High-performance Printed Circuit Board Production Equipment for Ultra-high Density Multi-layer Wiring

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OVERVIEW: Recent years have seen dramatic progress in the performance of electronic devices such as mobile phones, notebook PCs, and electronic books. These performance improvements require not only the miniaturization and performance enhancement of the semiconductors and other components used in these devices but also the ability to achieve higher densities, multi-layer structures, and smaller hole diameters in the PCBs on which these components are mounted to form electronic circuits. As a manufacturer of production machinery for PCBs, Hitachi Via Mechanics, Ltd. supplies mechanical and laser drilling machines able to drill small-diameter interlayer connection holes with high speed and precision and direct exposure machines capable of producing the very fine wiring and high precision needed for higher wiring densities. These machines are supplied to the PCB industry throughout the world where they contribute to improvements in the performance of electronic devices.

INTRODUCTION

THE trend toward producing PCBs (printed circuit boards) with higher densities as electronic products have become more sophisticated is driving demand for smaller diameters and higher precision in the machining of interlayer connection holes on PCBs by mechanical and laser drilling machines.

Meanwhile the circuit patterns produced by the

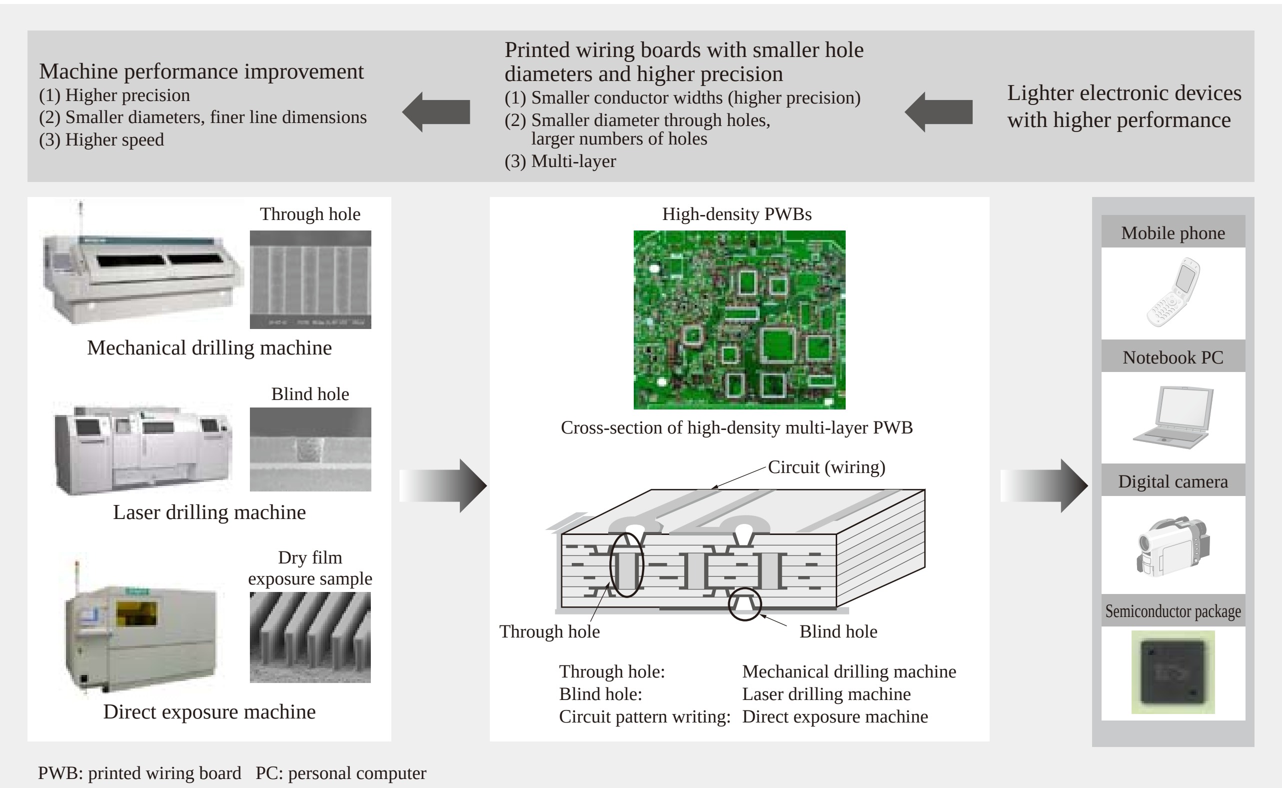

Fig. 1—Role of Drilling Machines and Exposure Machines in Printed Wiring Board Production.
Mechanical and laser drilling machines are used to machine interlayer connection holes on multi-layer printed wiring boards and direct exposure machines are used for circuit pattern formation.

circuit forming process are becoming ever finer and this creates a need for smaller inter-wire spacings and greater precision in through hole and pad alignment accuracy.

This article describes the trends in hole machining technology using drills and lasers able to produce PCBs with higher densities, and in ultra-fine, high-precision exposure technology using direct exposure machines.

TRENDS IN PRINTED CIRCUIT BOARDS AND PRODUCTION EQUIPMENT

Role of Drilling and Direct Exposure Machines

The need for high-density mounting on PCBs has made the build-up printed wiring board an essential technology. Similarly, the machining of THs (through holes) using drills and BHs (blind holes) using lasers are both important techniques for making connection holes during mass production. Meanwhile, circuit pattern formation is starting to shift away from the mask exposure technique used in the past toward direct exposure which can draw the circuitry directly using fine lines (see Fig. 1).

Technologies for Higher Density

The demand for PCBs with higher densities is also accompanied by a need for higher precision, smaller diameters, finer lines, and faster speeds. To achieve these requirements, Hitachi Via Mechanics, Ltd. is adopting high-speed spindles [350,000 rpm (revolutions per minute)] and table servo technology with high speed and precision for mechanical drilling machines, galvano technology using panels and multiple beams with high speed and precision (> 3,000 Hz positioning) for laser drilling machines, and small high-precision lenses and high-speed data processing techniques (1.7 Gbyte/s) for direct exposure machines. The following sections describe the technologies used for each type of machine (see Fig. 2).

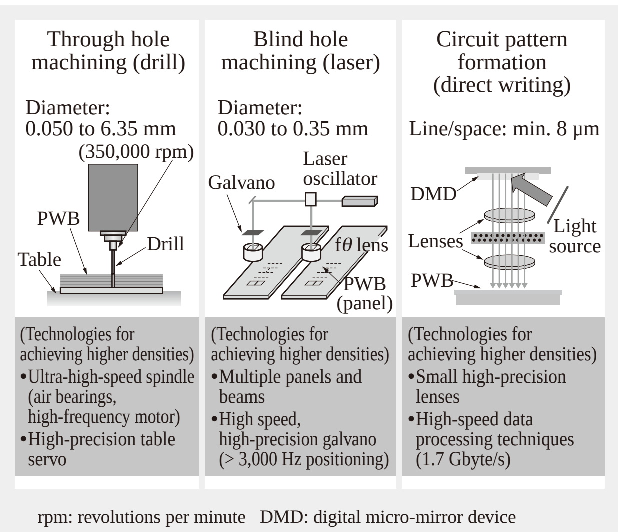

Fig. 2—Drilling and Exposure Machine Technologies for Achieving Higher Densities.
The processing capacities of different machines and the technologies they use to achieve higher densities are shown.

DRILLING TECHNOLOGY

PCBs can be divided into single-sided, double-sided, and multi-layer boards depending on the application, and the higher mounting densities associated with making products smaller and more sophisticated have led to drill hole diameters being reduced to 0.3 mm or less for various different device types including PCs (personal computers) and mobile phones. Recent years have also seen a shift toward use of FC-BGA (flip chip ball grid array) and CSP (chip-size package) packages which has led to drill hole diameters as small as 0.1 mm.

It is anticipated that hole diameters of 0.10 mm or smaller will be required in future (see Table 1).

High-speed Spindle

The spindle is the rotating part that holds the drill bit and is a critical component for small-diameter drilling. Current practice aims to achieve higher

TABLE 1. Drill Hole Diameters for Different PCB Applications
Drill hole diameters and hole positioning accuracy for different PCB (printed circuit board) applications (products) are shown.

Application	Hole diameter (mm)	Hole positioning accuracy (mm)
PCs, notebook PCs	ϕ0.3 – ϕ0.4	<0.075
Mobile phones	ϕ0.2 – ϕ0.3	<0.050
Digital cameras, games	ϕ0.2 – ϕ0.3	<0.050
FC-BGA	ϕ0.1 – ϕ0.25	<0.035
CSP	ϕ0.15 or less	(<0.025)

FC-BGA: flip chip ball grid array CSP: chip-size package

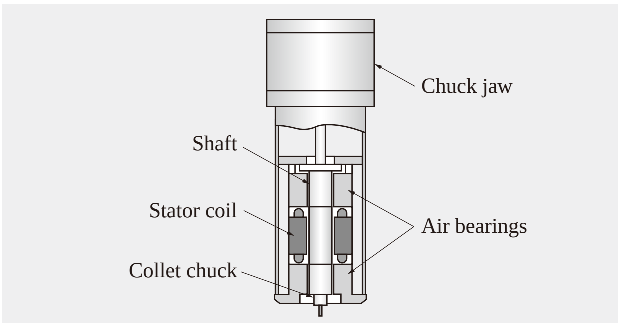

Fig. 3—Spindle Structure.
The internal structure of a high-speed spindle with air bearings is shown.

spindle speeds as well as smaller diameters, with machining of 0.10-mm holes being performed at a (maximum) speed of 350,000 min^{-1}. To cope with these high speeds, the spindles use air bearings and a direct drill bit held by a precision collet chuck built into the rotor. The system also requires technology for stable high-speed rotation that can keep the dynamic vibration of the drill bit tip to within 10 µm. The development of ultra-high-speed spindles able to operate above 350,000 rpm is an important challenge for achieving reliable machining of sub-0.10-mm hole diameters in future (see Fig. 3).

Hole Position Accuracy

The smaller hole diameters needed to increase the density of PCBs require more accurate positioning of where the holes are machined (see Table 1). Achieving this high-precision machining using a conventional six-drill drilling machine requires servo technology able to position, in 50 ms or less, a large (approximately 500 kg) table on which circuit boards are placed at six stations. Recently, Hitachi Via Mechanics has devised a new system in which the vibration caused by the movement of this large mass can be reduced by splitting the table and spindle units into two three-drill units so that the left and right halves can move in mutually opposing directions to damp vibration, as shown in Fig. 4. This is complemented by a new type of drilling machine with higher precision. For the Z-axis, the machine uses a tunnel actuator type linear motor jointly developed with Hitachi Research Laboratory which moves the spindle up and down at a rate of more than 800 hits per minute. An indication of the hole position accuracy required in practice is that future CSP components with a 0.08-mm hole diameter will require an accuracy of 0.025 mm or less (see Fig. 5).

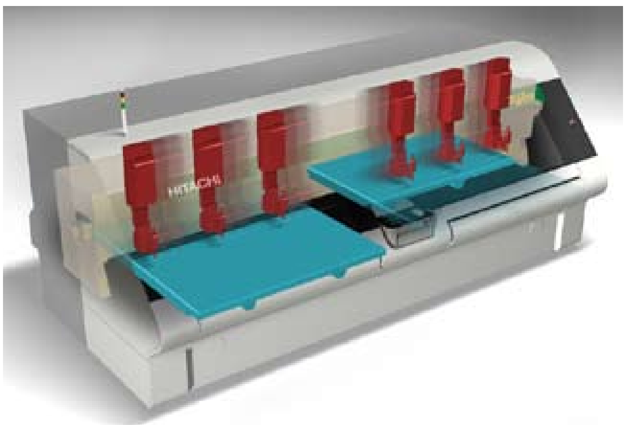

Fig. 4—Drilling Machine that Uses Opposing Motion to Minimize Vibration.
The mechanism moves the tables and spindles on the left and right in mutually opposing directions to minimize mechanical vibration.

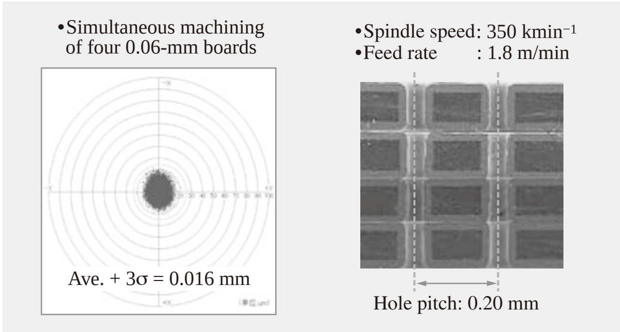

Fig. 5—Positioning Accuracy for Drilling 0.8-mm Diameter Holes.
The hole positioning accuracy for a circuit board machined using a drilling machine and the cross-section after hole electroplating are shown.

Technologies for High-speed Drilling

Higher PCB density means more holes to be drilled. Whereas the 500 × 600-mm boards used in the production of mobile phones typically require 30,000 to 50,000 holes, for a CSP board this number rises to 200,000 to 300,000. With some boards requiring as many as one million holes, higher drilling speeds have become essential. The drilling process involves positioning the board in the XY axes and the vertical movement of the drill in the Z axis. Because hole pitches are becoming smaller, the benefits of faster XY-axis movement are limited and instead speed improvement requires a shorter Z-axis stroke and faster Z-axis feed rate. However, with the Z-axis feed rate being determined by the drill diameter, spindle speed, and board material making it highly dependent on increases in the spindle speed, minimizing the Z-axis stroke is essential. In response, Hitachi Via Mechanics has developed a “hovering system” to minimize the Z-axis stroke and prevent scratching caused by negative pressure from the dust collection system lifting the top board (aluminum).

The hovering system applies compressed air to the top board from the underside of the end bush to prevent scratching of the top board caused by suction from the dust collection system lifting it upward as moves in the XY axes. It is anticipated that this will improve productivity by approximately 20% by minimizing the Z-axis stroke.

As these technologies indicate, there is a never-ending need for smaller diameters, higher precision, and greater productivity in hole drilling (see Fig. 6).

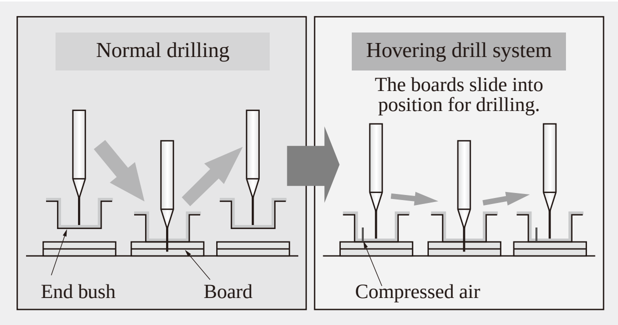

Fig. 6—Operation of Hovering System.
A model of how the hovering system works is shown.

LASER MACHINING TECHNOLOGY

Techniques for using lasers to machine holes in circuit boards were developed as a way of machining BHs in the build-up process used to increase PCB density. Recent years have seen growing demand for smaller hole diameters and higher precision. Use of lasers for BH machining can be divided by product application into general-purpose build-up PWB (printed wiring board) used for products such as mobile phone motherboards, BGA (ball grid array), CSP module circuit boards, FC-BGA module circuit boards, flexible printed wiring boards, and so on. In all cases, however, the demand is for smaller hole diameters and improved hole positioning accuracy in order to achieve the higher densities needed for better product performance (see Fig. 7).

Current manufacturing practice: Type	Material	Hole diameter	Process	Forecast for small-diameter machining (2012 to 2014)
General-purpose build-up	RCC FR-4	75–200 µm	CO_2 Conformal Large window Cu direct	Diameter: 75–50 µm Process: CO_2 Cu direct
BGA CSP SIP	BT	100 µm	CO_2 Conformal Cu direct	Diameter: 75 µm Process: CO_2 Double-sided thin Cu foil
FC-BGA	Resin	50–60 µm	CO_2, UV Resin direct	Diameter: 50 µm or less Process: CO_2, UV Resin direct
Flex*	PI	75–200 µm	CO_2 Conformal UV Cu direct	Diameter: 50 µm or less Process: UV Cu direct

CO_2: carbon dioxide Cu: copper BGA: ball grid array
SIP: single in-line package UV: ultraviolet
* Flex is either a registered trademark or trademark of Adobe Systems Incorporated in the United States and/or other countries.

Fig. 7—Forecast Developments in PCB Production Using Laser Machining.
The figure shows likely developments in the materials, hole diameters, and laser machining processes used for various types of PCB including general-purpose build-up, BGA, CSP, SIP, FC-BGA, and Flex boards.

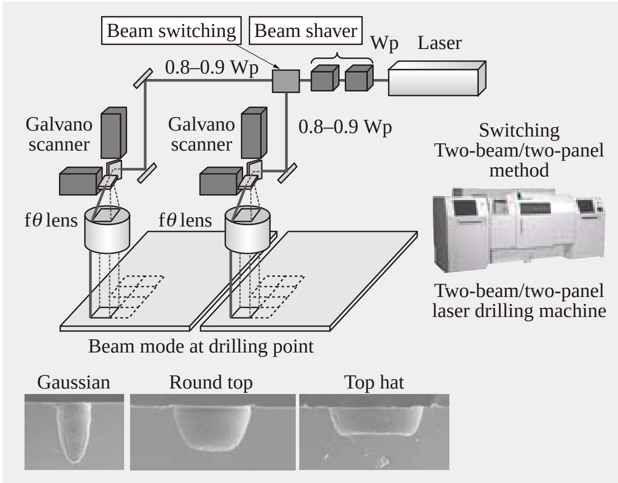

Fig. 8—Technologies Used in Laser Drilling Machines.
Beam mode control technology and optics and other technologies required for laser drilling machines.

Technologies Used in Laser Drilling Machines

This section describes the technologies required for the use of laser drilling machines to machine small-diameter holes in PCBs. Laser drilling machines consist of optics made up of components such as the aperture used to control the hole diameter and lenses that can be used to select the energy distribution of a laser beam generated by the laser head to suit the desired type of machining, a beam switching mechanism that generates multiple beams at high speed with consistent pulse energy, a galvano scanner that performs positioning with high speed and precision, and an fθ lens that focuses the beam uniformly onto the scanning area. The machines are also equipped with a proprietary step pulse control method to optimize the individual beam energies (see Fig. 8).

Ensuring Productivity and Improving Hole Position Accuracy

Features of the next generation of circuit boards will include smaller inner-layer pad diameters as a consequence of the smaller hole diameters as well as significantly more holes to be drilled due to the higher number of build-up layers. Accordingly, in addition to achieving the productivity needed to cope with the increase in the number of holes, laser drilling machines will also require the ability to machine holes with smaller diameters as well as improved hole positioning accuracy to align the machining location with the smaller inner-layer pads.

The speed of the galvano scanner determines the laser drilling speed. Galvano speeds of around

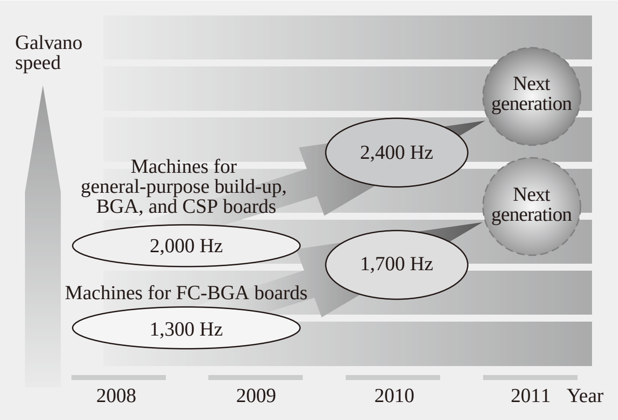

Fig. 9—Galvano Speed Roadmap for Laser Drilling Machines.
With the number of holes to be drilled growing extremely fast as PCBs achieve higher densities, improving productivity has become the critical issue. The graph shows the galvano scanner speed (which determines the laser drilling speed) for different process types.

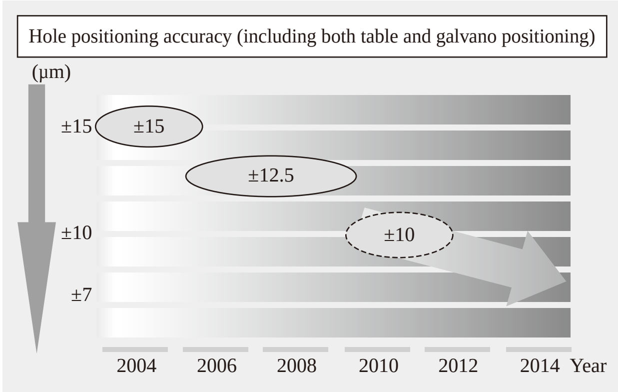

Fig. 10—Hole Positioning Accuracy Roadmap for Laser Drilling Machines.
In addition to productivity improvement, better hole positioning accuracy is also required to cope with the increasing density of PCBs. The graph shows the improvement in positioning accuracy over time for laser drilling machines designed to meet the demand for greater precision.

1,000 Hz a few years ago have since improved considerably to 2,400 Hz or more on machines designed for machining general-purpose build-up, BGA, and CSP boards that use standard galvano mirror sizes and 1,700 Hz or more on machines designed for machining FC-BGA boards that use large galvano mirror sizes for small-diameter drilling. This has already led to a dramatic improvement in the drilling speed of laser drilling machines and work on further improvement is in progress (see Fig. 9).

In parallel with the need to improve productivity to cope with higher densities and larger numbers of holes,

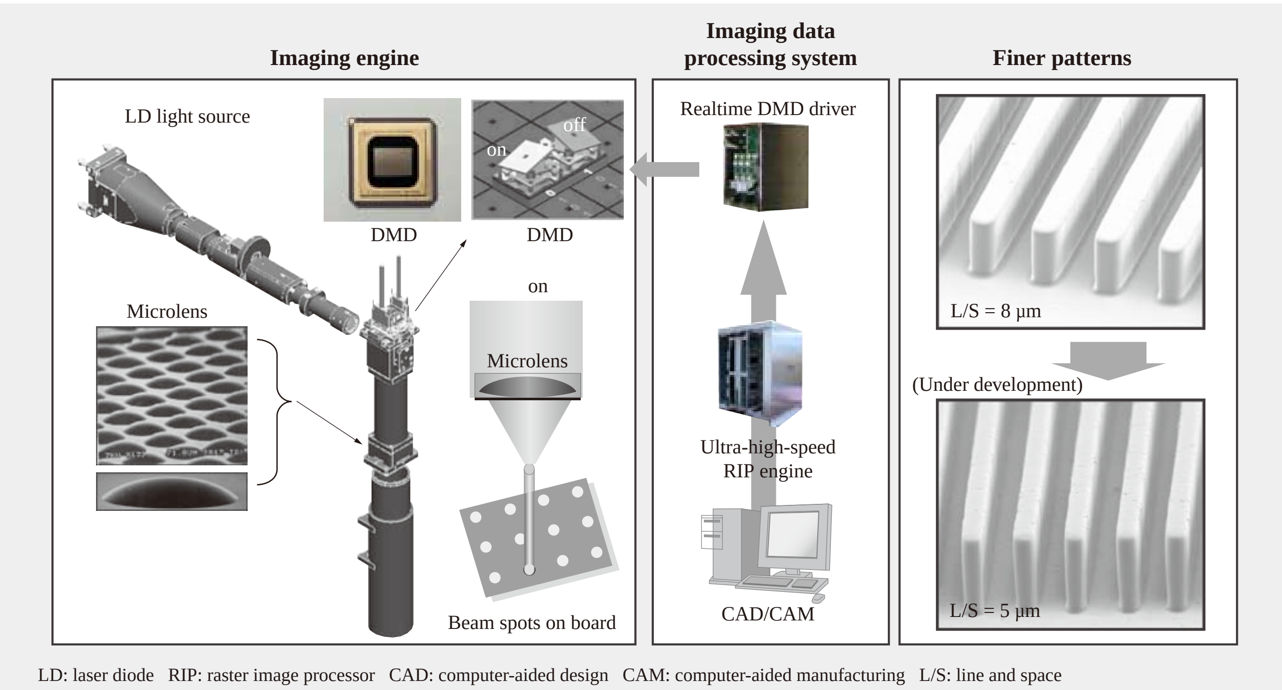

Fig. 11—Technologies Used for Direct Exposure Machines.
The main components used for direct exposure machines are an imaging engine (405-nm LD light source, DMD, projection optics) and an imaging data processing system (ultra-high-speed conversion of vector data to raster data). To produce finer patterns, progress is being made on achieving narrower beam spot diameters and higher data resolution. It is currently possible to produce hole diameters of 3.5 μm with resolution of 1 μm.

there is also a requirement to improve the precision of hole positioning which is made more difficult as inner pad diameters get smaller. Improvements including positioning technology for galvano servo control, compensation technology for galvano positioning control, and better table positioning accuracy were implemented to improve hole positioning accuracy to 0.010 mm or better and ways of further enhancing precision are being investigated along with work aimed at improving both productivity and accuracy (see Fig. 10).

DIRECT EXPOSURE TECHNOLOGY

As circuit patterns achieve higher densities, the circuit pattern formation process needs to handle finer pattern widths and more accurate alignment of THs and BHs with the pattern and this is directing attention away from mask exposure used in the past toward direct exposure.

The direct exposure technique improves alignment accuracy by digitizing the system used to process the imaging data and by converting the imaging data based on the expansion, contraction, and deformation of the board. Advances in imaging data processing systems have increased the capacity by a factor of about 17, from 0.1 Gbyte/s in the early days (2004) to 1.7 Gbyte/s now. This allows free-deformation/multiple division compensation to be performed separately for each board to improve alignment accuracy further. To produce finer patterns, testing is underway aimed at achieving line and space of 5 μm by improving the imaging engine optics to produce a narrower beam spot diameter (see Fig. 11).

CONCLUSIONS

This article has described the trends in hole machining technology using drills and lasers able to produce PCBs with higher densities, and in ultra-fine, high-precision exposure technology using direct exposure machines.

In response to the ongoing adoption of higher densities, smaller hole sizes, finer patterns, multi-layer structures, and more diverse designs and materials in PCBs, Hitachi Via Mechanics, Ltd. intends to continue acting as a best solution partner for the PCB manufacturing industry and supplying products that meet market needs in a timely manner.

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