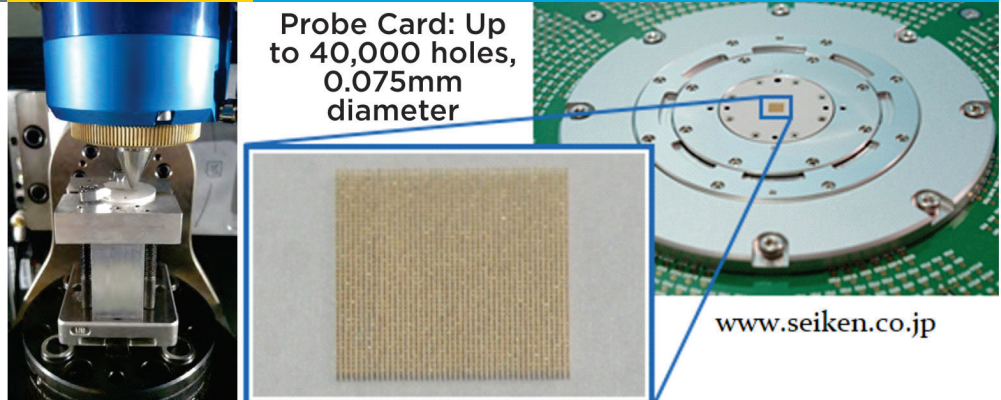


## High Metal Removal Rate Process for Machining Difficult Materials

A Novel Machining Platform Using Ultrafast Lasers to Produce High-Precision Components.

Machining is used in a variety of manufacturing applications in order to remove some material to create a finished product. Typical examples of machining include turning operations where a workpiece is rotated against a cutting tool, milling operations where the cutting tool rotates against the workpiece, and drilling operations where holes are produced or refined. However, traditional machining platforms are poorly suited to produce small parts with high accuracy requirements. The current machining methods are often too large, too inflexible, and lack the necessary precision to manufacture parts with complex shapes or micron-sized features.

The use of ultrafast (femtosecond) lasers can overcome these limitations and machine advanced materials into high-precision components. Short laser pulses can use athermal ablation, which produces the final part without requiring post-processing to eliminate machining defects. Combining a laser with high-precision manipulators would automate and therefore expedite the machining process. This machining platform could remove material with micron precision, without modification or damage to the remaining material, and in a single-step manufacturing process. The project focus is to prove this new method in the production of gasoline direct injection (GDI) fuel injectors and difficult to machine materials.



The Multi-Axis Hybrid Processing (MAxHP) module (left) is one of the three main components of the multi application testbed built by Microlution to expand applications beyond gasoline direct injection fuel injectors. The MAxHP Module was used to demonstrate ceramic hole drilling to produce standard probe-card holes (right). Probe cards are used to test semiconductor wafers for the electronics industry. *Images courtesy of Microlution, Inc.*

### Benefits for Our Industry and Our Nation

Developing the ultrafast laser platform is a gateway to numerous advances in manufacturing. Combining lasers and motion control devices into a simple interface that can mesh with computer-aided design (CAD) renderings will expedite manufacturing compared to electro-discharge machining, a typical method used today for machining difficult materials. Energy efficiency is expected to increase by 20-25% and cycle time could decrease substantially. No consumables are required, which reduces materials costs and energy associated with their production. In addition, this process will eliminate post-production and its associated chemicals use. This technology could have broad impacts in diverse manufacturing sectors.

### Applications in Our Nation's Industry

Ultrafast laser technologies represent a leap forward for machining processes, reducing both time and energy versus standard micro-machining platforms. Applications that could utilize the technology are diverse. For example, GDI fuel injectors play an important

role in efforts to develop cars with better fuel economy. Engines that use GDI injectors are more energy efficient due to their higher compression ratios and better compatibility with turbocharging. Turbocharged GDI engines could be downsized to improve fuel economy by 10% or more without affecting performance. This technology would also be available for use in other applications including electronics, defense, solar energy, wind energy, biosciences, and medical devices.

### Project Description

This project developed an automated, ultrafast laser machining device that was first used to prototype GDI fuel injectors. Combining the manipulators with the laser resulted in a machine that is able to machine parts to high specifications. The platform can turn CAD drawings into high-precision prototypes. Simultaneous to the creation of this platform, specifications needed for GDI fuel injector component manufacturing was established. Once the laser drilling system was completed, the platform was used on a sample production line. The resulting prototypes were tested to ensure that they met known customer and performance requirements.

## Barriers

- Ensuring that the laser can be tuned to work with necessary precision at an acceptable rate.
- Designing the mechanical manipulator to the necessary specifications.
- Ensuring that the laser and the mechanical manipulator can communicate with each other and take commands from the design software.
- Producing a prototyped part that is able to meet mechanical and performance metrics at cost.

## Pathways

This project proceeded through two separate tracks that were eventually combined in order to reach the final objective. Researchers simultaneously developed the enhanced ultrafast laser and the microscale manipulator, then integrated and tested these two devices to specifications set by Delphi. Delphi then tested the automated laser drilling device by making GDI fuel injectors. Spray and flow performance for these injectors were determined via bench testing before the injectors were evaluated in engines. The resulting advanced components offered improved manufacturing efficiency and lower energy inputs compared to products made with currently available machining techniques.

## Milestones

This project began in 2012 and was successfully completed in 2016.

- Develop an integrated laser and scan head that meets target rotational speed that exceeds 200Hz at an attack angle above 80% (Completed).
- Demonstrate drilling of fuel injector spray holes in less than 8 seconds and an overall 50% cycle time reduction in machine time with no degradation in quality compared to existing micro-machining processes (Completed).
- Increase laser machining efficiency by 20-25% compared to standard micro-machining processes (Completed).
- Produce fuel injectors that pass cold start engine tests and move technology towards production setting (Completed 2014 and adopted by Delphi in 2015).

## Commercialization

Delphi successfully adopted the technology to make GDI fuel injectors in 2015. In addition, Microlution successfully developed platform applications relevant to the electronics and biomedical industries, including ceramic hole drilling (electronics industry), precious metal drilling (biomedical industry), and precious metal tube cutting (biomedical industry). Process validation tests for the various applications were successfully completed. Consequently, completion of the project ultimately resulted in a manufacturing method offering reduced process steps and energy consumption for hard-to-machine materials across multiple markets.

## Project Partners

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