#### Manufacturing of Multi-Scale Freeform Grooves Using a Micro-Scale Machine Tool

**Professor Richard E. DeVor and Professor Shiv G. Kapoor**

**Graduate Student: Keith Bourne**

### Goals
- Develop a rapid and inexpensive micro-groove cutting process for cutting arbitrary patterns of grooves with micron to submicron cross-sections and meso-scale lengths.
- Fast cutting speeds
- Open-air micro-machining
- Embossing mold production
- Micro-forming dies
- Lithography mask fabrication
- Micro-heat exchangers
- Free-form curvilinear patterns
- Large workpiece area (12.25 cm²)
- Microfluidic devices
- Engineered Surface Textures
- Optical features

### Mapping to Center’s Objectives
- Cost effective technology for the manufacture of precision meso-scale components with micro-scale grooves.
- Other research groups can machine experimental devices with highly detailed patterns of grooves.

### Fundamental Questions/Challenges
- Development of process and suitable machine tool topology.
- Effect of variations in cutting conditions and tool geometry on groove geometry and tool life.
- Modeling cutting mechanics at submicron scale.

### Research Plan
- Design, construct, and test a micro-groove cutting device.
- Use commercial AFM probes as tools in order to gain an basic understanding of how cutting speed, cutting load, and tool geometry effect the micro-groove cutting process.
- Develop cutting tools suitable for micro-groove cutting.
- Simulate micro-groove cutting process using finite element analysis and determine ways of improving the process.

### Research Results
- **Micro-Groove Cutting Device**
  - 35 x 35 x 35 mm of XYZ-stage travel.
  - 20 nm linear resolution.
  - Laser displacement sensor measures tool cantilever deflection with 10 nm resolution.
  - Variable tool orientations
  - Arbitrary cutting speeds

- **Micro-Groove Cutting Process**
  - Flexible single-point diamond cutting tools.
  - Cantilever is bent to apply a load to a cutting geometry.
  - Bending is measured and controlled by feedback.
  - Workpiece is traversed under the tool to form a chip.
  - Depth of cut is function of cutting load, tool geometry, and workpiece material.

### Tool Fabrication
- Tools fabricated by modifying diamond AFM probes via FIB.
- Four thru cuts
- Each cut made into the poster to remove the gray shaded sections.
- 50 – 64 nm edge radii achieved.

### Developed Rectangular Groove Cutting Capabilities
- Grooves up to 2 µm deep.
- Good reproduction of tool profile.
- Negligible tool wear when cutting at least 200 nm in aluminum.

### Developed Compound V-Groove Cutting Capabilities
- Micro-optics applications such as LCD backlight light guides.
- Tools can be fabricated to cut nearly arbitrary cross-sections.
- Target groove cross-sections achieved with very little burr formation.

### Developed Curvilinear Groove Cutting Capabilities
- Diffraction grating fabrication.
- Fabrication of long densely packed microfluidic channels.
- Continuous spiral grooves with 3 µm spacing and 82 mm length.

### Tightly Packed Groove Cutting Capabilities
- Fabrication of high-density micro-heat exchangers.
- Rectangular grooves 1 µm wide have been spaced as closely as 0.75 µm apart.
- Grooves as narrow as 300 nm but over 2 µm deep.

### Intersecting Groove Cutting Capabilities
- Required for microfluidics and surface patterning applications.
- Small exit burr if intersecting grooves are less than 0.5 µm deep.
- Burr reduction strategies must be developed for deeper grooves.

### Broader Impact
- Develop a low cost open-air microscale manufacturing process that will permit inexpensive manufacturing in a research laboratory, factory, or classroom environment.

### Future Efforts
- Develop finite element model of micro-groove cutting process.
- Demonstrate the ability to cut selected microscale features.
- Support Nano-CEMMS manufacturing needs.