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Interferometry: *Technology and Applications*

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Introduction

In its most common application interferometry is a versatile measurement technology for examining surface topography with very high precision. At the heart of interferometry is the interferogram, which is the recorded interference signal of two beams of light exiting from the same source. An interferogram carries a wealth of information about the profile of an object under test and its material characteristics. This article serves as a short introduction to interferometry, its major measurement techniques and its primary applications in industry today.

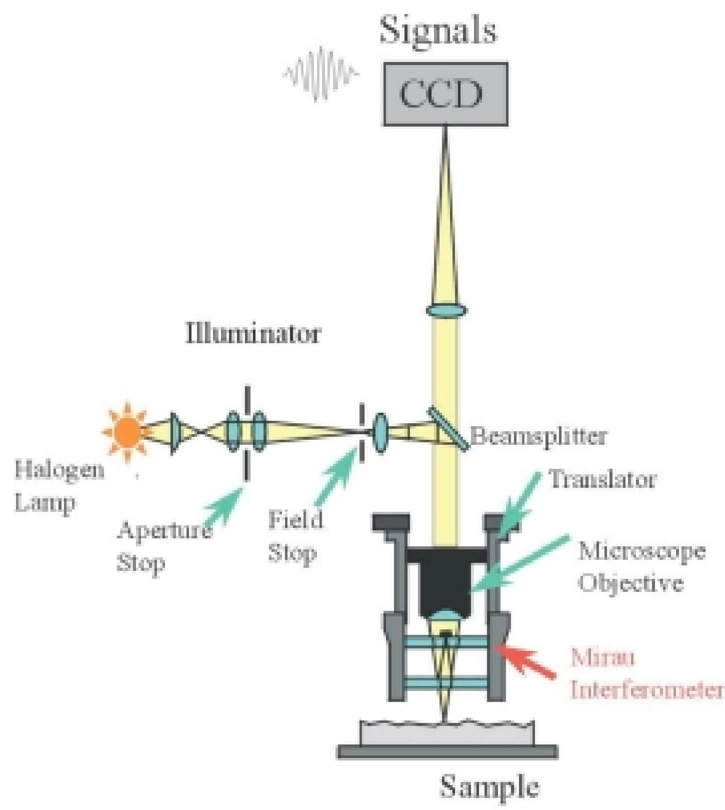

Figure 1: Typical microscope based white light interferometer. In the figure it is equipped with a Mirau-type interferometric objective, typically employed for magnifications of up to 50x.

Technology Overview

An interferometer is an optical device that splits a beam of light exiting a single source into two separate beams and then recombines them. The resulting interference phenomena are subsequently recorded in the form of an interferogram. Commonly, interferometers employ a system where one beam is reflected from the object under test and the other beam is reflected from a reference mirror. The beams are recombined to create bright and dark bands called “fringes” that make up the interferogram. Fringes, like lines on a topographic map, represent the topography of the object. Completing the interferometric setup is a CCD detector that registers the interferogram and forwards the frame to the computer for processing using interferometric phase-mapping programs [1].

Techniques have been developed to retrieve a wide range of information from the object under test. These techniques match a specific interferometric setup and interferogram analysis program to the object itself and the kinds of information required. The most popular interferometric measurement techniques are Phase Shifting Interferometry (PSI)[2], Vertical Scanning Interferometry (VSI)[3] and Enhanced VSI (EVSI)[4]. PSI, which uses a monochromatic light source, is typically used to test smooth surfaces and is very accurate, resulting in vertical measurements with sub-nanometer resolution. However, PSI cannot obtain a correct profile for objects that have large step-like height changes and this method becomes ineffective as height discontinuities of adjacent pixels exceed one quarter of the used wavelength ($\lambda/4$). The monochromatic light source that yields similar contrast fringes at each point in the interferogram and allows for very precise measurement also limits the range where continuous fringes can be obtained. When fringes become discontinuous, obtaining correct profiles is not possible.

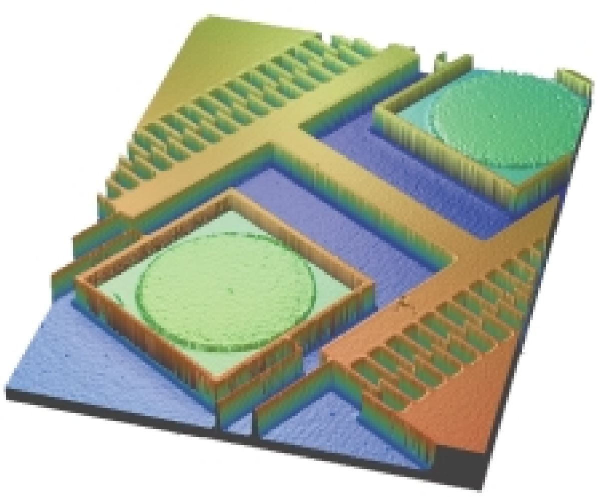

Figure 2. Example of MEMS structure – section of a comb capacitor drive measured using EVSI. High lateral and vertical resolution are combined with a large field of view. 950µm x 1.3mm

Rough-surfaced objects and those with a adjacent pixel height difference greater than $\lambda/4$, or about 150nm, are better measured using other techniques that can handle the greater surface roughness and height difference, but these result in lower resolution measurements. One technique that partially overcomes the height difference limitation is multiple wavelength interferometry (MWI)4. MWI, in which the two wavelengths are pre-selected, allows for sub-nanometer resolution while extending the dynamic range, which in MWI is the measurable height difference between two adjacent points. However, this technique does not work well with rough surfaces. For rough surfaces a white light interferometry (VSI) approach is effective because the light source is changed (white light vs. monochromatic) and we are no longer looking at the shape of the fringes (continuous) but rather are looking for the best focus position. However, VSI yields precision in the nanometer range rather than in the sub-nanometer range, as for PSI and MWI. In VSI because of the wide spectral bandwidth of the source (halogen lamp, filtered light from halogen lamp, LED etc.), the coherence length is short and good contrast fringes are obtained only when the two path lengths of the interferometer are closely matched in length. The interferometer is aligned so that the interference intensity distribution along the vertical scanning direction has its peak (best contrast fringes) at the best focus position. Many algorithms exist to analyze white light interferograms, but all of them in general detect the coherence peak. In short, PSI and MWI techniques have excellent resolution but limited dynamic ranges whereas VSI has a wider dynamic range but lower resolution.

Recently, aspects of PSI and VSI have been combined to take advantage of the strengths of each of these techniques; this new method is often called a white light phase shifting interferometry or enhanced VSI (EVSI). First, for each pixel of the detector, the best-focus frame position is found by locating the best contrast of interference intensity distribution along the vertical scanning direction. Second, the PSI technique is applied to intensity distribution around the peak to achieve high resolution measurement.

Interference Microscopy

Interference microscopy combines an interferometer and microscope into one instrument and is used for measuring engineering surfaces that demand testing with high resolving power. Interference microscopy uses three types of interferometric objectives: Michelson, Mirau and Linnik (all are modifications of the Michelson interferometer). In a Michelson interferometer objective, which is used for small magnifications, a beam-splitter cube and reference mirror are inserted between the objective and the tested surface. At magnifications up to fifty times, the working distance (the space between the last surface of the lens and the tested surface) becomes too small to squeeze in a beam splitter cube; a Mirau interferometric objective is then employed (Figure 1). For magnifications of one hundred times and above requiring even smaller working distances, a Linnik interferometric objective is used. In the Linnik configuration, a beam splitter cube placed before the light reaches the objective directs the beam onto two objectives; one beam is directed to the reference mirror and the other is directed to the test surface. An example of an interference microscope equipped with the full suite of interference objectives is the Wyko® NT3300™ (Veeco Metrology Group).

Techniques and Applications

Surface metrology is one of the main applications of interferometry. Microscope-based white light profilers are capable of mapping up to a ten millimeter wide area in a single measurement, with sub-nanometer resolution, providing instantaneous information about surface roughness, shape and waviness.

When larger areas need to be measured, a stitching procedure can be employed, in which a number of partially overlapping measurements are combined into one surface profile. The lateral resolution of an interferometer is defined by the optical system and the wavelength of light; this resolution can be as good as 300nm. Several interferometric measurement modes can be employed, each of which has its particular strengths, though there is some overlap among their capabilities.

As mentioned above, PSI yields the highest accuracy of all modes. With Angstrom-level vertical resolution and high lateral resolution, PSI is typically used to characterize high quality surfaces such as DWDM filters, wafers, etc. Short measurement time (less than 0.5 seconds) make PSI particularly appropriate for high-volume, automated quality control.

VSI is used to characterize surfaces with higher roughness and/or discontinuities, such as steps, cavities, islands, etc. Heights up to several millimeters can be resolved, though measurement time is longer (several seconds to a minute) due to the added vertical scan length. VSI is accurate down to single nanometers, making the method well-suited for applications in MEMS (MicroElectroMechanical Systems) and semiconductor measurements. Several important process parameters can be easily measured using VSI. When combined with high numerical aperture lenses such as a 100X Linnik objective (NA=0.95) it can be particularly attractive for characterizing such features as wall angles or vias. The same capability can be used for integrated optics circuits, waveguides, thick films, precision machined surfaces, and numerous other industrial measurements.

Enhanced VSI (EVSI) is capable of measuring the same heights and discontinuities as VSI but with resolution and repeatability similar to PSI. As with PSI, this method requires smooth surfaces with roughness below a hundred nanometers. The most important applications of this technology are in the telecommunications, MEMS and semiconductor industries. An example of a MEMS structure measured using EVSI is shown in Figure 2.

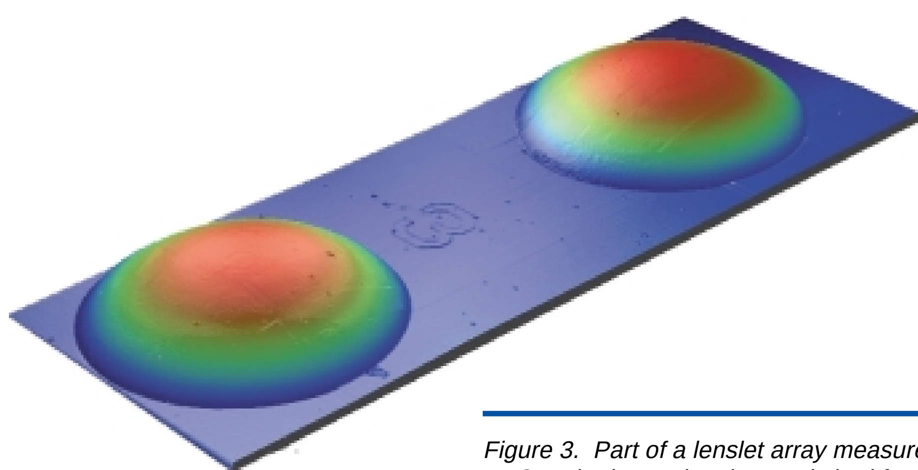

Figure 3. Part of a lenslet array measured using EVSI. The image has been stitched from two individual measurements. Each lenslet can be analyzed separately, as can its relative position in the array. 1.6mm x 620µm.

EVSI delivers sub-nanometer repeatability when measuring the surface of microlenses and microlens arrays—essential components of modern fiber optic network devices. Sag of a microlens surface can reach several tens of micrometers with diameters that can be as small as a few hundred micrometers. This requires the use of higher magnification, in which case the PSI technique is not feasible because of the small depth of focus. On the other hand VSI-related methods have significant noise when related to the surface roughness. By combining the quality of measurement of PSI with VSI's dynamic range, EVSI provides precise characterization of the lens surface. Its high precision allows measurement of parameters such as departure from sphericity, radius of curvature, etc. The result of a microlens array measurement is shown in Figure 3.

Laser interferometers have been the tools of choice for many years for shape characterization of large surfaces. These instruments resolve heights down to single nanometers while measuring areas up to 24 inches in diameter. The capability to instantaneously measure large areas is especially useful for characterizing large, polished semiconductor wafers, optical flats, mirrors, lenses, or optical filter substrates. Specialized laser interferometers are widely employed for micro-optics measurements, such as lens arrays covering a wide range of radii of curvature. An example of a laser interometer is the Wyko RTI-Series (Veeco Metrology Group).

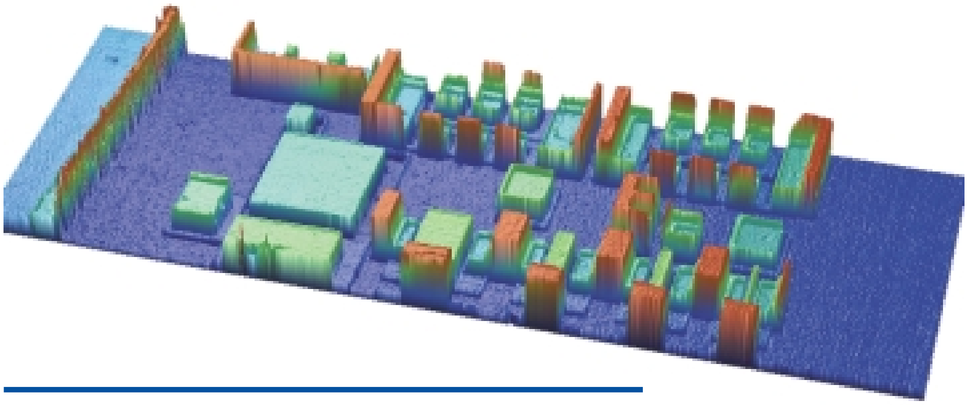

Figure 4. White light optical profiling are primarily used for characterization of surfaces. Here, ESD damage of a thin metallic film is shown. 75µm x 75µm.

Summary

The list above includes only some of the non-destructive testing applications for interferometers. Systems have been successfully employed to investigate dispersion of materials, complex indices of refraction and thermal properties. The instruments can also provide dynamic measurement capability, such as the analysis of resonant frequencies of structures, 3D motion mapping, and more. New applications are emerging every year, the most promising of which are in biotechnology and material sciences. The high vertical resolution, lateral resolution, throughput and repeatability of optical instruments provide a good complement to other techniques such as atomic force microscopy and projection shape measurement.

References

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