Case Study: Inchfab

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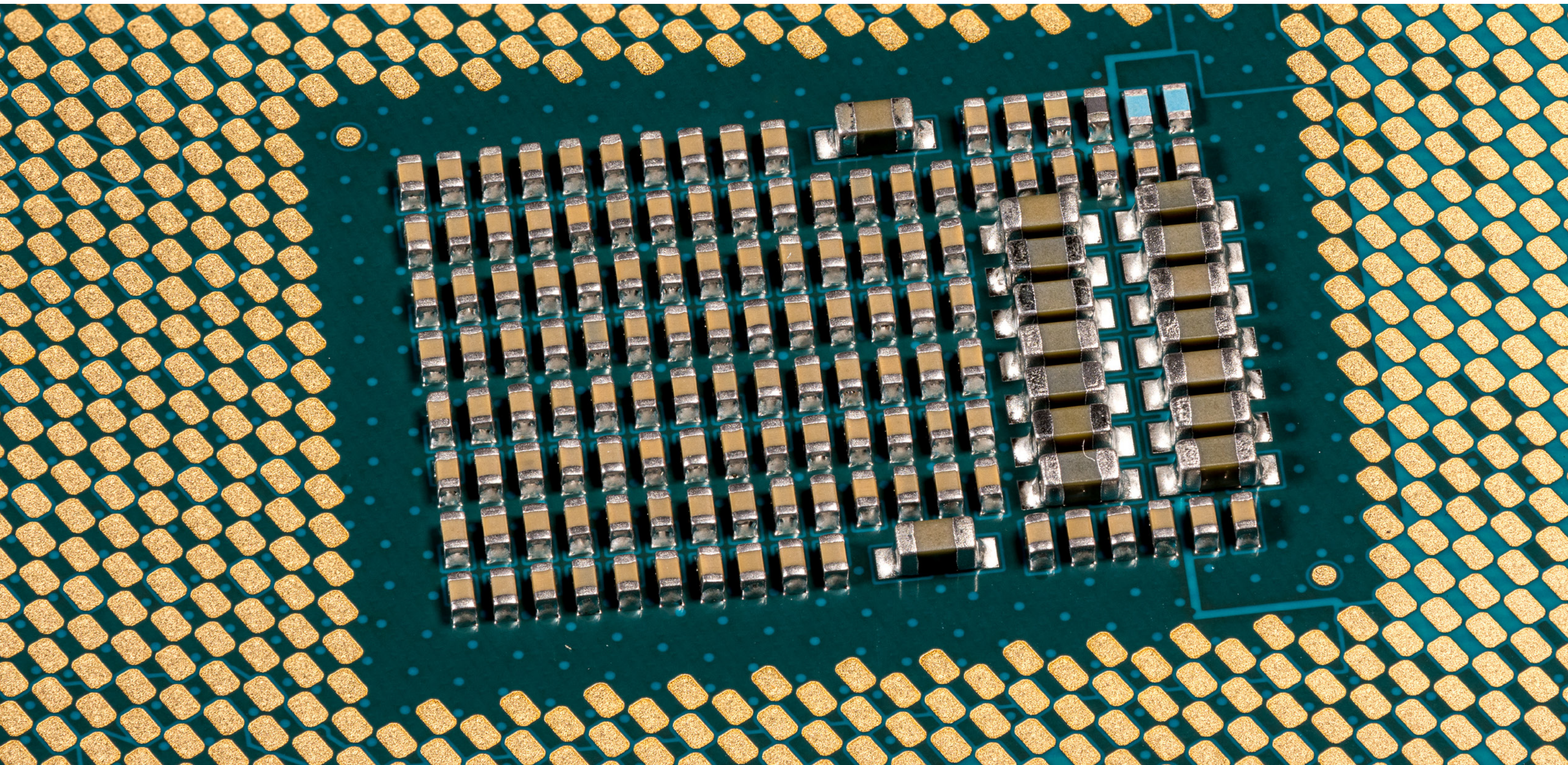
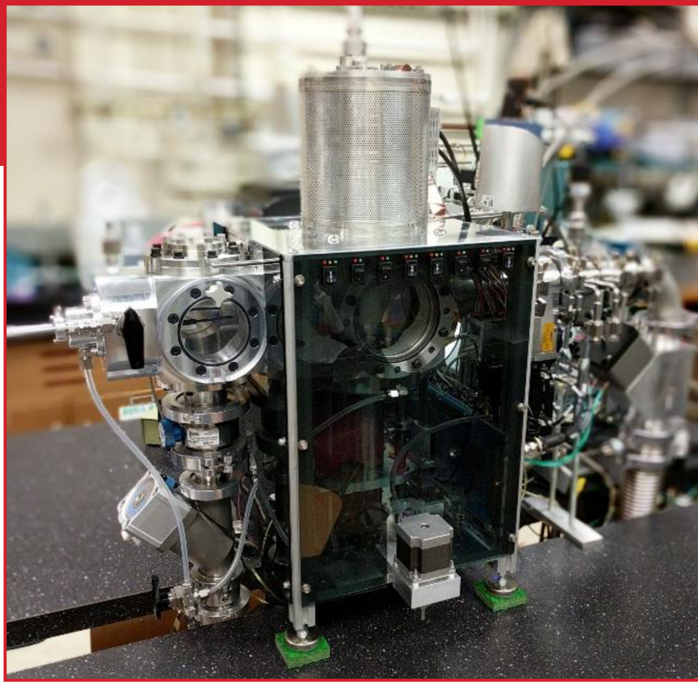


Figure 1: *Prototype Inchfab ICP-CVD System*



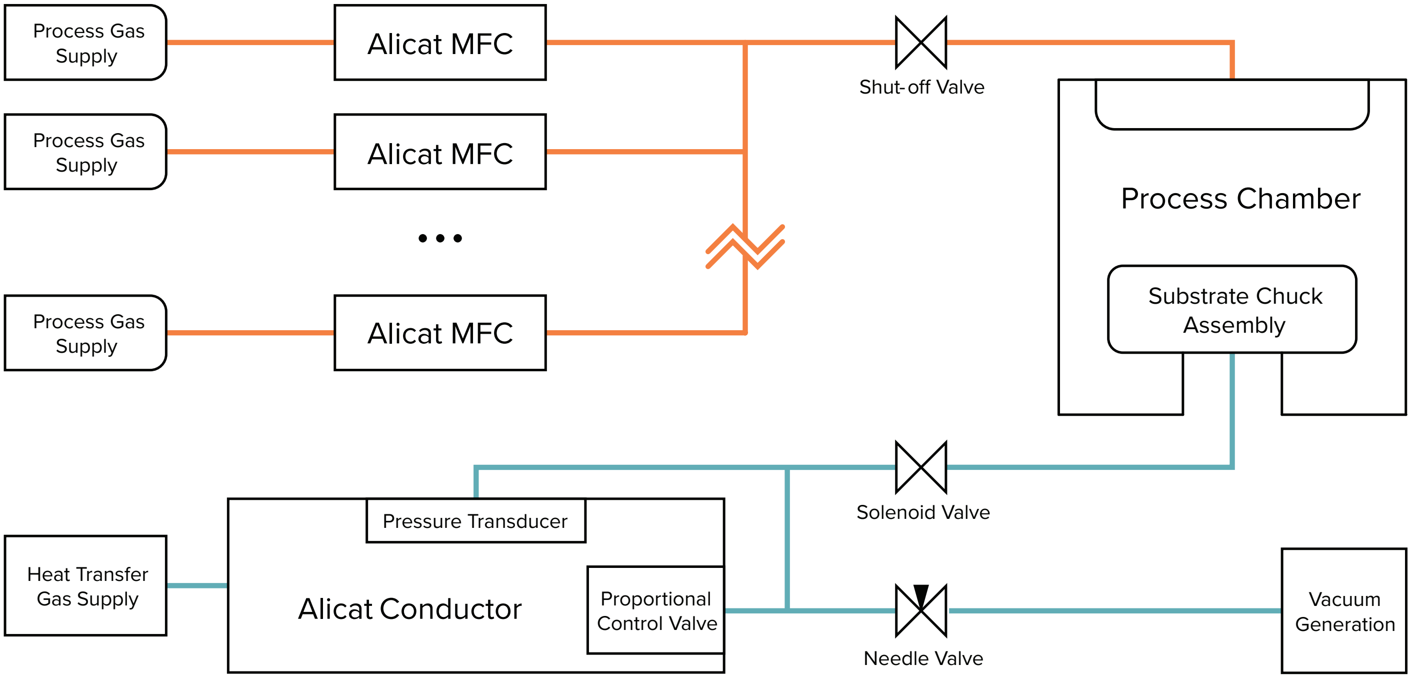
The increasing demand for computing power over the last 60+ years has led to exponential increases in both device complexity and production volumes. To keep up with this demand, the latest advances in micro- and nanofabrication technology have become inextricably coupled with increasingly larger substrate sizes. This has led to some of the most awe-inspiring engineering feats in history, but such precision comes neither easily nor cheaply. The capital cost of modern nanoscale fabrication facilities ("fabs") now routinely stretches well into the billions of USD and requires strict process controls that severely limit the types of devices that a single fab can create.

This high cost and minimal flexibility of nanoscale fabrication has become a major barrier in many different markets for groups seeking to develop innovative devices. Inchfab's novel platform of ultra-low cost, high performance fabrication tools is tearing down that barrier by decoupling advanced processing capabilities from large substrate sizes. By stepping back from the 150–300 mm (≈1 foot) diameter substrates commonly used in high volume production today, the capital cost and physical footprint of the tools and facilities needed for nanoscale fabrication can be decreased by orders of magnitude, radically increasing their accessibility. Additionally, Inchfab has demonstrated that the use of smaller substrates can also lead to performance improvements over existing commercial tools.

Two of the most important characteristics required of micro- and nanofabrication systems are run-to-run repeatability and spatial uniformity. Achieving high levels of repeatability and uniformity relies on the ability to control many different process inputs and environmental conditions. Among the most important of these are mass flow rates and process pressures. Unlike most mass flow controllers (MFCs), which measure the amount of flow thermally using heaters and temperature sensors along the flow path, Alicat MFCs measure flow rate by creating a laminarized (low Reynolds number) flow stream using a stack of "laminar flow elements" (LFEs) and measuring the pressure drop across the flow channel. From this measured pressure drop, the dimensions of the flow path, and the viscosity of the input gas, the volumetric flow rate can be calculated using the Hagen-Poiseuille equation. Given the gas type and the measured temperature and pressure, the volumetric flow rate can then be converted into a highly accurate mass flow rate. Importantly for Inchfab, Alicat's flow control technology provides faster response times, larger controllable ranges (up to 10,000:1), and no warm-up delays before operation. Combined with an economical price point, these capabilities are what make Alicat MFCs the go-to MFC for Inchfab systems. **Figure 2** shows how Alicat MFCs are connected in Inchfab's ICP-CVD system.

In addition to mass flow controllers, Inchfab has recently switched to using Alicat's new Conductor series pressure controller to improve heat transfer between chuck assemblies and the substrates being processed. Just like reliable mass flow rates, repeatable and uniform substrate temperature profiles are also essential for consistent and uniform deposition and etch profiles. For example, in plasma-based etching, excess substrate heat is generated largely from bombardment from energetic particles generated in the plasma discharge and exothermic chemical reactions on the substrate surface. For fluorine-based silicon etching, as the substrate temperature increases, the etch rate decreases and commonly used masking materials like photoresist can

Figure 2: *Block diagram showing how the Alicat controllers are used in the Inchfab ICP-CVD system.*



Note: This is a simplified version to remove proprietary information.

begin to erode, decreasing selectivity. To counteract this heating, heat exchangers are used to conduct heat away from the substrate. Because the substrates being processed may have delicate features on their backside, direct thermal contact with the chuck assembly is not advisable. Thus an effective solution is to introduce a layer of heat conducting gas between the substrate and chuck. The Alicat Conductor allows for a controlled sub-atmospheric pressure of gas (typically 5–20 torr, depending on the process) to be maintained on the backside of the substrate, minimizing the time needed to reach thermal equilibrium with the chuck assembly, and helping to maintain that equilibrium throughout processing. Compared to other controllers that use in-line Pirani or other sensor technologies, the vacuum sensor in the Conductor provides a precise, gas-independent measurement of the pressure in the substrate-chuck layer and can be routed independently of the fluid outlet. Switching to the Conductor series allowed Inchfab to remove a more expensive controller and several extra pieces of control hardware, since the Conductor uses a common digital interface with Alicat MFCs. It also uses the standard intuitive Alicat digital communications protocol, making it very simple to monitor the pressure and update setpoints whenever needed. **Figure 2** shows how the Conductor is integrated into Inchfab's ICP-CVD system.

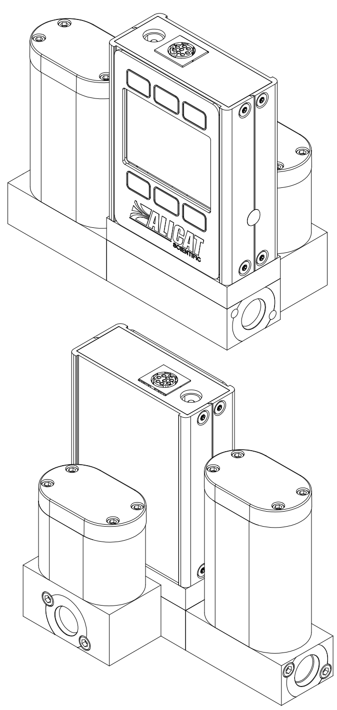


Figure 3: *A typical Alicat Conductor pressure controller*

Inchfab is continually striving to refine and expand its micro- and nanofabrication capabilities, and continuously looking for new technology that can assist in that effort. With instruments like Alicat's Conductor pressure controllers and MC-Series MFCs, there is no compromise needed between performance, reliability, and price-point, which makes them an easy choice for inclusion in Inchfab systems. Currently a member of the Activate – Cyclotron Road program at Berkeley National Lab, Inchfab is working with its partners to provide innovative and economical fabrication solutions for the micro- and nanoscale device community.

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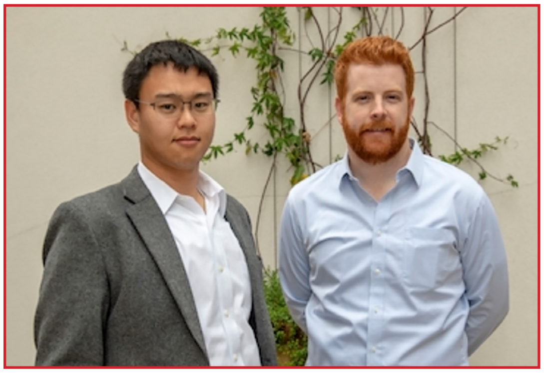

Mitchell Hsing, Ph.D.

CEO and Co-Founder at Inchfab

Dr. Hsing received his Ph.D. in electrical engineering with Prof. Martin A. Schmidt at MIT in 2018. Prior to his research into micro and nanofabrication methods he received a Masters of Science in electrical engineering at MIT, and a Bachelors of Science in electrical engineering at UC Irivine.

Parker Gould, Ph.D.

CTO and Co-Founder at Inchfab

Dr. Gould has spent more than a decade designing and researching novel micro- and nanofabrication methods. A Texas native, he completed his Ph.D. with Prof. Martin A. Schmidt at MIT in 2018, working on the development and characterization of low-cost fabrication tools and processes for "more-than-Moore" micro- and nanoscale devices. Prior to MIT, Parker received an M.Phil. in Micro- and Nanotechnology Enterprise from the University of Cambridge in 2012, and a B.Eng. in Electrical Engineering from Vanderbilt University in 2011.

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