Non-contact measurement in micro-drill holes

Drill holes determine the quality in circuit board production and are extremely small. Using fibre-optic sensors and miniature measuring probes, the layer position, drill hole depth and surface quality in **MICROVIAS** on multi-layer boards can be detected with high precision.

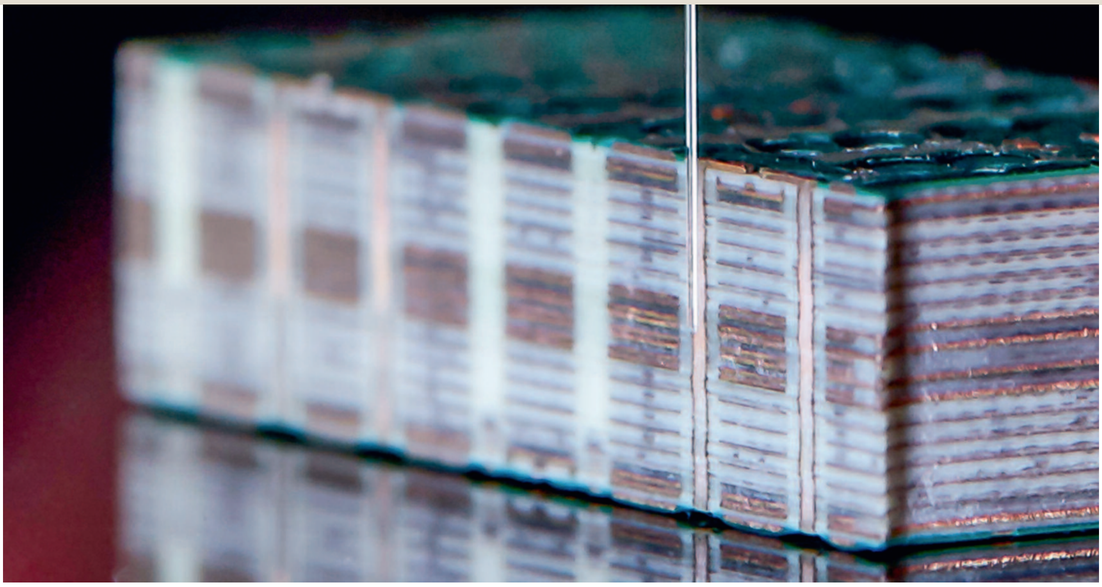

Figure 1. Measurement of a through drill-hole in a multi-layer board

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In the production of circuit boards, the trend is towards further increases in performance with a continuing reduction in size. The rise in productivity is achieved by higher packing densities and miniaturisation of structures and components.

For precise surface mounting (surface mounted technology, SMT) and through plating, in multi-layer boards it is essential to know the exact depth position of the individual copper layers. Particularly for applications in the high-frequency range, even minimal errors in contact position cause faults in the signal transmission or even short-circuits with adjacent layers. As a result of pressure and temperature effects during the production process, slight deviations in the actual dimensions of the board structures from the original CAD model cannot be avoided. The desired tolerances are in the single-digit µm range.

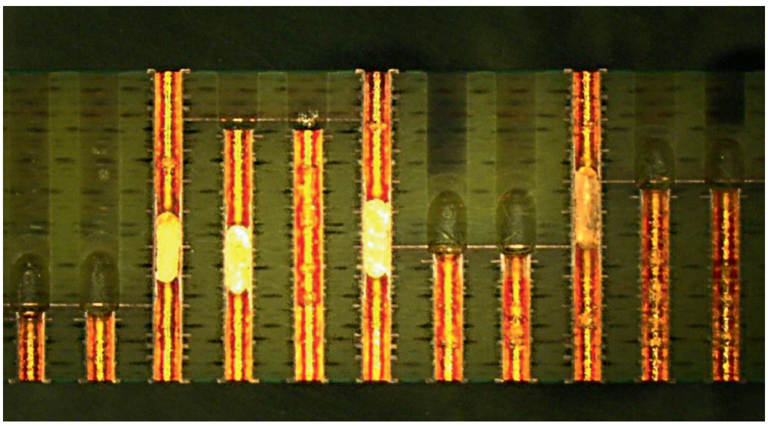


Figure 2. Cross-section through a multi-layer board with deep and through drill holes (microsection)

The requirements for maximum accuracy for the drill holes are also increasing, and a reliable detection of the drill hole depth is therefore also of importance. Topographic and geometric features of the inner sides, such as roughness and shape, are further quality assurance and performance-determining factors relevant to circuit board processing. Therefore, a metrology solution is required for fast, production-compatible and – as far as possible – non-destructive testing of the relevant parameters. The major challenge in detecting and measuring the inner sides of these microvias lies in the physical constraints of the objects to be measured **(Figure 1)**.

Figures: Fionec (1), Schmoll Maschinen (2)

Figures: Impex (3), Fionec (4)

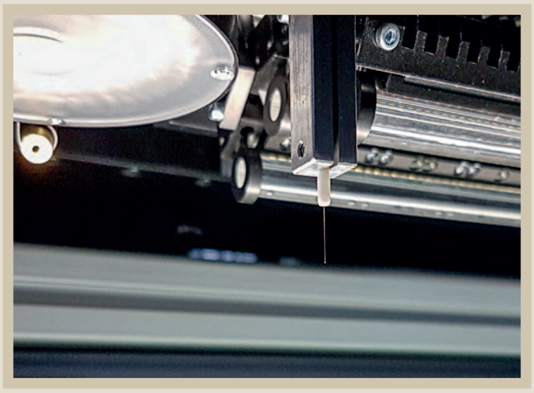


Figure 3. The miniature fibre-optic probe allows measurements in very small drill holes

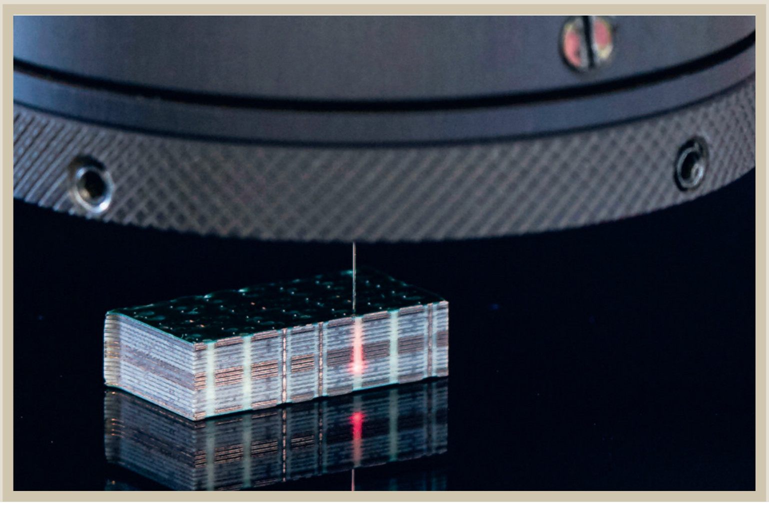


Figure 4. Measurement of a drill hole with a diameter of 0.6 mm

Measuring in confined spaces

With drill hole diameters of less than one millimetre, conventional measurement instruments and methods are of only limited use, as most metrology and camera heads cannot be inserted into the microvias due to their small size. As a result, previous assessment of the process and product quality was only possible using destructive methods, such as microsections **(Figure 2)**. In-line or 100 percent tests could not be performed. In addition, inspection following destructive testing unavoidably risks falsification, as destruction of the test samples naturally implies mechanical handling.

Therefore, the Aachen-based company Fionec upgraded its ›FDM-2‹ fibre-optic sensor for hole wall and drilling depth analysis on multi-layer boards, with miniaturised measuring probes and adaptation to the specific application **(Figures 3 and 4)**. The sensor function is based on the principle of white light interferometry and achieves absolute distance values with nanometre accuracy almost regardless of the surface.

The fibre-optic measurement system is non-contact, which makes it non-destructive and wear-free. With measurement frequencies up to 10 kHz, compared to tactile methods the technology delivers very high measuring point densities and short test times. Thanks to the use of optical fibres, the design allows minute probe diameters starting at just 80 µm.

Completely integrated

For analysis of microvias and detection of individual copper layers during circuit board processing on Schmoll machines, a miniature probe with a diameter of 125 µm and a 7 mm long bare fibre end was used **(Figure 5)**. The irradiation angle is 90° and the numerical aperture is 0.14. For drill hole depth and base condition measurements, an axial probe is used instead of a 90° probe.

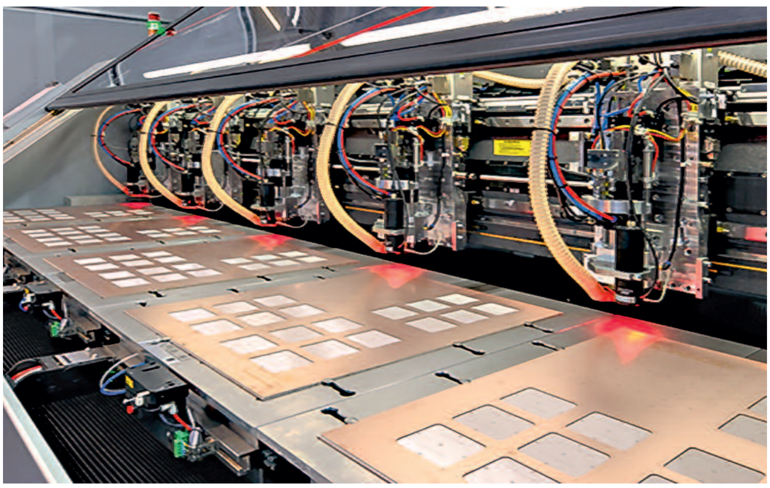
The prerequisite for achieving the required high accuracies in testing of the microvias is very precise positioning and guidance of the probe used. The fibre-optic FDM-2 sensors from Fionec were therefore completely integrated into the modular ›proX3‹ metrology system from Impex using appropriate interfacing. The three-axis granite-based precision mechanical system operates with absolutely no contact using air bearing technology. The system has an axis accuracy of less than 2 µm.

In addition to precise feeding of the measured value sensor, exact orthogonal alignment of the probe to the surface must be ensured. Because of the significant surface curvature of the small drill hole diameter, even small displacements of the axis or probe position have a negative effect on the measurement accuracy. Precise alignment of the miniature probe is ensured by a fully automated calibration routine. A mechanical insert in the measurement system also prevents alignment errors during clamping and makes it easy to change the probe.

Precision landing

Before performing the actual measurement, the proX3 uses a CCD camera module to first locate the drill holes to be tested by detecting the edges of the holes. The precision mechanical system then positions the fibre-optic probe. The micro-probe is

Figure 5. Drilling and milling machine with CCD registration and individual drive for all x- and y-axes



Figures: Impex (6), Schmoll Maschinen (7)

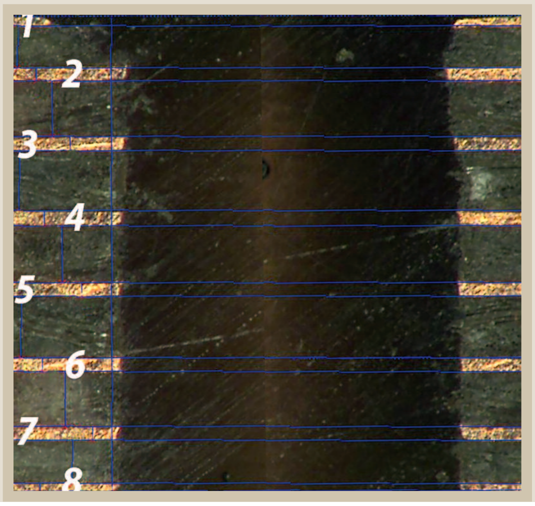


Figure 6. Microsection of a drill hole with copper layers

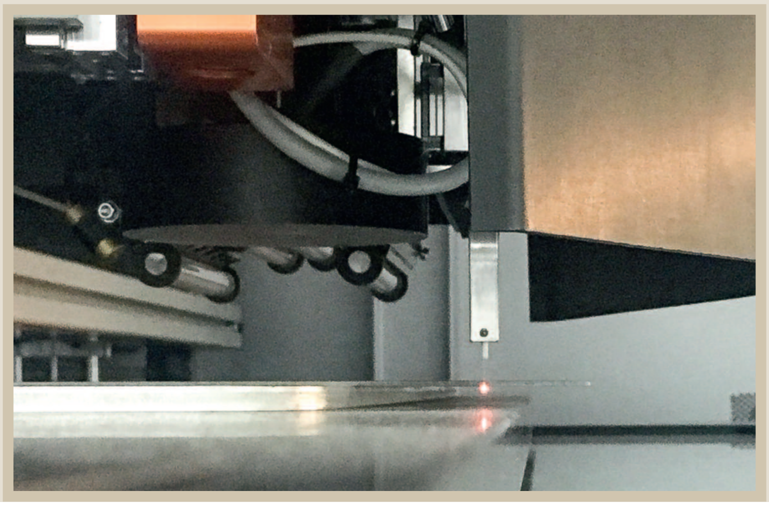


Figure 7. Inserted FDM-2 sensor for measurement of a through hole

Description	Cross-section result	Fibre-optic result	Deviation between results
Copper layer centre 1	9.08 µm	10.74 µm	–1.66 µm
Copper layer centre 2	93.60 µm	95.88 µm	–2.28 µm
Copper layer centre 3	206.32 µm	213.99 µm	–7.68 µm
Copper layer centre 4	323.34 µm	326.74 µm	–3.40 µm
Copper layer centre 5	439.41 µm	434.89 µm	4.52 µm
Copper layer centre 6	559.24 µm	553.01 µm	6.23 µm
Copper layer centre 7	669.14 µm	667.29 µm	1.85 µm
Copper layer centre 8	753.79 µm	750.89 µm	2.90 µm

Table 1. Comparison values from tactile and optical measurement of the layers

lowered into the drill hole to be tested and performs a linear scan on the inner side of the drill hole orthogonal to the surface. The working distance is normally 100 µm, but can be varied during assembly of the probes.

Depending on the individually definable point spacing, the system achieves sampling rates of up to 20 mm/s. As the entire calibration, feeding and testing process can be fully automated, rapid sequential measurements or pallet measurements can also be performed using this system.

By referencing the signal structure against the relevant axis position and the distance values from the sensors, the position of the individual copper layers can be determined with sub-micrometre accuracy.

Position determination

For the machine-based signal evaluation, Fionec works closely with the software and technology developer Meastream. The proprietary algorithms developed contain pre-filters for attenuation of high spatial frequency components, as well as cluster-analyses with a choice of maximum values or calculation of geometric focal points within those clusters that can be assigned to layers.

Comparing fibre-optic measured values with data obtained using microsections reveals variations of less than 10 µm. It is also important to consider that the copper layers can actually be deformed or damaged during creation of the microsection, which could increase the discrepancy in the values. **Table 1** compares the results of a tactile measurement with the results from an optical measurement for a panel with eight layers. The associated micrograph section can be seen in **Figure 6**.

In further investigations, the repeatability of the optical measurement was verified on eight-layer panels and with different drill hole diameters. This was done by measuring each drill hole 25 times, with each individual measurement

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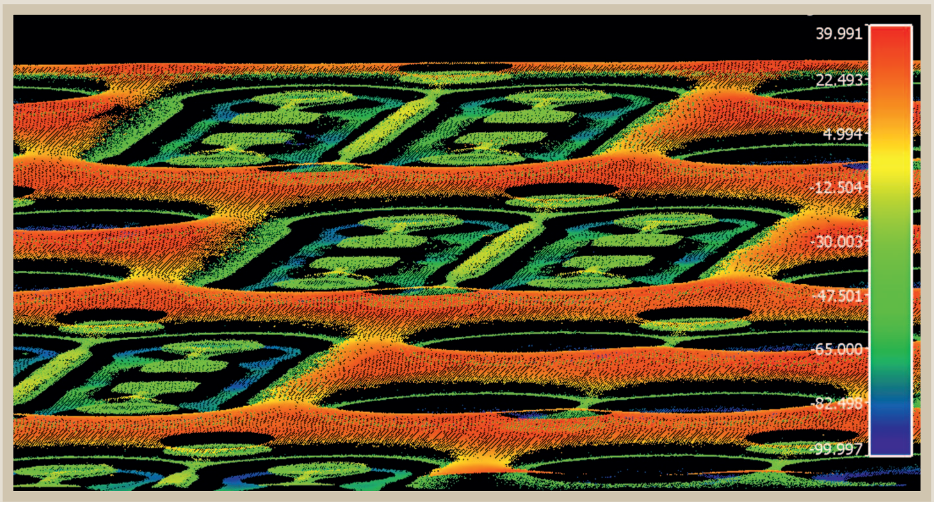

Figure 8. 3D point cloud for a topographic measurement on a board

Description	Standard deviation 1.6 mm hole	Standard deviation 2.2 mm hole	Standard deviation 3.175 mm hole
Copper layer centre 1	1.92 µm	1.71 µm	3.09 µm
Copper layer centre 2	1.95 µm	1.46 µm	1.75 µm
Copper layer centre 3	1.75 µm	1.36 µm	1.72 µm
Copper layer centre 4	1.72 µm	1.51 µm	1.65 µm
Copper layer centre 5	2.04 µm	2.10 µm	2.23 µm
Copper layer centre 6	1.89 µm	1.66 µm	2.05 µm
Copper layer centre 7	1.46 µm	1.61 µm	2.45 µm
Copper layer centre 8	1.98 µm	3.06 µm	2.22 µm

Table 2. Standard deviations from repeated measurements

incorporating camera-based detection of the drill hole and feeding of the measuring probe. The measurements show high reproducibility, with the associated standard deviations shown in **Table 2**.

Flexible quality control

The combination of fibre-optic FDM-2 sensors with miniature measurement probes and the proX3 mechanical system allows production-based high-precision testing of the relevant parameters and thus reliable production control in real time. Measurements in sync with the production cycle enable the results to be immediately fed back into the production process and thus facilitate immediate optimisation of the subsequent processing steps. Corrections to meet specifications with very tight tolerances can be made in good time, thus avoiding rejection of highly priced materials.

In addition to the challenging task of drill hole analysis, the small size of the measurement probe, the interferometric measuring principle and the precise interaction between the sensors and the mechanical system open up many other applications. Essentially, FDM technology is ideally suited for metrology tasks in very small holes, inaccessible and tight spaces, and for very finely structured surfaces or free-form surfaces with complex geometries **(Figure 7)**.

As well as detecting topographic profiles, shape and position tolerances, high-precision distance measurements and position determination with typical standard deviations of just a few nanometres are possible **(Figure 8)**. Furthermore, the measurement technology is suitable for detection of expansion, drift and vibrations on ultra-precision machinery and machine tools. Integrated system interfaces allow the FDM-2 sensors to be incorporated into a wide range of concentricity, roughness or coordinate measuring equipment, and also directly into production processes for in-line measurements with very short test times. ■ MI110506

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