Through-Transmissive-Media (TTM) Interferometric Techniques Applied to Characterizing Packaged MEMS and MOEMS Devices

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Abstract

MEMS (Micro-Electro-Mechanical Systems) and MOEMS (Micro-Opto-Electro-Mechanical Systems) are devices comprised of integrated mechanical, electrical and optical components, manufactured using techniques similar to those of integrated circuits. As in semiconductor manufacturing, quality control is the key to successful products—so much so that 50-80\% of the cost of a MEMS device is incurred in final packaging and test.

Optical profiling (white light interferometry), which combines high speed, accuracy, resolution and flexibility, has proven successful for measuring surface features of unpackaged MEMS devices. With the further productization of MEMS technology, however, devices also need to be tested in their final, packaged state, typically beneath a protective, transparent cover.

Objectives capable of imaging through transparent media at low magnifications have been available for several years. Increasingly, however, higher magnifications are required to resolve smaller critical features. At high magnifications, transmissive media can greatly degrade interferometric measurements due to dispersion and aberration effects.

In this paper we describe an improved technique for measuring MEMS features through transmissive media, at magnifications as high as 40X. The technique enables improved dispersion compensation, reduced coherence effects, thickness variation insensitivity, and enhanced illumination. Measurement results are presented, as well as examples of MEMS applications.

1. Introduction to MEMS metrology

MEMS [1] and MOEMS [2] are micro-fabricated devices with integrated mechanical and/or optical elements, sensors, actuators, and electronics on a common silicon substrate. As in the manufacture of semiconductors, quality control is a key to making a successful MEMS product—in fact, approximately 50-80\% of the total cost of a MEMS device is incurred during final packaging and test. Successful products require rapid, accurate metrology to sustain high yields and to maintain profitability.

Since the first commercial MEMS became available, optical profilers (Figure 1) have been widely used to measure surface features of unpackaged devices. Optical profiling combines high speed, accuracy, and flexibility, allowing manufacturers to maintain a common metrology platform from R&D through full-scale production.

With the increasing productization of MEMS technology, however, manufacturers now need to test devices in their final packaged state as well, typically through a protective, transparent cover made of glass, plastic, sapphire or similar.

Low-magnification objectives capable of imaging through such media have been available for several years. In these objectives, a small slide, made of the same material and thickness as the cover glass, is inserted into the reference arm of the interferometer, balancing the system to compensate for the cover glass.

Today’s smaller devices features, however, can only be resolved by higher magnifications. At these magnifications, transmissive media can greatly degrade interferometric measurements due to dispersion and aberration effects [3]. In addition, the distance between the protective cover and the MEMS device demands longer working distance optics.

Fig. 1. Conventional interferometric profiler.

In this paper we describe improved techniques for measuring MEMS features through transmissive materials at high magnifications. We will also describe how these techniques have been employed to create a flexible measurement system supporting a range of magnifications and cover glass materials and thicknesses.
2. High resolution measurement challenges

Three major issues arise when using an optical profiler to measure packaged versus unpackaged MEMS devices at high magnifications. Firstly, aberrations and dispersion caused by the cover glass greatly degrade the image quality at magnifications above 20X. Figure 2 shows a 20µm pitch standard as imaged through a 3mm cover glass. The image was taken with a 20X, NA 0.4 objective on a standard optical profiler. The fringes in this image are barely visible, with contrast reduced virtually to 0%.

Secondly, the addition of compensation glass in the reference arm is insufficient to overcome dispersion issues and create high-contrast interference fringes. In fact, in addition to the base optical path difference, material dispersion and diverging angle of illumination beam both have a significant influence on the interference fringes [4].

Thirdly, objectives that are simply compensated with a matching slide in the reference arm are only capable of measuring through one particular type, and thickness, of cover media. Any variation in the cover material requires a separate objective—an expensive solution at best.

3. Compensated high resolution objective

To overcome these issues, we present a system which optimizes the performance of a conventional profiler for testing samples through cover material. Figure 3 illustrates the essential components of the system, including a Michelson-type interferometric objective module (O) and a separate illumination module (I). This configuration is suitable for replacing a high-magnification Mirau objective in a standard profiler.

As with low magnification objectives, a compensating slide of similar thickness and material to the cover glass is inserted into the reference arm. To compensate for dispersion, the system was also designed to produce a substantially shaped beam, by coupling a conventional light source (LED, filament-based bulb, or super-luminescent diode) by means of an optical connector, both within the illumination module and the objective module.

Figure 4 shows the 20µm pitch standard through 3mm cover glass, now imaged with a compensated 20X objective. The fringe contrast is improved to 65%, comparable to that of an uncovered sample measured by a conventional objective. We found that only this combination of compensation glass and substantially collimated reference and test beams could produce sufficient fringe contrast to permit analysis of a covered sample at high magnifications.

Based on the design shown in Figure 3, a real system has been developed, including the objective module (Figure 5) and illumination module. The objective module has NA 0.28, lateral resolution of 1.15µm and working distance from 5.35mm to 8.5mm, depending on the thickness of cover glass and the spacing between the glass and the sample below it.
Fig. 5. Objective for measuring samples through transmissive media at magnifications from 1-40X.

The objective module includes a basic primary section with interchangeable objectives to provide varying magnification. This design allows manufacturers to choose from magnifications ranging from 1X to 40X, with lateral resolution down to 1.2µm. Figure 6 shows a typical kit, including the primary objective section and three interchangeable magnification objectives (2X, 10X and 20X).

For flexibility, the design also includes a holder that allows the user to switch compensation slides to match the cover glass in various packages. This feature allows manufacturers to use a single objective to image multiple devices in various packaging form factors. Cover glass thicknesses from 0 to 3mm are supported, with a thickness tolerance up to 0.1mm. This tolerance is dependent on the diverging angle of illumination beam, the material index of the cover glass and the spectrum bandwidth of the light source.

The illumination source contains both narrow-band and broad-band sources, depending on whether VSI (Vertical Scanning Interferometry), PSI (Phase Shifting Interferometry) or both optical profiling measurement modes are employed. The sources can automatically be switched using software control.

4. Results with compensated objective

To verify performance of the through glass objective, we measured a 20µm pitch standard, a fused silica mirror, and a NIST-traceable 10µm step height standard. The samples were measured at 20X, uncovered, to establish a baseline. The samples were measured again at the same magnification with a compensated objective through a 3mm thick cover glass. In all of the measurements, a 20X objective and a 2X system magnification were used, for a total magnification of 40X. The average step height, line width and roughness proved to be virtually equivalent between the standard objective and the compensated version, with no noticeable performance degradation.

5. Applications

Having determined that the through glass objective performed to the same level as standard objectives, the system was employed to test MEMS under actual use conditions. A packaged lateral resonator from Sandia National Laboratories was measured through 3mm of cover glass, with no loss of image quality. Figure 7 shows a 3D rendering of the measurement data. The false colors represent varying height over an approximately 10µm range.

Another primary application of the through-glass system as shown in Figure 8 is for measuring samples inside small environmental chambers. These chambers, which are several centimeters in size, let researchers subject devices to varying pressure, temperature, and atmospheres, without the need for expensive pumps and controls associated with large chambers. They also typically includes a transparent window for observation of the sample.

An optical mirror array was imaged inside such an environmental chamber, through the 170µm thick glass chamber window. The sample was exposed to temperatures up to 170°C to determine how the surface of the mirrors would be affected by elevated temperatures. Figure 9 shows the array as imaged with a standard objective and a through-glass objective. Although 170µm of glass is fairly thin, fringe contrast with the standard 10X objective was poor and did not allow for data collection. By
compensating the objective with the chamber glass, the fringe contrast greatly improved.

Fig. 8. Micro-mirror array imaged through the window of an environmental chamber, without compensation (left) and with compensation (right). Courtesy Sandia National Laboratories.

Figure 9 shows a high quality data analysis that was produced using a compensated 10X objective. The data from these measurements allowed us to determine how radius of curvature, shape, and roughness changed as a function of temperature. The same principles could be applied to samples tested in vacuum or in other environments.

Fig. 9. 3D analysis of a MEMS micro-mirror as imaged inside of an environmental chamber (Courtesy Sandia National Laboratories)

6. Conclusions

We presented a surface profiling solution for high-magnification through-glass measurements. Compatible with existing conventional interferometric profilers, the design adds new objective and illumination modules. Three techniques are introduced into the profiler, including the aberration correction and long working distance for the objective, shaped illumination and dispersive compensation. Dispersive material up to 3mm thickness can be used, with a remaining working distance up to 8.5mm from the objective to the sample. The magnification can be changed from 1X through 40X. Different transmissive media can be quickly inserted and removed from the objective to support a larger variety of parts, and the objective was designed for ease-of-use and robustness in both R&D and production environments.

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References