Knudsen Pump for On-Chip Vacuum

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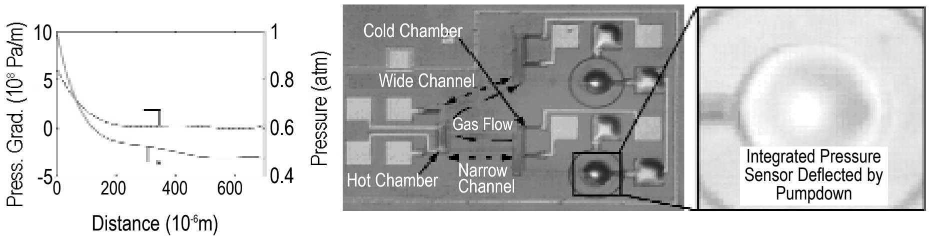

Left – Pressure gradient along the narrow channel connecting the hot and cold cavities as predicted by the Kennard's model with hot end being at the left edge. Middle – Photograph of a fabricated Knudsen pump. Right – An integrated pressure sensor is deflected by the interior vacuum generated by the Knudsen pump.

In the recent past, the first fully micromachined Knudsen pump was reported by our group. While this effort demonstrated experimental feasibility, a predictive model was not reported. We are now developing a system-level model that combines analytical and numerical methods. This details how the viscous and free molecular gas flow characteristics can be integrated with the dimensional constraints and the material property characteristics to provide a design methodology, and extrapolates to new (multistage) designs with superior performance. A preliminary approach involves numerical modeling of the thermal response (using finite element analysis), followed by an analytical estimate of the pumping using Kennard's analytical model for thermal transpiration. The loss of performance resulting from gas diffusion through walls of the pump is specifically addressed. The results are subsequently validated against the previously reported experimental measurements of a single-stage Knudsen pump. The fabricated device, which has a total footprint of less than 1500 x 2000μm^2, has multiple narrow channels connecting two cavities, one of which is heated. This cavity is further connected through a wide channel to a third cavity that remains at ambient. The simulation model for this device predicts a vacuum pressure of 0.47atm at an input power of 97.6mW, compared with 0.46atm at 80mW power that was measured experimentally, which translates to accuracy of more than 80%. This work has been supported in part by the University of Michigan.