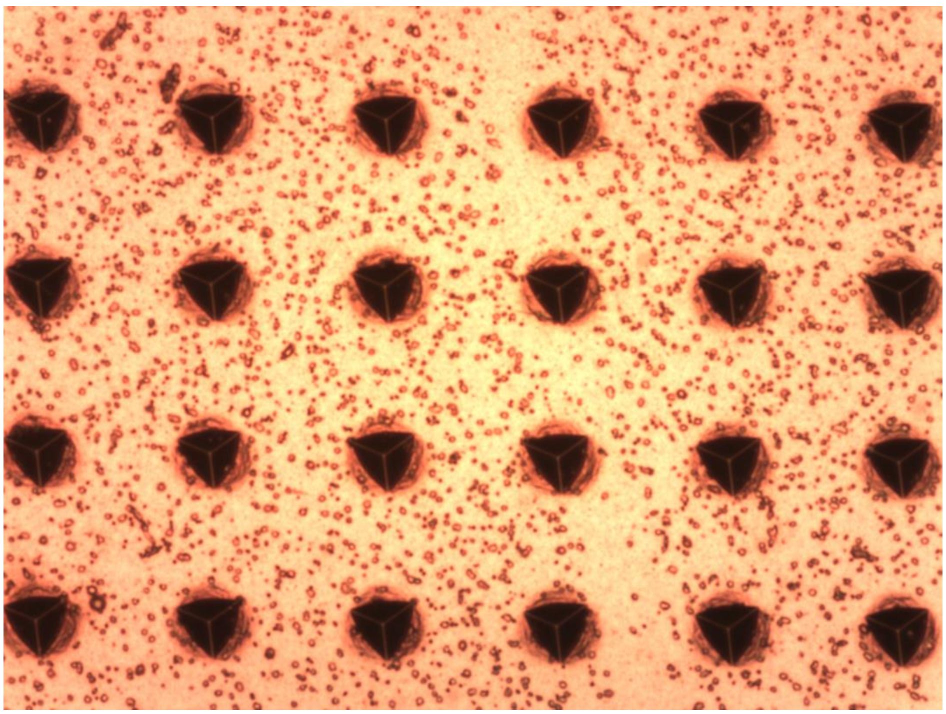
FASTMAP – HIGH SPEED NANOINDENTATION MAPPING



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INTRODUCTION

Nanoindentation has become a widely applied technique for measuring mechanical behaviors of materials at small scales[i ii]. The high-resolution load-displacement curves from the nanoindentation measurement can provide a variety of physicomechanical properties, including hardness, Young's modulus, creeping, fracture toughness and many others.

IMPORTANCE OF FAST NANOINDENTATION FOR QUALITY CONTROL IN MASS PRODUCTION

One significant bottleneck for further popularization of the nanoindentation technique is time consumption. A mechanical property mapping by conventional nanoindentation procedure can easily take hours – this hinders the application of the technique in the mass production industries, such as semiconductor, aerospace, MEMS and many others.

Mechanical integrity of the circuit boards for integrated circuit (IC) chips is a key factor in manufacturing failure free product. As the circuit board production technology progressively scales down into the micron/nanometer regime, it not only enables increased number of components to be integrated on a single board, but also make quality control of the circuit board more difficult and time-consuming. The thinner wires with a more complex structure bring challenges in the mechanical integrity checkup. A fast but reliable nanoindentation procedure is in need in quality control and R&D.

MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Tester, in FastMap mode is used to map the mechanical property of a circuit board at a high speed. We would like to showcase the capacity of Nanovea Mechanical Tester in performing fast nanoindentation mapping with high precision and reproducibility.

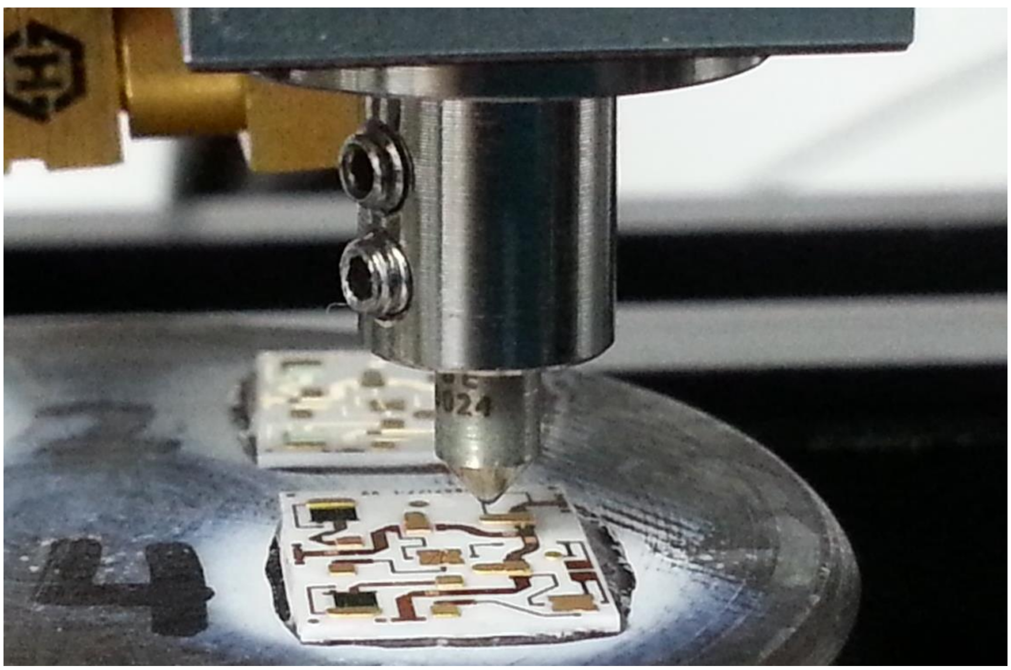

Fig. 1: Nanoindentation tip on the tested circuit board.

MEASUREMENT PRINCIPLE

Nanoindentation is based on the standards for instrumented indentation, ASTM E2546 and ISO 14577. It uses an established method where an indenter tip with a known geometry is driven into a specific site of the material to be tested, by applying an increasing normal load. When reaching a pre-set maximum value, the normal load is reduced until complete relaxation occurs. The load is applied by a piezo actuator and the load is measured in a controlled loop with a high sensitivity load cell. During the experiment the position of the indenter relative to the sample surface is precisely monitored with high precision capacitive sensor.

The resulting load/displacement curves provide data specific to the mechanical nature of the material under examination. Established models are used to calculate quantitative hardness and modulus values for such data. Nanoindentation is especially suited to load and penetration depth measurements at nanometer scales and has the following specifications:

Maximum displacement (Dual Range)	: 50 μm or 250 μm
Depth Resolution (Theoretical)	: 0.003 nm
Depth Resolution (Noise Level)	: 0.15 nm
Maximum force	: 400 mN
Load Resolution (Theoretical)	: 0.03 μN
Load Resolution (Noise Floor)	: 0.3 μN

Analysis of Indentation Curve

Following the ASTM E2546 (ISO 14577), hardness and elastic modulus are determined through load/displacement curve as for the example below.

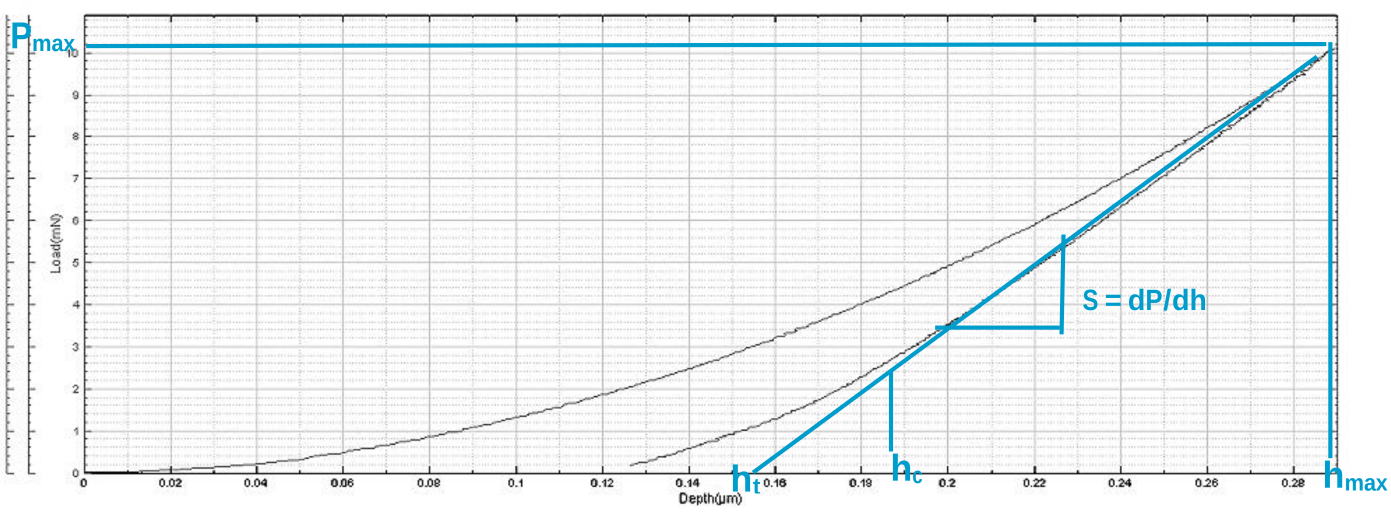

Fig. 2: Load-displacement curve of nanoindentation.

Hardness

The hardness is determined from the maximum load, P_{max}, divided by the projected contact area, A_c:

$$H = \frac{P_{\max}}{A_c}$$

Young's Modulus

The reduced modulus, E_r, is given by:

$$E_r = \frac{\sqrt{\pi}}{2}\frac{S}{\sqrt{A_c}}$$

Which can be calculated having derived S and A_C from the indentation curve using the area function, A_C being the projected contact area. The Young's modulus, E, can then be obtained from:

$$\frac{1}{E_r} = \frac{1-\nu^2}{E} + \frac{1-\nu_i^2}{E_i}$$

Where E_i and ν_i are the Young's modulus and Poisson's ratio of the indenter and ν the Poisson's ratio of the tested sample.

How are these calculated?

A power-law fit through the upper 1/3 to1/2 of the unloading data intersects the depth axis at h_t. The stiffness, S, is given by the slope of this line. The contact depth, h_c, is then calculated as:

$$h_c = h_{\max} - {}^{3P_{\max}}\!/_{4S}$$

The contact Area A_c is calculated by evaluating the indenter area function. This function will depend on the diamond geometry and at low loads by an area correction.

For a perfect Berkovich and Vickers indenters, the area function is A_c=24.5h_c^2. For Cube Corner indenter, the area function is A_c=2.60h_c^2. For Spherical indenter, the area function is A_c=2πRh_c , where R is the radius of the indenter. The elastic components, as previously mentioned, can be modeled as springs of elastic constant E, given the formula: $\sigma = E\varepsilon$ where σ is the stress, E is the elastic modulus of the material, and ε is the strain that occurs under the given stress, similar to Hooke's Law. The viscous components can be modeled as dashpots such that the stress-strain rate relationship can be given as $\sigma = \eta\frac{d\varepsilon}{dt}$, where σ is the stress, η is the viscosity of the material, and dε/dt is the time derivative of strain.

Since the analysis is very dependent on the model that is chosen, Nanovea provides the tool to gather the data of displacement versus depth during the creep time. The maximum creep displacement versus the maximum depth of indent and the average speed of creep in nm/s is given by the software. Creep may be best studied when loading is quicker. Spherical tip is a better choice.

Other possible measurements by Nanovea Mechanical Tester:

Stress-Strain & Yield Stress, Fracture Toughness, Compression strength, Fatigue testing and many others.

TEST CONDITIONS

The Nanovea Mechanical Tester was used to perform a series (10x 10, spaced 0.04 mm apart, 100 indents in total) of nanoindentations with the FastMap Mode on a circuit board using a Berkovich indenter. All indentations were performed to a maximum load of 300 mN at a rate of one indent per three seconds.

RESULTS AND DISCUSSION

The load-displacement curves of the ceramic substrate and the metal wire are shown in Fig. 3 as an example. The image of the 10x 10 indentation matrix is displayed in Fig. 4. In order to demonstrate the mechanical behaviors of different materials, the indentation matrix is planned at the border of the metal wire and ceramic substrate. The high-precision position control of the sample stage allows users to pinpoint the target area for mechanical properties mapping.

The hardness and Young's Modulus calculated using Oliver and Pharr Method [iii] are summarized and compared in Fig. 5 and Fig. 6. The metal wire and ceramic substrate exhibit distinct mechanical properties – the metal wire possesses an average hardness of ~2.7 GPa and Young's modulus of ~53.5 GPa, compared to ~20.5 GPa and ~128 GPa, respectively, for the ceramic substrate.

Such a 10x 10 indentation matrix was finished within minutes with superior precision and repeatability, thanks to the fast piezo load control and the direct load/displacement measurement of the Nanovea Mechanical Tester. Compared to conventional nanoindentation procedure, FastMap mode in this study is substantially less time-consuming and more cost-effective. It enables speedy quantitative mapping of mechanical properties including Young's modulus and hardness, and provides a solution of detecting mechanical defects of the circuit board, which is critical for quality control of a variety of materials in mass production.

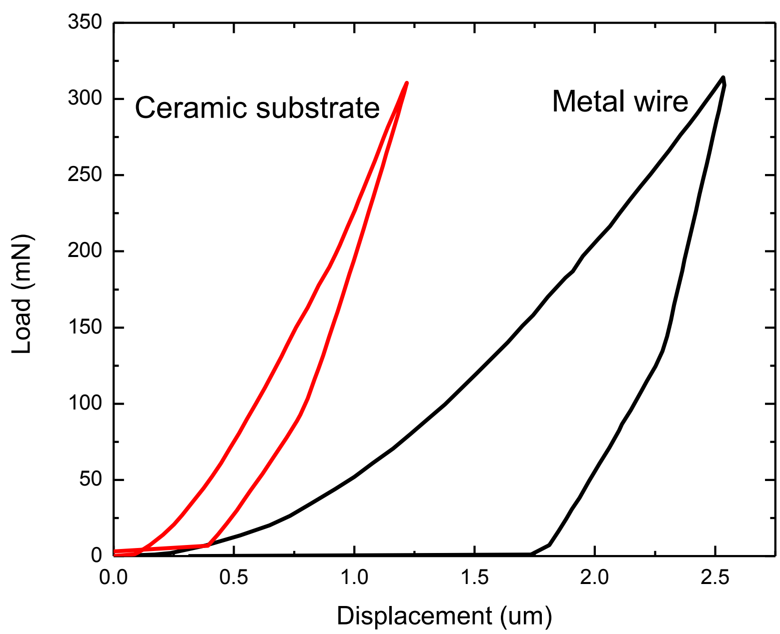

Fig. 3: Load-displacement curves of the ceramic substrate and metal wire.

(a)

(b)

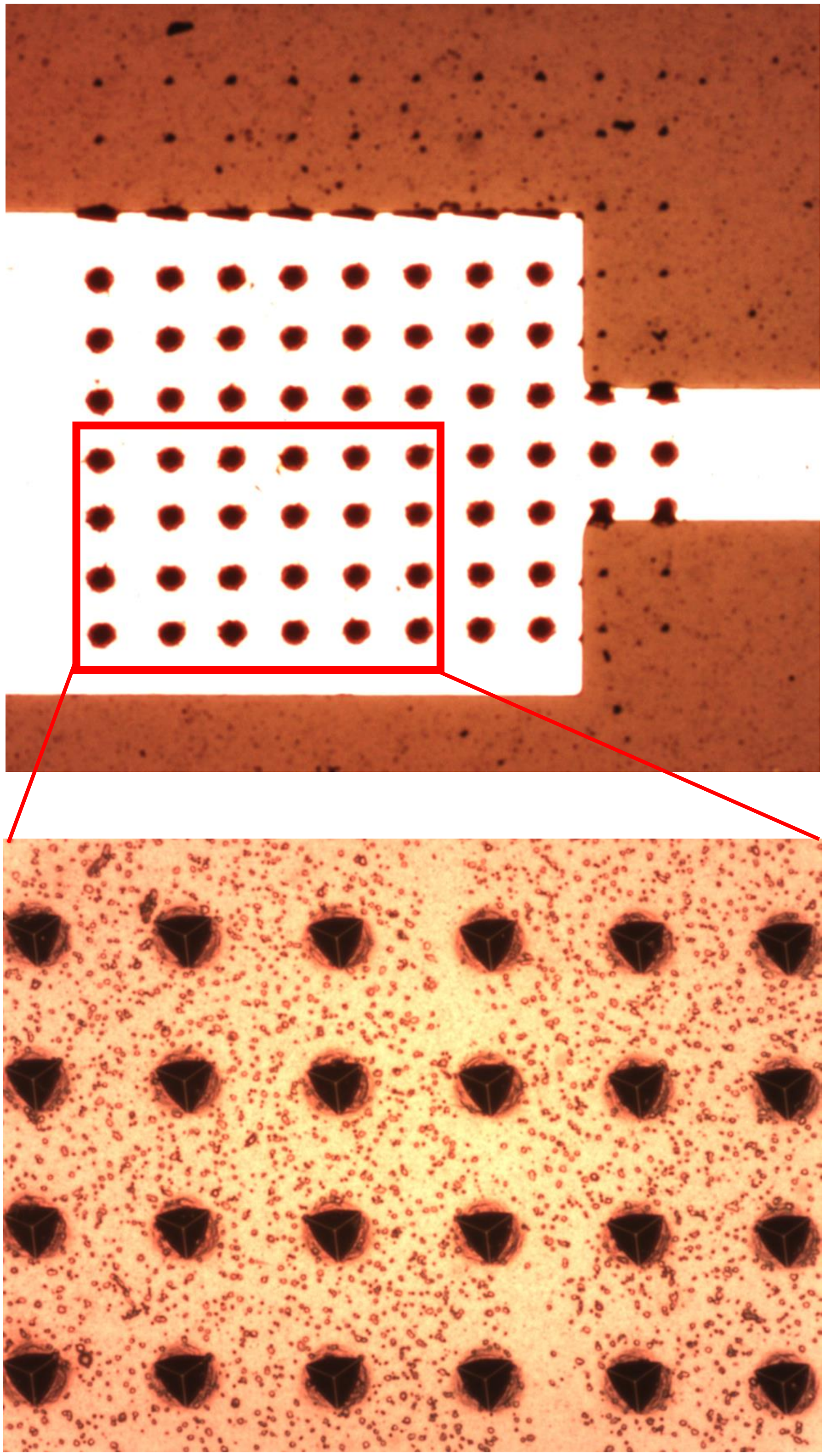

Fig. 4: Distribution of the indentation on the circuit under the microscope at different magnifications: (a) 50X, (b) 200X.

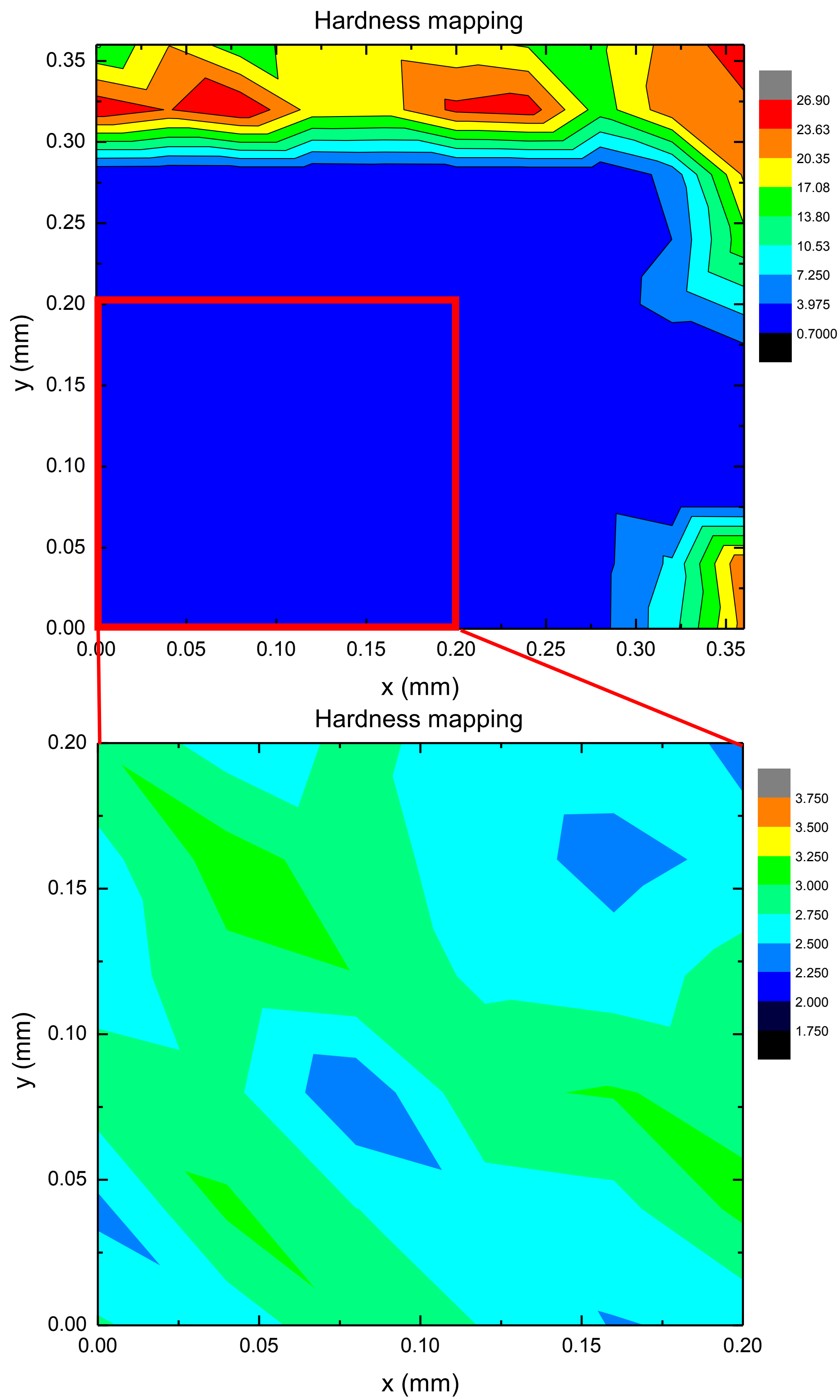

Fig. 5: **Distribution of Hardness at different locations of the circuit board.**

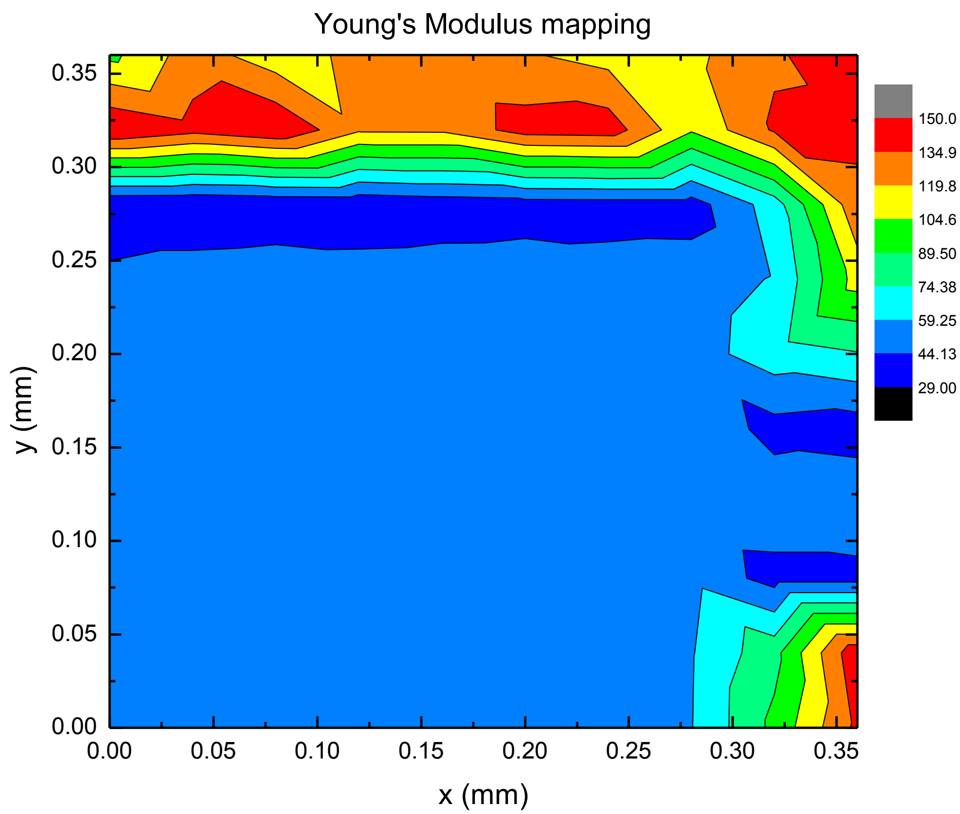

Fig. 6: Distribution of Young's Modulus at different locations of the circuit board.

CONCLUSION

In this study, we showcased the capacity of Nanovea Mechanical Tester in performing speedy and precise nanoindentation mapping using FastMap mode. The mechanical property map at the border of the metal wire and the ceramic substrate demonstrates the precise position control and accurate measurement of hardness and Young's modulus of different materials at a high speed. The fast nanoindentation is particularly important for quality control of precision devices/tools in mass production.

The Nano, Micro or Macro modules of the Nanovea Mechanical Tester all include ISO and ASTM compliant indentation, scratch and wear tester modes, providing the widest and most user friendly range of testing available in a single system. Nanovea's unmatched range is an ideal solution for determining the full range of mechanical properties of thin or thick, soft or hard coatings, films and substrates, including hardness, Young's modulus, fracture toughness, adhesion, wear resistance and many others.

In addition, optional 3D non-contact profiler and AFM Module are available for high resolution 3D imaging of indentation, scratch and wear track in addition to other surface measurements such as roughness.

To learn more about Nanovea Mechanical Tester or Lab Services.

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[i] Oliver, W. C.; Pharr, G. M., Journal of Materials Research., Volume 19, Issue 1, Jan 2004, pp.3-20
[ii] Schuh, C.A., Materials Today, Volume 9, Issue 5, May 2006, pp. 32–40
[iii] Oliver, W. C.; Pharr, G. M., Journal of Materials Research, Volume 7, Issue 6, June 1992, pp.1564-1583