

# Development of Advanced Machining Technology Using ABLASER<sup>®</sup> Laser Micromachining System - Targeting Laser Solutions in the Fields of Mobility and Electronics -



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*In recent years, laser machining has been applied to products in various fields including the semiconductor industry. However, it is difficult for conventional laser machining techniques to meet the need for high-precision, high-quality micromachining that accompanies the miniaturization and performance improvement of parts because of the thermal effects on the workpiece material. Therefore Mitsubishi Heavy Industries Machine Tool Co., Ltd. has adopted a short pulse laser, combined it with our proprietary technologies including the laser head and the control mechanism to develop the ABLASER<sup>®</sup> laser micromachining system and realized high-precision and high-quality micromachining stably during long periods of time. We have also clarified that not only metallic materials, but also brittle materials such as ceramics and glass can be micromachined by laser.*

## 1. Introduction

Since its introduction in the 1960s, laser machining has made remarkable progress to this day and has spread widely to the industrial world. Laser machining is applicable not only to metallic materials, but also to non-metallic materials such as brittle materials and has been utilized in various fields. On the other hand, in all industries including the automobile and semiconductor industries, as products become smaller and more sophisticated and the need for high-precision and high-quality micromachining increases, conventional laser machining has become unable to satisfy the quality required for such products in terms of hole diameter accuracies, machined surface properties, etc., because of the thermal effects on the workpiece material. In addition, it is extremely difficult for conventional laser machining techniques to secure positional accuracy on the 1/1000 mm level during operation over long periods of time for mass production machining.

Therefore, we adopted a short pulse laser based on the laser technologies we have cultivated in the heavy industry field and combined it with our machine tool expertise, enabling application to accuracy improvement to develop the ABLASER<sup>®</sup> laser micromachining system, which realizes high-precision and high-quality machining stably during long periods of time.. This report presents micromachining technologies for various materials using the developed ABLASER<sup>®</sup>.

## 2. Features of ABLASER<sup>®</sup> laser micromachining system

### 2.1 Features of ABLASER<sup>®</sup> laser micromachining system

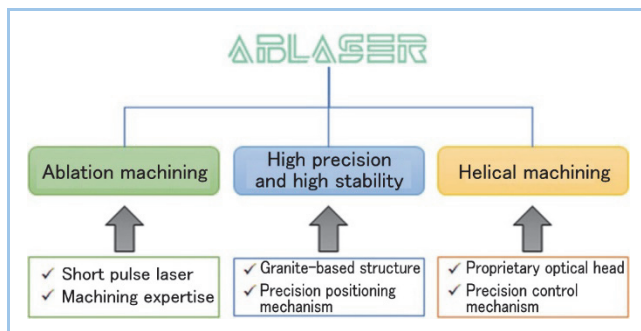
**Figure 1** presents the three features of ABLASER<sup>®</sup>. The first feature, ablation machining, uses a short pulse laser to sublimate (ablate) the material and suppress the thermal effect to a minimum on the surroundings. **Figure 2** illustrates the features of the short pulse laser. The shorter pulse width can reduce the heat damages such as thermal-affected layer and micro crack to the workpiece material and the deposits on the periphery such as residue (dross) generated during

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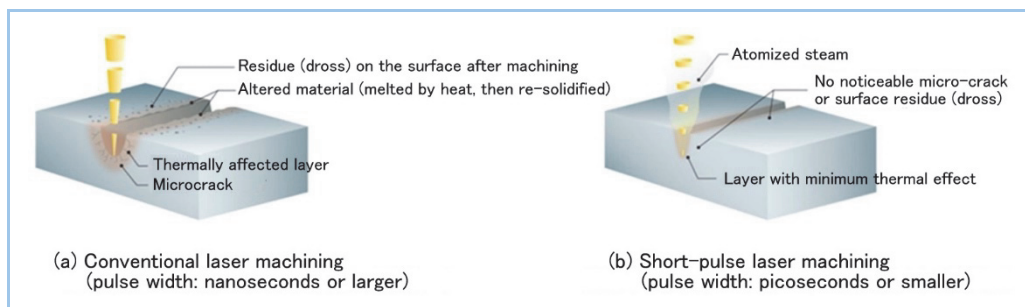
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machining. The second feature, high precision and high stability, is achieved by using granite, which has little thermal displacement and a high vibration damping effect, for the main structure, and adopting a precision scale for the positioning mechanism. As a result, not only is high positioning accuracy achieved, but also the positional accuracy change during operation over long periods of time is also suppressed, and a machining accuracy higher than that of conventional laser machine tools is achieved. The third feature, helical machining, enables high-precision and high-quality hole machining. We applied the laser optical systems and a control mechanism that provides precise synchronous control to develop our proprietary optical laser head that enables helical machining.

With the technologies for the three features above, high-precision and high-quality laser machining was achieved and the stability during continuous operation over long periods of time was secured. As a result, we realized a laser micromachining system that can even be applied to mass-production machining, which was difficult to put into practical use until now.



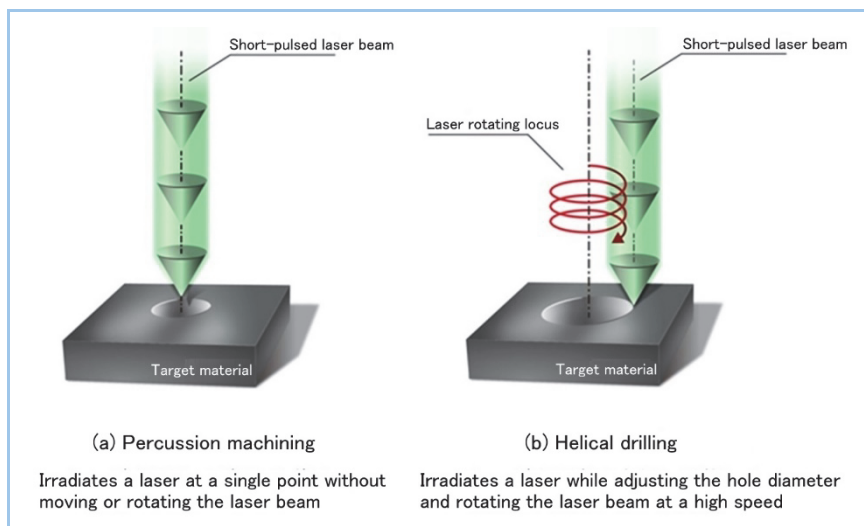
**Figure 1** Features of ABLASER<sup>®</sup> laser micromachining system



**Figure 2** Features of short pulse laser machining

## 2.2 Features of helical drilling

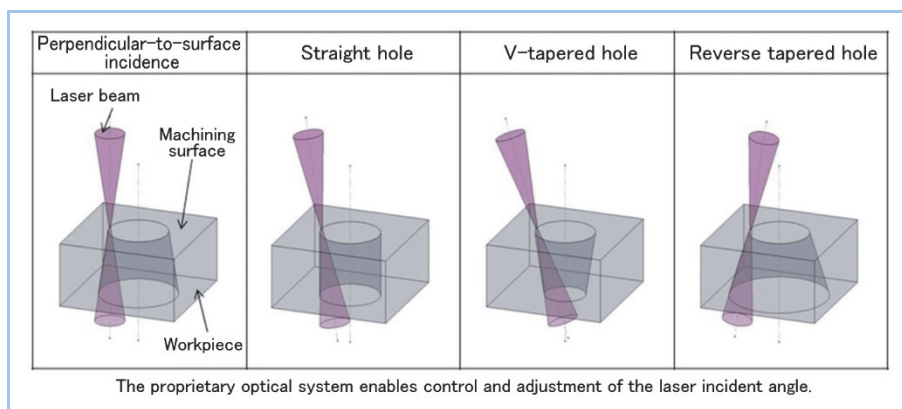
Generally, laser hole machining techniques include (a) percussion machining and (b) helical drilling as shown in **Figure 3**.



**Figure 3** Laser hole machining techniques

Percussion machining is a technique that irradiates a laser at a single point without moving or rotating the laser. This technique can perform micromachining of the smallest diameter but cannot form a precise hole shape. In addition, since the spread generated by the light condensing occurring at the lens is transferred, the cross section of a machined hole is unintentionally taper-shaped.

On the other hand, helical drilling irradiates a laser while adjusting the hole diameter and rotating the laser at a high speed. The beam rotating mechanism of our proprietary laser optical system adopts a spindle structure using precision machine tool bearings and can precisely control the rotating diameter of the laser. Furthermore, as shown in **Figure 4**, the incident angle of the laser can also be adjusted. As a result, this system can perform machining of any hole diameter and sectional shape.



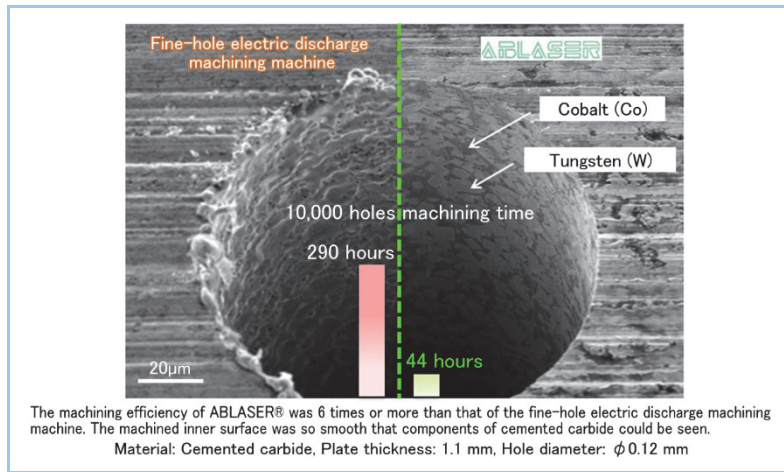
**Figure 4** Hole cross-sectional shape examples provided by laser incident angle control

### 3. Comparison with machining holes by fine-hole electric discharge machining machine and ABLASER<sup>®</sup> machining system

Micro-hole machining techniques other than laser machining include mechanical machining, electric discharge machining, etc. With either of them, generally the machining time tends to be longer as the hole diameter is smaller. However, with laser machining, which concentrates energy in a minute area for machining, as the hole diameter is smaller, the removal volume decreases and the machining time becomes shorter.

In addition, when performing high-precision micromachining, mechanical machining and electric discharge machining need to use appropriate small diameter tools and electrodes, so continuous machining over long periods of time is difficult because of necessity of small diameter tools and electrodes consumed by processing. However, since ABLASER<sup>®</sup> does not require to change tools or electrodes, making continuous high-precision micromachining over long periods of time possible by using laser.

**Figure 5** compares case examples of machining hole between ABLASER<sup>®</sup> and an electric discharge fine-hole machining machine used for the micro-hole machining of molds. With the electric discharge fine-hole machining machine, it took 290 hours to drill 10,000 holes with a hole diameter of  $\phi 0.12$  mm in a cemented carbide plate with a thickness of 1.1 mm, and it was necessary to replace the electrodes frequently during the process. Minute burrs were generated on the edge and a modified layer appeared due to electric discharge on the inner surface of the hole. On the other hand, with ABLASER<sup>®</sup>, the machining time was 44 hours, that is, the machining efficiency was 6 times or more than that of electric discharge machining and non-stop machining was possible from start to finish. In addition, there were no burrs generated on the edge and the inner surface could be machined so smoothly that cobalt and tungsten, which are components of cemented carbide, could be seen.



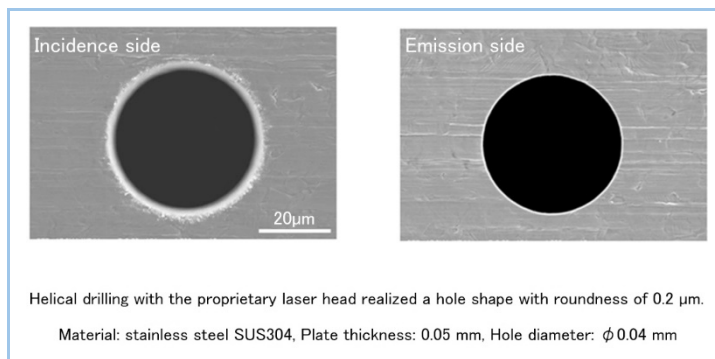
**Figure 5 Comparison with machining holes between by electric discharge machining and ABLASER®**

## 4. Machining examples of ABLASER®

### 4.1 High-precision and high-stability hole machining

#### (1) High-precision hole machining (workpiece material: stainless steel SUS304)

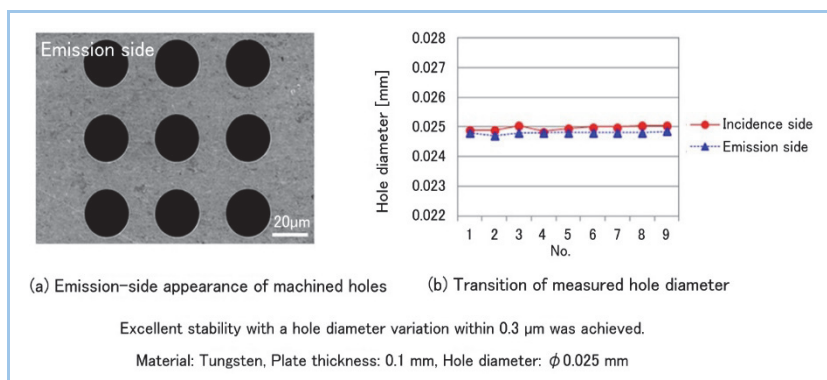
**Figure 6** gives an example of high-precision hole machining of a hole with a diameter of  $\phi 0.04$  mm in a stainless steel (SUS304) plate with a thickness of 0.05 mm. Helical drilling with the proprietary laser head realized a hole shape with a roundness of  $0.2 \mu\text{m}$ .



**Figure 6 High-precision hole machining**

#### (2) High-stability hole machining (workpiece material: tungsten)

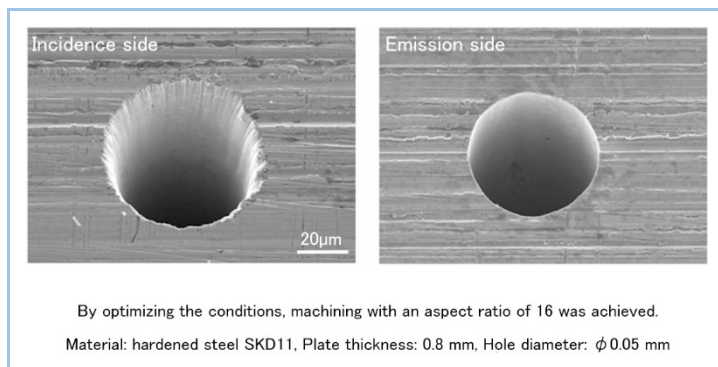
**Figure 7-(a)** is a photograph of the appearance of 9 holes with a diameter of  $\phi 0.025$  mm machined continuously in a tungsten plate with a thickness of 0.1 mm. **Figure 7-(b)** depicts the transition of the measured hole diameter. Even the continuous machining of 9 holes resulted in high-precision hole shapes equivalent to the one shown in **Figure 6**, and the hole diameter variation was within  $0.3 \mu\text{m}$ . High precision and excellent stability are achieved, so ABLASER® can be expected to be applied for a semiconductor manufacturing device for machining parts.



**Figure 7 High-stability hole machining**

#### 4.2 High-aspect ratio machining (workpiece material: hardened steel SKD11)

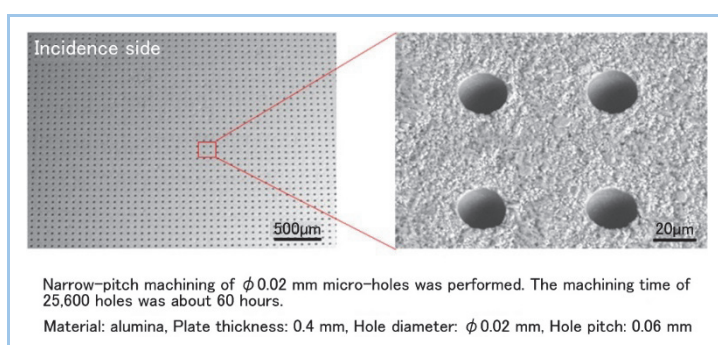
**Figure 8** presents an example of high-aspect ratio machining of a hole with a diameter of  $\phi$  0.05 mm in an hardened steel SKD11 plate with a thickness of 0.8 mm. By optimizing the conditions, machining with an aspect ratio of 16 was achieved. The smooth inner surface of the machined hole indicates that the thermal effect during machining was minor. This technique is applied to the machining of press dies holes in green sheets used in ceramic substrates manufacturing for semiconductor products.



**Figure 8 High-aspect ratio machining (aspect ratio: 16)**

#### 4.3 Multi-hole machining of ceramic material

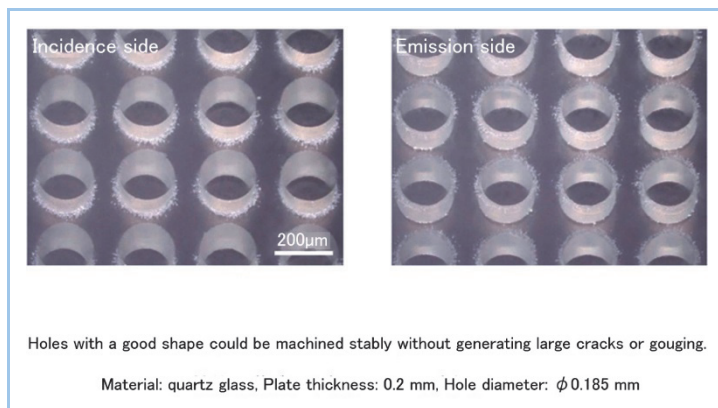
**Figure 9** is an example of the machining of 25,600 holes with a diameter of  $\phi$  0.02 mm and a hole pitch of 0.06 mm in a plate made of alumina, which is a ceramic material, with a thickness of 0.4 mm. For not only metallic materials, but also alumina, brittle material, small-diameter machining with an aspect ratio of 20 could be performed. For mechanical machining with tools, it is very difficult to perform narrow-pitch machining because it generates cracking by chipping on the hole edges. In addition, mechanical machining with tools causes a large amount of tool wear, resulting in a significant burden in terms of cost. ABLASER<sup>®</sup> realizes machining that results in edges without cracking between holes by the combination of ablation machining with less thermal affect and high precision helical drilling machining, which is free from the problems described above. Furthermore, high-aspect ratio micromachining of 25,600 holes could be completed without stopping the machine for the replacement of consumables such as tools, despite continuous machining for about 60 hours. ABLASER<sup>®</sup> is capable of machining ceramic materials as described above and can be expected to be applied to the machining of parts that require insulation and those that require wear resistance, such as inspection tools and precision parts for semiconductor products.



**Figure 9 Multi-hole machining of alumina**

#### 4.4 Hole machining of glass material

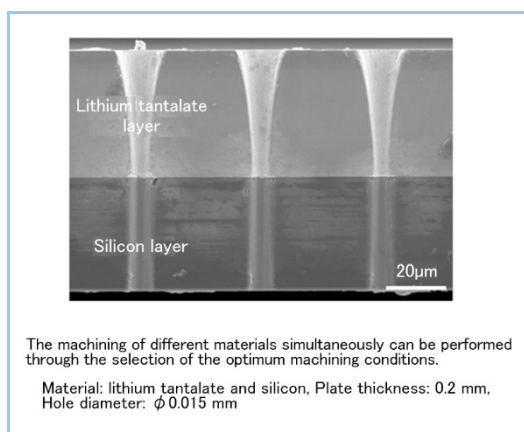
**Figure 10** gives an example of machining holes with a diameter of  $\phi$  0.185 mm in a quartz glass plate with a thickness of 0.2 mm by directly irradiating a laser. Holes with a good shape could be machined stably without generating large cracks or gouging. It is very difficult for conventional laser machining of the machining of glass material to control the hole diameter and the taper angle to any value, but ABLASER<sup>®</sup> can control them



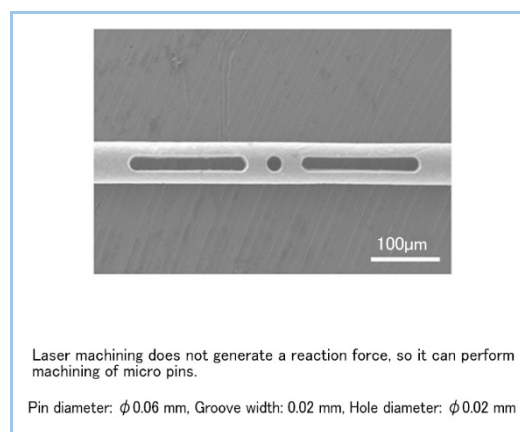
**Figure 10** Hole machining of quartz glass

#### 4.5 Hole machining of multi-layer material (lithium tantalate and silicon)

**Figure 11** is a cross-sectional photograph of forward taper holes with a diameter of  $\phi$  0.015mm machined in a multi-layer material (with a thickness of 0.2 mm) made of lithium tantalate and silicon used for electronic devices. Conventionally, etching with different processes depending on the material was used. However, ABLASER<sup>®</sup> can perform machining of different materials simultaneously through the selection of the optimum machining conditions. This is greatly advantageous for the reduction of cost and cycle time.



**Figure 11** Cross-sectional photograph of holes machined in multi-layer material



**Figure 12** Cross-sectional photograph of groove and hole machined in micro pins

#### 4.6 Machining of micro pins

**Figure 12** shows an example of machining grooves with a width of 0.02 mm and a hole with a diameter of  $\phi$  0.02 mm in a steel pin with a diameter of  $\phi$  0.06 mm. It is difficult for contact machining such as mechanical machining to perform machining of a micro pin, etc., because of the reaction force. However, laser machining does not generate a reaction force, so it can perform the machining of micro pins and can be applied to the manufacture of stents and syringes used in the medical field.

In this way, ABLASER<sup>®</sup> is capable of not only hole machining, but also micromachining of parts with various shapes.

## 5. Conclusion

The ABLASER<sup>®</sup> laser micromachining system, which was developed based on our proprietary technologies, realizes higher-precision and higher-quality machining in comparison with conventional laser machining and also ensures stability during operation over long periods of time. This report demonstrated that ABLASER<sup>®</sup> is a laser machining system featuring high accuracy and excellent stability while also presenting machining examples. This paper also gave examples of micromachining of not only metallic materials, but also brittle materials such as ceramics and glass. It is expected that products will become smaller and more sophisticated in a wide range of fields, centering on the fields of mobility—where electrification technology such as

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autonomous driving will continue to advance—and electronics, including IoT and 5G. In this context, we will continue to offer laser micromachining solutions that satisfy the needs of our customers.

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## References

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- (2) Yuji Imamiya et al., Development of Microfabrication Technology using DUV Laser, Mitsubishi Heavy Industries Technical Review Vol. 53 No. 4 (2016)