldrich) was heated in a glass chamber to a temperature of 60 °C, and fed into the reactor through a pipe heated to 90 °C. The initiator, tert-butyl peroxide (TBPO) of 98% purity (Aldrich) was vaporized at room temperature. The initiator/precursor flow was controlled by metering valves. The substrate temperature was kept below 25 °C by means of water cooling on the back of the substrate holder. Current, voltage and temperature measurements were done using 175 True RMS multimeters and an 80TK Thermocouple Module (Fluke). Pressure was controlled by an MKS 615C pressure controller.

### 3. Results and discussion

In thermal equilibrium, the power supplied by the power supply is the total input power dissipated in resistively heated wires which can be described by the following expression:

$$P_{\text{input}} = P_{\text{rad}} + P_{\text{cond}} + P_{\text{conv}} + P_{\text{re}} = I \cdot V \quad (1)$$

where  $P_{\text{rad}}$  is the radiative power loss,  $P_{\text{cond}}$  is the power lost by conduction of the gas,  $P_{\text{conv}}$  is the power loss through convective heat transfer and  $P_{\text{re}}$  is the power that is consumed by the chemical reactions at the wires. Experiments in which we varied the gas flow rate showed no alterations in the power consumption. Furthermore, the heat conductivity at higher pressures saturates towards a constant

<sup>\*</sup> Corresponding author.

E-mail address: [R.Bakker@uu.nl](mailto:R.Bakker@uu.nl) (R. Bakker).

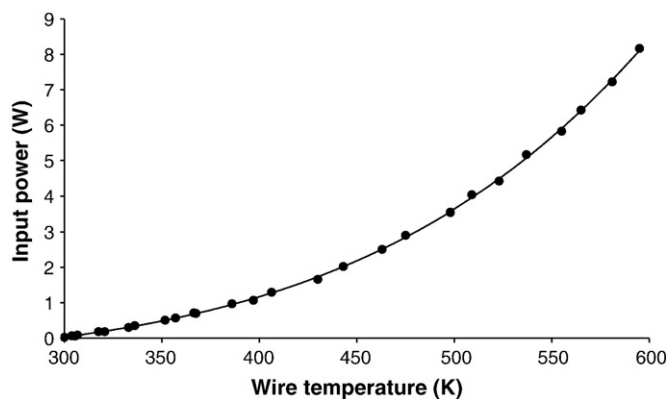


Fig. 1. The input power of the filament in vacuum versus the wire temperature. The line is a fit with the Stefan-Boltzmann radiation law (Eq. (1)).

value (see below). This means that convective heat transfer is only small and can be neglected.

In Fig. 1, the power input to the filaments in thermal equilibrium is given at the vacuum base pressure (0.01 mbar) for various wire temperatures. At this low pressure, the effects of heat conduction are minimized. The power loss through blackbody radiation is described by the Stefan-Boltzmann radiation law:

$$P_{\text{rad}} = P_{\text{vac}} = \varepsilon \sigma_{\text{SB}} A_w (T_w^4 - T_s^4) \quad (2)$$

in which  $\sigma_{\text{SB}}$  is the Stefan-Boltzmann constant,  $\varepsilon$  the emissivity of the system (the emissivity of the wire being the relevant value),  $A_w$  is the surface area of the wire,  $T_w$  its temperature and  $T_s$  the temperature of the surroundings (the walls of the reactor). The measurements (dots) are fitted with Eq. (2) and the proper emissivity  $\varepsilon$  was determined, and amounted to 0.31, which corresponds reasonably with values found in literature for nichrome alloys with 80% Ni (0.36) [8], the material used in our experiments.

The heat conduction from the hot wire to the wall of the reactor through the gas is dependent on the type of gas, the pressure, the temperature of the wire and geometry of the reactor. In our case, the reactor walls are cooled with water to maintain a constant temperature ( $T_s$ ). Keeping the temperature of the wire ( $T_w$ ) constant ( $100 \pm 5^\circ\text{C}$ ) and well below the temperature at which TBPO starts to dissociate significantly ( $150^\circ\text{C}$ ) [9] allows us to study the pressure dependence of the heat conduction of GMA and TBPO.

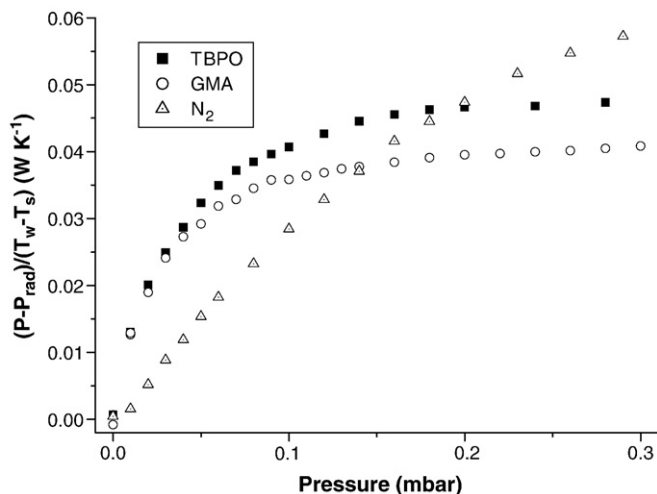


Fig. 2. The pressure dependence of the heat conduction for the relevant gases.

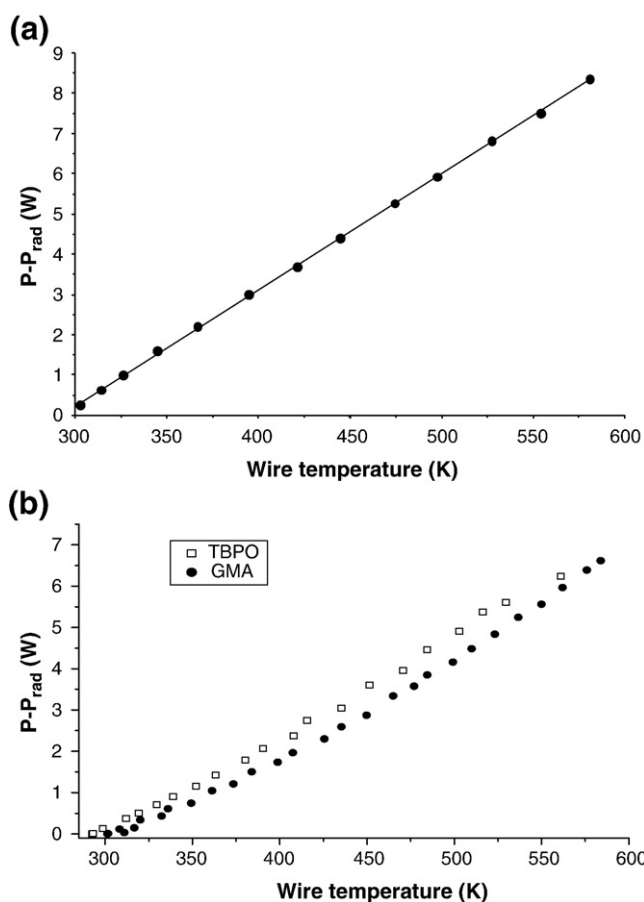


Fig. 3. The power consumed by heat conduction of (a)  $\text{N}_2$  at 0.10 mbar (the line is a linear fit) and (b) TBPO and GMA at 0.02 mbar.

Heat conduction takes place via different mechanisms in different pressure regimes. An important parameter in studying the pressure dependence of the heat conduction is the mean free path:

$$\lambda = kT/p\sigma_c\sqrt{2}, \quad (3)$$

in which  $k$  is the Boltzmann constant,  $p$  the pressure and  $\sigma_c$  the collision cross-section of the molecule. At high pressures, for which the mean free path of a molecule is smaller than the typical size of the reactor ( $\lambda \ll D$ ), heat conduction is independent of pressure [10]. At low pressures ( $\lambda \gg D$ ), the heat conduction is linearly dependent on the pressure [10,11]. Dividing the measured conductive power ( $P - P_{\text{vac}}$ ) by  $T_w - T_s$  corrects for the small fluctuations in the wire temperature. Fig. 2 shows the pressure dependence of conductive power loss of  $\text{N}_2$ , TBPO and GMA gases at the intermediate pressure range. Nitrogen gas is the only one of these gases for which the heat conduction does not saturate in the measured pressure regime (0–0.3 mbar).

Fig. 3a shows the power loss by conduction of 0.10 mbar  $\text{N}_2$  versus the wire temperature. As can be seen from Fig. 2, this is well within the pressure dependent regime (see Fig. 2). Conductive power is linearly dependent on  $T_w - T_s$ , as predicted by the theory for low-pressure conduction [10]. For GMA and TBPO, the temperature dependence at lower pressures (shown in Fig. 3b), studied at a relatively lower pressure regime (0.02 mbar) where the conduction is pressure dependent), seems to deviate slightly from this linear behavior. Since the deviation is comparable for both gases and GMA does not dissociate at these relatively low temperatures, it is unlikely that it is due to any chemical reaction.

Download English Version:

<https://daneshyari.com/en/article/1673745>

Download Persian Version:

<https://daneshyari.com/article/1673745>

[Daneshyari.com](https://daneshyari.com)