Uniform Molecular Flux in a Vertical Reactor with
Pulsed Transition Regime Gas Flow
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Pulsed-CVD technology accomplishes reactant delivery by timed injection of gas into a continuously evacuated reactor. The reactor conditions produced by this method are new to CVD processing. Seminal investigations to characterize the flow dynamics and transport phenomena for pulsed-transition regime flow are reported. Non-dimensional parameters for reactor design and process control are proposed, and the theory describing molecular impingement rate as a function of these parameters is presented. An experimental, industrial-scale reactor, as shown in Figure 1, and experimental methods, including naphthalene sublimation, have been developed to investigate the flow dynamics. Pulses of known volume and pressure N_2 were delivered into the reactor at timed intervals, while monitoring the resulting reactor pressure and molecular flux field. Results demonstrate that uniform molecular flux can be achieved by Pulsed-CVD at pressures where steady flow would result in stable boundary layers, and thus non-uniform heat and mass transport fields at the substrate, and throughout the reactor.

A known volume of gas, at a set pressure is injected into the reactor at controlled pulse intervals. The reactor pressure pulses as shown in Figure 2, and as given by Eqn. [1].

$$P^*(t) = \frac{P(t) - P_{\min}}{P_{\max} - P_{\min}} = \exp\left(-\,t/\tau\right) \qquad [1]$$

Where τ is an important operating parameter and given by the ratio of the reactor volume to the reactor pumping rate.

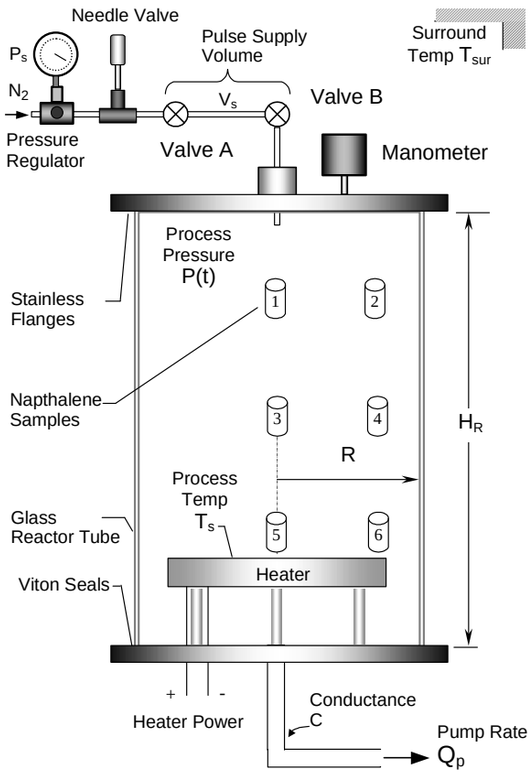

Figure 1. Schematic of the Pulsed-CVD reactor and experimental set-up.

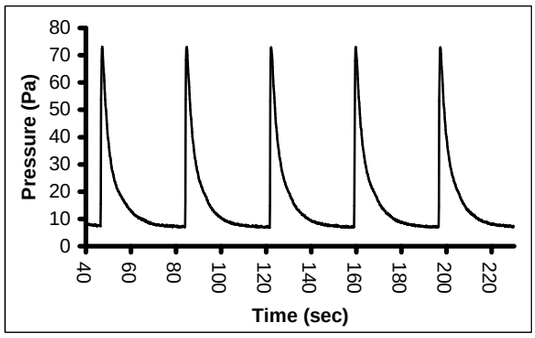

Figure 2. Reactor pressure over several pulse cycles. Pulse cycle time, t_p=38 s, reactor volume V_R= 4.45 lit, pump rate S_P= 2.5 lit/s, conductance, C= 1.64 lit/s, injection volume, V_s= 1400 mm^3, supply pressure, P_s=150 Pa(g), τ = 4.5 s.

Napthalene sublimation rates were measured for a constant vacuum, equal to the vapor pressure of naphthalene, for the pulsed flow conditions shown in Figure 2, and for two steady flow experiments. Nitrogen gas flow was controlled by micrometer valve on the gas inlet. The molecular flux, $\phi = \Sigma\phi(t_i)\Delta t$, was determined from Eqn. [2] and integrated over the pulse cycle.

$$\phi(t) = \frac{P(t)}{\sqrt{2\pi M R_o T_R}} \qquad [2]$$

Equivalent molecular flux would be achieved in steady flow at 17 Pa. During the first 5 sec of the pulse, the equivalent molecular flux would occur in steady flow at 50 Pa. The Figure 3 shows the results of sublimation tests run at constant vacuum, pulsed flow, and steady flow at 10 Pa and at 50 Pa. The evidence of viscous flow effects are the variable sublimation rates at different reactor positions. It is evident that, as expected under steady flow conditions at 50Pa, uniformity of the flow field in the reactor is not achieved. However, in the pulsed reactor, with pressure ranging from P_{max}= 74 Pa to P_{min}= 7.4 Pa, the sublimation rate is constant throughout the reactor.

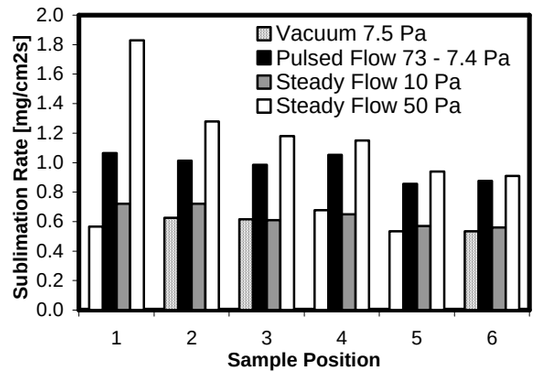

Figure 3. Napthalene sublimation rates for pulsed and steady flow dynamics.

Sublimation evidence indicates that pulsed operation produces equivalent molecular flux rates to viscous flows, but with uniform flux field throughout the reactor and on the substrate surface in particular.