

# Integrated Microsystems for Industrial Flow Control

Albert K. Henning  
Redwood Microsystems, Inc.

## Goals and Potential Impact if Successful

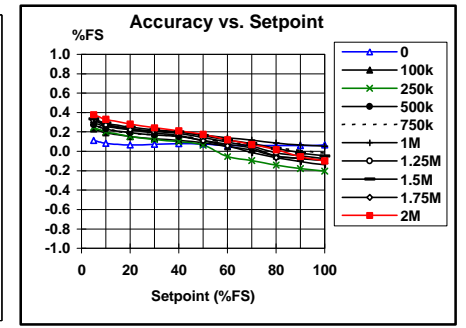
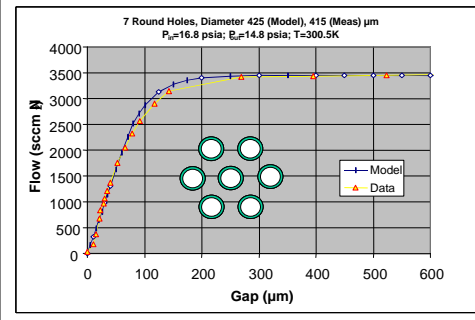
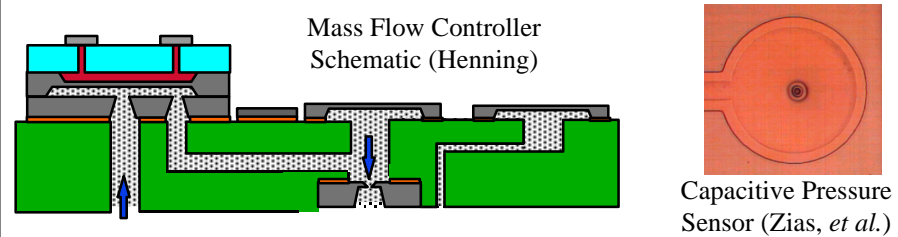
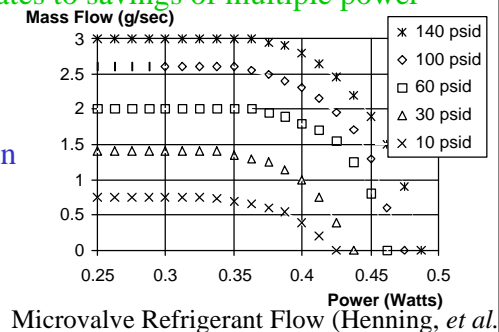
Substantial improvements in yield, throughput, reliability and overall cost of ownership for semiconductor process tools

Reduction in size and cost, and increase in reliability, of industrial pneumatic control systems

3-12% improvement in residential refrigeration energy efficiency through active flow control (translates to savings of multiple power plants per year on a national basis)

Improvement of automotive fuel injection and emissions controls systems, reducing fuel consumption and waste emissions

Reliability and safety improvements for all manner of industrial flow control systems



## Accomplishments

- Integrated MEMS-based flow control systems for distribution and control of semiconductor process gases, with high performance, accuracy, repeatability, and reliability
- Development of integrated flow control systems using silicon MEMS components, compatible with all relevant gases except atomic fluorine
- Development of MEMS component packaging techniques with low stress, low drift, and high reliability
- Development of compressible gas flow models for SPICE-like, steady-state and transient flow modeling of orifices, microchannels, and microvalves
- Development of comprehensive design tools (modeling of actuation and flow) and fabrication technology for microvalves
- Development of MEMS-based refrigerant flow control technology
- Novel, wide dynamic range pressure sensor
- Flow delivery systems for microscale chemical reactors

## Bottlenecks and Open Research Questions

- Reliable, corrosion-resistant coatings for silicon and other system materials; materials compatibility between controlled fluid and system materials; mechanical properties of microfabrication mat'ls.
- Physics of coefficient of discharge in micrometer-scale orifices as function of pressure, temperature, gas type and shape; effect of departure from assumptions of ideal gas behavior, adiabatic flow, and isentropic flow; effects of fluid interaction with channel walls
- Robust tools for transient simulation of compressible gas flow in highly integrated microsystems
- Characterization of and calibration between modeling tools (lumped and FEA) and actual hardware
- Physics of discrete vs. continuum flow for Knudsen and molecular flow, as system sizes shrink to the micro and nanoscale
- Need for fast response, high force, high displacement, low energy/power actuation mechanisms