Non-contact 3-D surface profiler using optical fiber

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Abstract

We present a non-contact 3-D surface profiler specially devised for the measurement of silicon wafer or CSP(Chip Scale Package) of which surface profile is difficult to be measured with conventional interferometers. The profiler comprises multiple light sources made of single-mode optical fiber. It turns out to be well suited for the warpage inspection of microelectronics components.

1. Introduction

Recently new profile measurement techniques are needed in the industry because of various product developments. Especially microelectronics components such as chip package and silicon wafer are difficult to be measured with conventional non-contact profiler. Which is based on the following two points of view. Their profile should be fabricated with within a few micrometer accuracy, but their surfaces have a characteristic of light scattering.

Until now, the existing typical metrology to overcome these problems has two methods. At first, Kwon and Wyant have measured rough surfaces by using CO_2 laser of 10.6µm wavelength.[1] The second, Petriccione and Ume have just applied typical Shadow Moire method to measure rough surface.[2] Because of using extended wavelength; this two metrology could not obtain very high accuracy.

Therefore, we present a non-contact 3-D surface profiler using optical fiber system that has been specially devised for the inspection of microelectronics components such as unpolished backsides of silicon wafers and plastic molds of integrated-circuit chip packages.

2. Principle of the proposed method

Figure 1 shows the overall optical configuration for the measurement method proposed in this investigation. The system is constituted with six light sources and a CCD camera of two-dimensional photo-detectors array. The light sources are deployed along the circumference of a circle, while the camera is located about at the center of the circle facing the object surface during measurement.

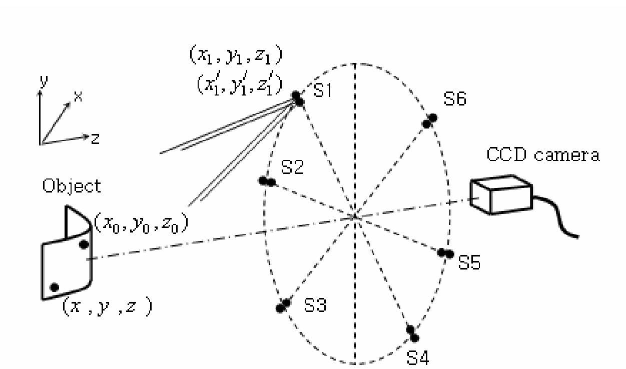

Figure 1. Geometrical arrangement of the 3-D profiler configured for the profile measurement of microelectronics surfaces. S1 to S6 are the light sources, each of which projects a unique fringe pattern generated by the interference of two spherical wavefronts diffracted from a pair of single-mode optical fibers. The light sources are activated one by one in sequence, while resulting fringe patterns are observed using a CCD camera of two-dimensional photo-detector array.

Each light source is an independent one made of a pair of single-mode optical fibers that are connected to a He-Ne laser via a 2X1 coupler as shown in Figure 2. The fibers are polished in their ends and housed in a single ceramic ferrule side by side with a predetermined lateral offset. Each single mode fiber works as a light source emitting an almost perfect spherical wave front. Two spherical wave fronts emanated from the two fibers constituting a light source interfere with each other and subsequently generate a unique fringe pattern over the target surface to be tested. A He-Ne source provides coherent light to the two fibers through a 2X1 optical fiber coupler, while one of the fibers is elongated using a piezoelectric PZT tube to produce phase shifting.

Two spherical wave fronts emanate by diffraction at the ends of the fibers, which then interfere with each other and generate a unique fringe pattern on the object surfaces to be profiled. The PZT tube extends the length of a fiber to induce phase shifting in the resulting fringe pattern.

The camera captures fringe patterns while switching on and off all the diffraction sources one by one in sequence to obtain multiple fringe images projected from different geometrical angles as shown in Figure 3.

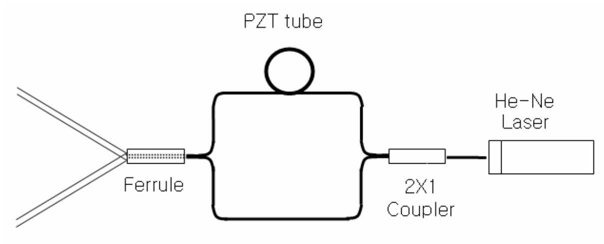

Figure.2 Optical configuration of a two-point diffraction source made of a pair of single-mode optical fibers coupled to a single coherent source

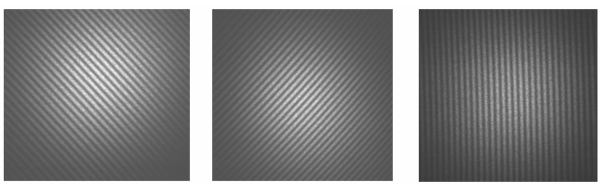

Figure.3 Fringe images captured by CCD camera which are projected on the non-polished backside of silicon wafer from three different geometrical angles.

For analysis, two conjugate spherical wave fronts from a single diffraction source is designated as u_1 and u'_1, whose complex amplitudes are expressed in the xyz-coordinate system as

$$u_1(x,y,z) = \frac{A_1}{r_1(x,y,z)} \exp[-j(kr_1(x,y,z) + \phi_1)] \quad (1)$$

where $r_1(x,y,z) = \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2}$ and

$$u'_1(x,y,z) = \frac{A_2}{r'_1(x,y,z)} \exp[-j(kr'_1(x,y,z) + \phi'_1)] \quad (2)$$

where $r'_1(x,y,z) = \sqrt{(x-x'_1)^2 + (y-y'_1)^2 + (z-z'_1)^2}$.

Note that ϕ_1 and ϕ'_1 are the initial phases of u_1 and u'_1 which are measured at their origins located at (x_1,y_1,z_1) and (x'_1,y'_1,z'_1), respectively. Then, the intensity of the fringe pattern generated on the object surface by the interference between u_1 and u'_1 is worked out as

$$I(x,y,z) = |u_1(x,y,z) + u'_1(x,y,z)|^2 = a(x,y,z) + b(x,y,z)\cos[\Phi(x,y,z)]$$
$$\text{where } a(x,y,z) = \frac{A_1^2}{r_1^2} + \frac{A_2^2}{r_1'^2}, b(x,y,z) = 2\frac{A_1}{r_1}\frac{A_2}{r'_1}, \quad (3)$$
$$\Phi(x,y,z) = k(r_1 - r'_1) + \Delta\phi, \text{and} \Delta\phi = \phi_1 - \phi'_1.$$

There are three fringe variables; a(x,y,z) is the background intensity, b(x,y,z) is the amplitude of intensity variation, and $\Phi(x,y,z)$ is the absolute phase. Among them, the absolute phase $\Phi(x,y,z)$ relates to the xyz-coordinates of the surface profile to be measured with a most uncomplicated relationship, i.e., by the difference of the distances to the two diffraction sources plus the difference of the initial phases. Adopting well-established phase-shifting technique allows for the principal value of $\Phi(x,y,z)$ to be accurately determined within the range of $-\pi$ to π[3], for which one of the fibers in each diffraction source is elongated using a piezoelectric PZT extender.
Therefore, at least three measurements of $\Phi(x,y,z)$ are required to determine the coordinates (x,y,z), each of which should be performed with a different diffraction source.

3. Experimental results

A series of tests has been performed against actual rough surfaces whose profiles cannot be measured using conventional Fizeau or Twyman-Green interferometers due to their too high surface height irregularities.[4]
Figure 4 shows a measurement result, which was obtained from the backside profile of a silicon wafer in the middle of integrated-circuit fabrication process.

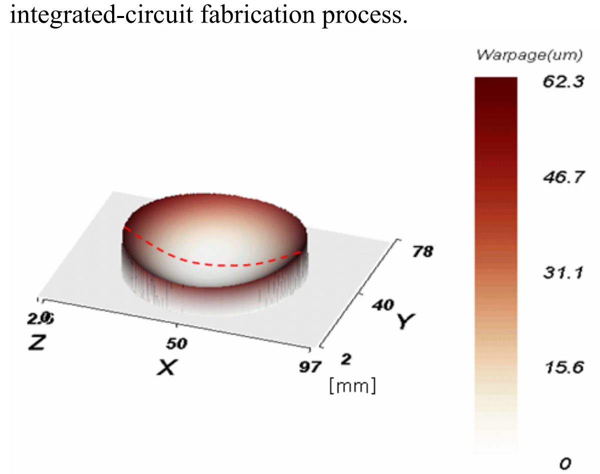

Figure.4 A measurement result of the non-polished backside profile of a silicon wafer for warpage inspection; an exemplary three-dimensional profile measured and reconstructed by the proposed 3-D surface profiler.

Another measurement example is presented in Figure 5, which has been performed for the warpage inspection of chip scale package (CSPs) that are tape-mounted on ball grid arrays (BGAs). The measured result indicates that the global surface is distorted by high temperature environment during curing process.

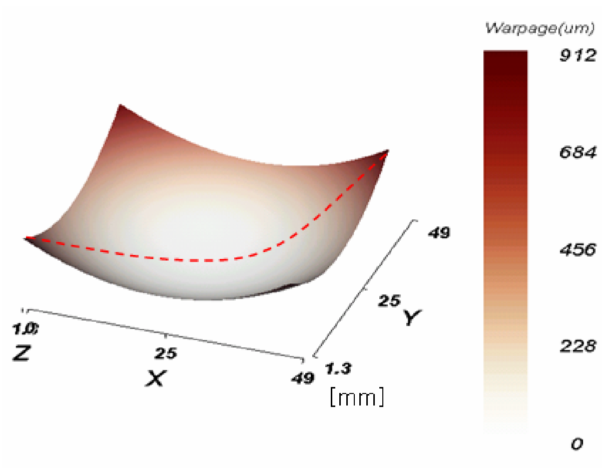

Figure.5 Inspection of IC package warpage; an exemplary three-dimensional profile measured and reconstructed by the proposed 3-D surface profiler.

4. Conclusions

A new 3-D surface profiler has been proposed to measure the warpage of electronics with light scattering surfaces. This method uses multiple sets of light sources made of two single-mode optical fibers emitting spherical wave fronts to generated unique fringe patterns on the target surface. The experimental results turn out to be well suited for the warpage inspection of microelectronics components.

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