Featured Articles

# Measurement of Surface Profile and Layer Cross-section with Wide Field of View and High Precision

## —VS1000 Series Coherence Scanning Interferometer—

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*OVERVIEW: Techniques for measuring thin films and surfaces have become an essential part of the technology underpinning our way of life in recent years. Examples include a wide variety of thin films now in use, such as the advanced films used in smartphones or the electrolyte membranes used in fuel cells, and controlling the surface roughness of pistons used in engines to improve their fuel economy. Hitachi High-Tech Science has released the VS1000 series* CSI, extending its range of models that provide solutions for these types of surface analysis. CSI can be used to perform three-dimensional measurement of surface profiles, surface roughness, and film thickness. Measurements can be performed in just a few seconds and provide high vertical resolution (0.01 nm) over a wide measurement range (several millimeters). Another feature is that they can perform non-contact and non-destructive measurement of thickness and cross-sections of multi-layer transparent film, and detect the presence of contaminants in the film, peeling, or other defects.*

## INTRODUCTION

COHERENCE scanning interferometer (CSI) uses optical interference to measure surface profiles. Fig. 1 shows how CSI compares to other forms of three-dimensional profile measurement. CSI takes a few seconds to measure a wide area (up to 7.1 mm × 5.3 mm) with similar vertical resolution to a scanning probe microscope (SPM) (0.01 nm). This makes CSI suitable for obtaining surface profiles for an entire specimen with high height precision. Furthermore, being a non-contact method of measurement that uses light means that it does not damage or contaminate the specimen. Another feature is its ability to measure the thickness of multi-layer transparent film.

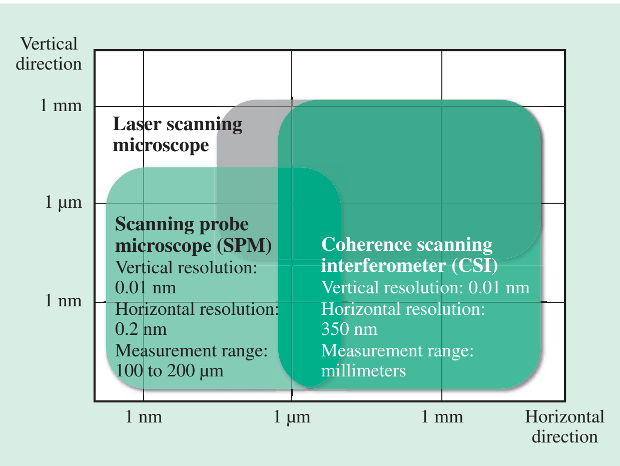



*Fig. 1—Role of CSI in Three-dimensional Profile Measurement Instruments.*
*CSI is a solution for surface analysis that is complementary to an SPM.*

## CSI MEASUREMENT PRINCIPLES AND OPTICS

Fig. 2 shows the optics of a CSI microscope. White light from the light source first passes through a band pass filter to eliminate all but a particular wavelength of light. The light then enters the two-beam interference objective lens where the beam splitter splits it into two components, one to the reference mirror and one to the specimen. The light reflected back from the reference mirror and specimen respectively is then captured by

* VS1000 series is only sold in Japan.

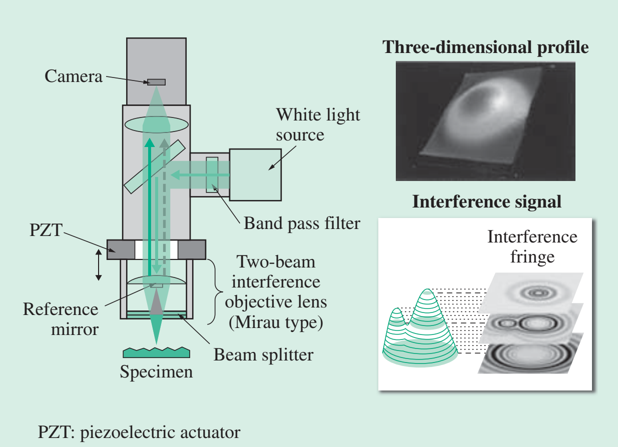



*Fig. 2—CSI Optics and Interference Fringe Image.*
*An interference signal is obtained by using a piezoelectric actuator to vary the distance between the beam splitter and the specimen surface. This interference signal is then converted into a three-dimensional profile.*

the camera. An interference signal of bright and dark fringes is formed by using a piezoelectric actuator to move the objective lens in the Z direction, thereby varying the distance between the beam splitter and the specimen. The surface profile of the specimen is then determined by using a proprietary algorithm to convert this interference signal into height information[1].

Whereas the vertical resolution of a conventional optical microscope varies due to the changing of the focal depth in accordance with the magnification of the objective lens, because CSI uses optical interference, the vertical resolution remains constant regardless of the objective lens magnification. As a result, it can achieve a high vertical resolution of 0.01 nm across the full range from low magnification/wide field of view to high magnification/narrow field of view.

Table 1. VS1550 Main Specifications
*CSI can achieve a high level of vertical resolution over a wide area. It is also possible to produce images of regions up to tens of millimeters in size by using a function for stitching images together.*

| Parameter | Value |
|---|---|
| Specimens | Height: 90 mm or less<br>Weight: 1 kg or less |
| Automatic XY stage | Movement: XY ± 75 mm |
| | Specimen surface:<br>Width 160 mm × Depth 160 mm |
| Vertical resolution | 0.01 nm (max.) |
| Horizontal resolution | 340 nm (for × 110 objective lens) |
| Maximum measurement area | 7.1 mm × 5.3 mm (single field of view) |

## VS1000 SERIES CSI

The VS1000 series CSI is available in four models to suit different specimen sizes: the VS1330, VS1530, VS1540, and VS1550. Table 1 lists the main specimen specifications of the top-end model, VS1550, and Fig. 3 shows a photograph of it. The VS1000 series can be used to perform measurements on larger specimens compared to scanning electron microscopes (SEMs) and SPMs.

## EXAMPLES OF SURFACE PROFILE MEASUREMENT USING CSI

### Quantitative Height Measurement Using CSI

Fig. 4 shows an image obtained using CSI and a backscattered electron image from an SEM. The image obtained by CSI matches that obtained by the SEM, and the cross-section profile measurement data indicates a grain height of 16 µm. The SEM is able to perform accurate topographical observations with high horizontal resolution and the CSI can obtain quantitative height measurements, enabling grain size to be determined with high precision from multiple perspectives.

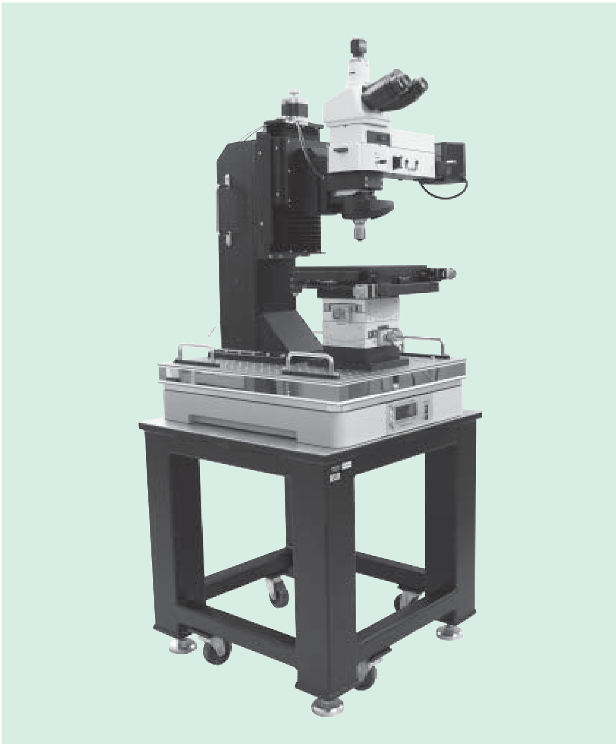
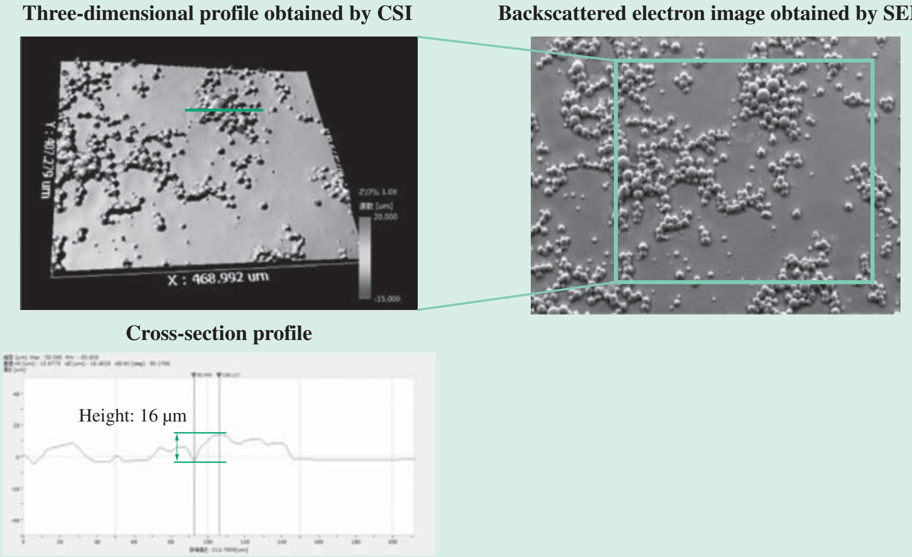


*Fig. 3—VS1550 CSI.*
*The VS1550 is the top-end model in the VS1000 series.*




SEM: scanning electron microscope

*Fig. 4—Comparison of CSI and SEM Images.*
*Observations were made of the same area on a food package that had been made water repellant. A feature of the image obtained by CSI is that it matches that obtained by the SEM and also provides quantitative height data.*

## Profile Measurement with High Aspect Ratio

Fig. 5 shows an example measurement of a groove with a high aspect ratio (narrow and deep). The profile can be measured all the way to the bottom of the groove despite having an aspect ratio of 14 (4 μm wide and 57 μm deep). Profiles with a high aspect ratio have been a problem for other types of microscopes, with the light of the laser scanning microscope or the cantilever of the SPM having difficulty reaching the bottom of the groove. Taking advantage of the fact that the vertical resolution with CSI is not dependent on the magnification of the objective lens, it can measure profiles with a high aspect ratio by using an objective lens with low magnification and keeping the numerical aperture (NA) low so that the light reaches the bottom without being focused.

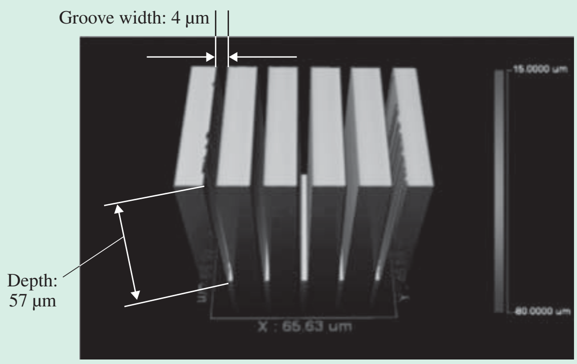



*Fig. 5—Measurement of Deep Groove.*
*By taking advantage of the high level of vertical resolution, measurement of a groove with a high aspect ratio is possible even with a low-magnification lens.*

## Use of Wide-angle Measurements to Identify Linear Defects and Irregularities

Fig. 6 shows a profile measurement of the surface of wrapping film. While there is visible evidence of linear defects, measurements taken over a small area are unable to identify the difference between areas where the defect is and is not present. The use of CSI to perform a wide-angle measurement (on the order of millimeters) over the entire specimen indicates that the surface profile is different in areas where the defect is present, and it can be used to measure the localized differences in roughness between areas with and without the defect. This is an example of the benefits of being able to combine a high level of vertical resolution with low magnification and a wide field of view.

## Use in Tribological Measurement

Automotive piston heads are engraved with grooves several micrometers in size that enable the lubricant to spread more easily. Fig. 7 shows a surface representing

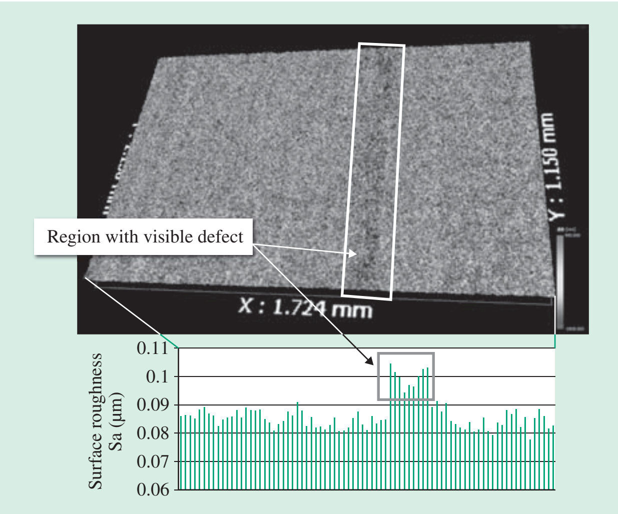



*Fig. 6—Linear Defects in Wrapping Film.*
*The differences in surface profile and roughness between areas with and without the defect can be identified by wide-angle measurement*

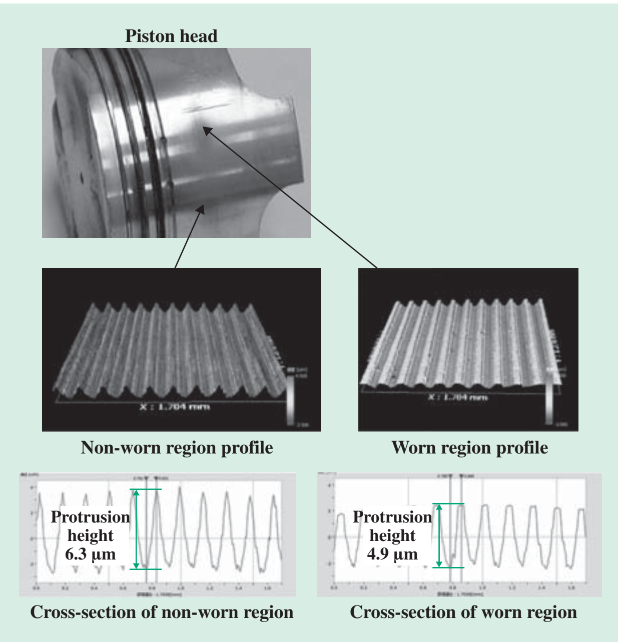



*Fig. 7—Comparison of Worn and Non-worn Regions of Piston Head.*
*CSI provides height information and can quantitatively determine the condition of protrusions in worn and non-worn regions.*

the variation in wear. Measurement of a worn region shows that the protrusions have been worn down by 1.4 µm. As the VS1000 series can determine surface quality (roughness measurement) in accordance with the International Organization for Standardization (ISO) 25178 international standard for surface roughness, it can quantitatively assess the degree of wear.

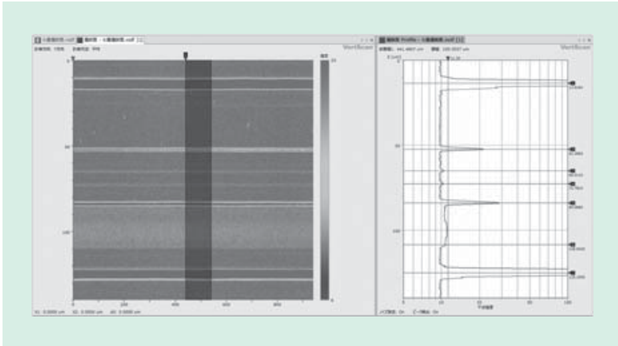


*Fig. 8—Cross-section Analysis of Six-layer Wrapping Film.*
*The VS1000 series can measure the thickness of multi-layer transparent film using a proprietary detection method.*

## MEASUREMENT OF FILM THICKNESS BY ANALYZING FILM CROSS-SECTION

CSI can be used to measure the thickness of multi-layer transparent film and detect the presence of contaminants, peeling, or other defects. By using the interference signal obtained from the optical boundaries within multi-layer film to generate images of the multi-layered structure, this provides a non-destructive technique for determining the layer structure of multi-layer film or its internal condition without making a cross-section. Fig. 8 shows an analysis of the cross-section of a six-layer film used for wrapping. It indicates how the interference due to each boundary can be interpreted as a cross-section image. It also obtains depth information on any defects such as air bubbles present in the film layers. Measurement of the internal film thicknesses is possible because thicknesses with an optical distance of 1 µm or more can be resolved in the interference signal. This measurement can be performed even if the difference between the refractive indices of the optical boundaries is small. Because the measurement is performed from the top surface, another feature is that, if the top surface profile is flat, it will be seen as being flat even if the substrate is uneven.

## CONCLUSIONS

This article has described how, by using optical interference, CSI can perform non-contact and non-destructive measurements over a wide area, quickly, and with high vertical resolution.

By adding the VS1000 series CSI to its range of surface analysis solutions alongside SEMs and SPMs, Hitachi High-Tech Science Corporation intends to provide advanced solutions that contribute to the latest leading-edge business development by customers.

## REFERENCES


(1) T. Yoshizawa ed., "Optical Three-dimensional Measurement," Asakura Publishing Co., Ltd. (2006) in Japanese.

(2) M. Iyoki et al., "Industrial Application of Scanning Probe Microscope with White Light Interferometer," Hitachi Hyoron **95**, pp. 600–605 (Sep. 2013) in Japanese.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