Gas Flow in Nano-Channels: Thermal Transpiration Models

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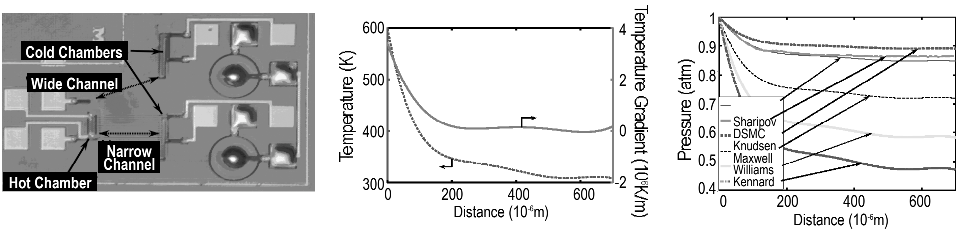

Left – Photograph of the fabricated Knudsen pump, Middle – Temperature distribution along the narrow channels connecting the hot and cold cavities—as predicted by the ANSYS model for the Knudsen pump, Right – Pressure distribution along the narrow channels—as predicted by various analytical and semi-analytical models.

In the recent past, the first fully micromachined Knudsen pump was reported by our group followed by a preliminary system-level modeling that used analytical methods to predict the performance of a Knudsen pump. While this effort demonstrated the importance of analytical models for developing the understanding of the physics of the Knudsen pump, there was room for optimization of the modeling strategy. We are now benchmarking various analytical and semi-analytical models against a very precise but computationally expensive molecule tracking technique known as direct simulation Monte Carlo (DSMC) technique. This details the applicability of various analytical and semi-analytical models to different flow conditions and highlights the potential of Sharipov's model to serve as a computationally economical alternative to the DSMC technique for preliminary analysis of the thermal transpiration in microsystems. Characterization of Sharipov's model against the DSMC technique, with the help of specially designed test cases, predicts that the Sharipov's model is potentially the most representative model for DSMC in this context. Sharipov's model is subsequently used to optimize the design parameters of the Knudsen pump. The analysis shows that a 200μm-long channel on a well-insulated glass substrate, with a channel height of 100nm and 10μm width, provides a mass-flow-rate of 1.5 x 10^{-6}sccm with a ΔT of 300ºC. This project has been supported in part by a graduate fellowship from the University of Michigan.