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Non-destructive method of surface mapping to improve accuracy of mechanical stresses measurements

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Abstract. In this paper, we describe a non-destructive method for determining the mechanical stresses based on the mapping of the sample surface. The method shortens the measurement time. The loading of PC's RAM decreases during measurement process. Determine the area of local surface irregularities. The magnitude of the curvature of the structure estimate over the entire surface of the substrate. This makes it possible to increase the accuracy of the calculation of the magnitude of mechanical stresses using the Stoney formula. The use of the proposed technique increases probability of success of substrates bonding operations and contact lithography.

1. Introduction

It is important to monitor and change mechanical stresses in thin films. This allows you to create structures with controlled stresses [1]. The mechanical stresses can be controlled in various ways: change the parameters of the technological process of formation of structures, perform heat treatment operations [2], form an additional layer on the sample [3], apply external influences. Using the above methods can reduce the number of operations to prepare the surface with the required relief.

Various methods of monitoring mechanical stress exist. One of the non-destructive methods is the control of the bending of the plate with the subsequent calculation of the stress value by the Stoney formula. Forming a surface map allows you to obtain an array of values of the measured parameter in the local area. When calculating stresses using the Stoney formula, following variables are used: substrate thickness, film thickness, and curvature of surface. Thus, by measuring each parameter in the local region of substrate, it is possible to reduce the error in measuring the value of mechanical stresses [4].

This method is applied to products of microelectronics, especially to devices based on microelectromechanical systems (MEMS). In a number of cases, MEMS is a thin micro- or nanosized film on a silicon wafer. Membrane is the area of the film in the air. Contact of the measuring device with MEMS membrane can lead to deformation of the device. Consequently, the development and application of non-contact methods for monitoring mechanical stresses allow to improve the yield of suitable ones.

2. Goal

Previous authors have been developed a non-destructive method for determining the mechanical stresses in the thin films on the wafer [5]. The surface profile passing through the center of the plate perpendicularly or parallel to the base cut was analyzed. In comparison with the method described in [4], the calculation of the local curvature of the surface was carried out by analyzing the geometric arrangement of points without the use of derivatives. This allowed to increase the accuracy of measurement of mechanical stresses.

The purpose of this work is to develop and test a method of mapping the surface. This approach will allow us to localize regions with maximum curvature values over the whole surface of the sample. Reduce the load on the PC's RAM. Also reduce the time to complete this task. More accurately calculate the Stoney formula mechanical stresses on the substrate.

3. Description of the method

Surface of the sample can be planar or relief. A damping table is used in the implementation of the described method. This allows the sample to be placed on a flat surface. The polished surface of the sample also require to detect the reflected signal.

On the example of the non-contact optical profilometer Veeco Wyko NT9300 follows the description of the method. The standard measurement mode allows to obtain a three-dimensional image of a surface of 0.84×1.1 mm. A longer length of the region is needed to analyze the curvature of the plate surface (100 mm for substrate Ø100, 150 mm for substrate Ø150 etc.). Thus, a series of sequential measurements is carried out (Figure 1). The software of the optical profilometer makes it possible to carry out a series of sequential measurements in an automatic mode. The «Stitching» mode is used, which includes setting the start and end points for stitching images, the degree of overlap of the images (about 30%), the scanning range for height, etc.

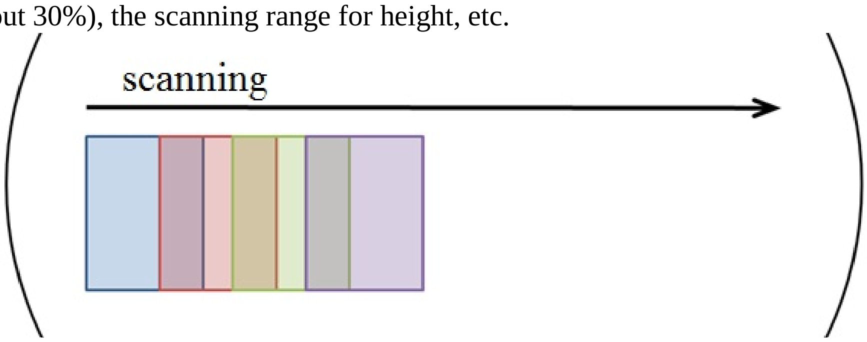

Figure 1. Illustration of the process of measuring the plate surface profile as a series of successive measurements with an overlap of about 30%.

The principle of the interferometer is as follows. The beam of electromagnetic radiation is spatially divided into two coherent beams. Each beam passes a different optical path to the screen. Thus, an interference pattern is created, along which the phase shift of the beams is established.

An important advantage of optical profilometers is that they create a three-dimensional image without contact with the surface. Thus, the method is non-destructive. This makes it possible to work with samples regardless of the mechanical strength of the structure under study. The method allows recording the features of the relief, starting from a roughness of nanometer scale to steps of millimeter height. For example, after vertical etching of silicon (Bosch process), distance between minimum and maximum point of the surface relief can be hundreds of micrometers, as shown in Figure 2. The ability to perform a high-precision analysis of the surface and record the amount of deflection of the sample, which amounts to millimeters, determined the use of an optical profilometer to solve this problem. Detection of the optical response is performed in the mode of vertical scanning interferometry.

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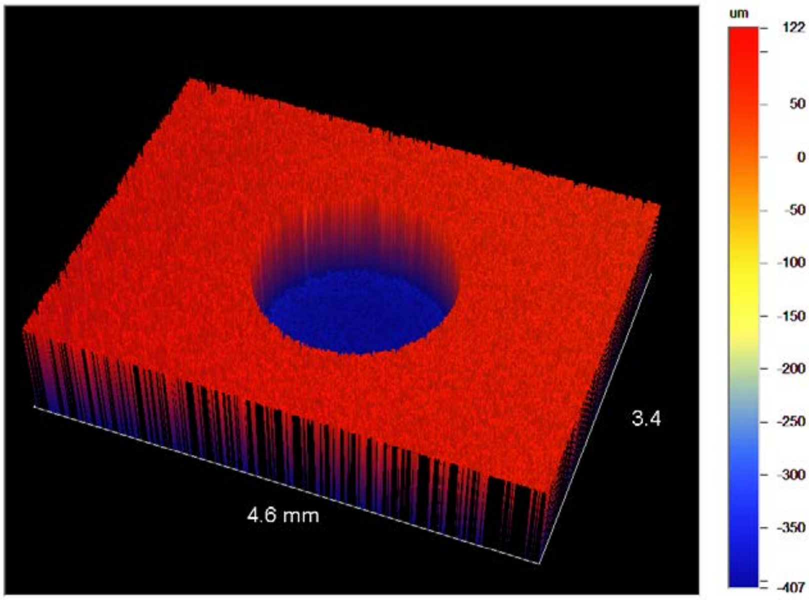

Figure 2. Measurements on the optical profilometer of the surface relief.

In the case of presence of local irregularities (depressions, elevations) on the sample, scanning along two different lines lagging behind by several millimeters can lead to different results (Figure 3). Therefore, tags are set for repeated measurements of samples. In Figure 3, dark areas show local surface irregularities (depressions or elevations).

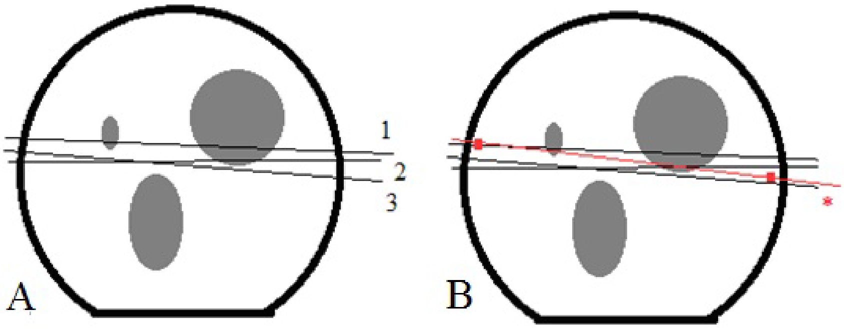

Figure 3. Effect of selecting measurement direction on final profile.

It should be noted that when scanning along two lines there is a high probability to overlook the presence of significant local irregularities. This is due to the fact that the scan lines will not cross them. The presence of such local defects and irregularities can have a significant negative impact on the conduct of subsequent technological processes (for example, bonding substrates, contact lithography) and cause the end product to be inoperative.

Thus, one can see the prospects and the need to develop a method for mapping surface, which will allow us to evaluate entire surface of sample and localize surface irregularities.

One way to carry out measurements using a technique similar to the one described above is to use the "Stitching" mode and overlap along the horizontal and vertical axis. However, in most cases this is not possible due to the large amount of data that exceeds the storage and processing capabilities of standard personal computers. Therefore, the "Stitching" method can be useful in the process of studying small-diameter substrates or using supercomputers. During the measurement on an optical profilometer, use of reference points (Figure 4) instead of overlapping data will reduce the loading of the RAM of the personal computer.

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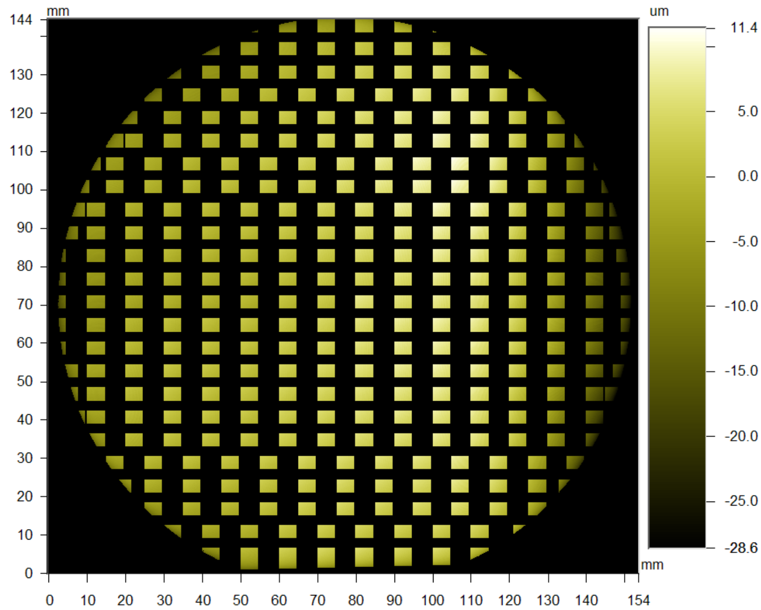

Figure 4. Result of scanning the surface using the reference points.

A series of sequential measurements is performed in automatic mode. In this case, a mode is used in which the coordinates of each of the scanning areas are set (300 regions for Ø150 substrates). Due to this approach, memory of a standard personal computer becomes sufficient to remove the entire data set from entire area of substrate. Also, measurement time is significantly reduced.

In this method, neighboring regions are not superimposed on each other (there is no overlap in 30%). On the contrary, there are significant "voids" in the data (Figure 4). In this regard, it is necessary to carry out the data recovery procedure in the intermediate areas. An example of implementation using the Veeco Wyko NT9300 optical profilometer software is shown in Figures 5 and 6. After processing the data, a complete map of the surface can be observed, in view of which it is possible to estimate the curvature of the substrate and observe local surface irregularities.

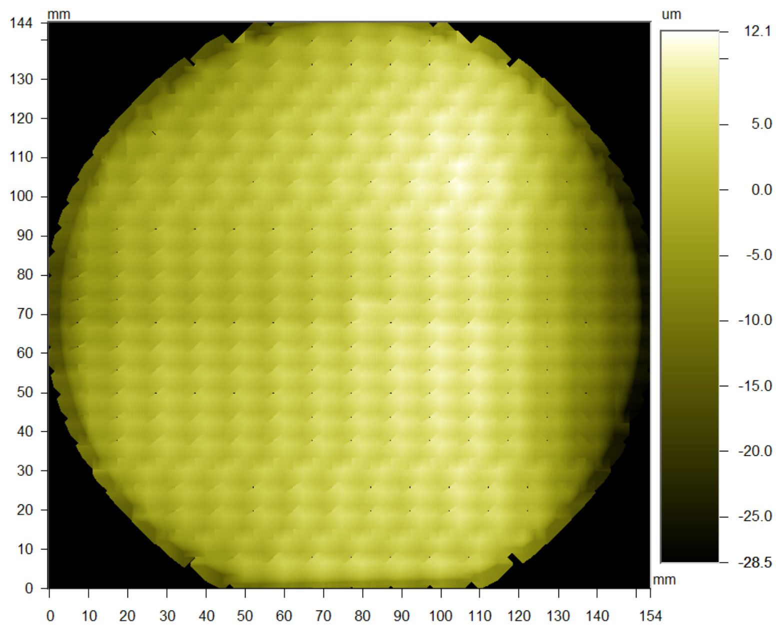

Figure 5. Restored surface map-2D.

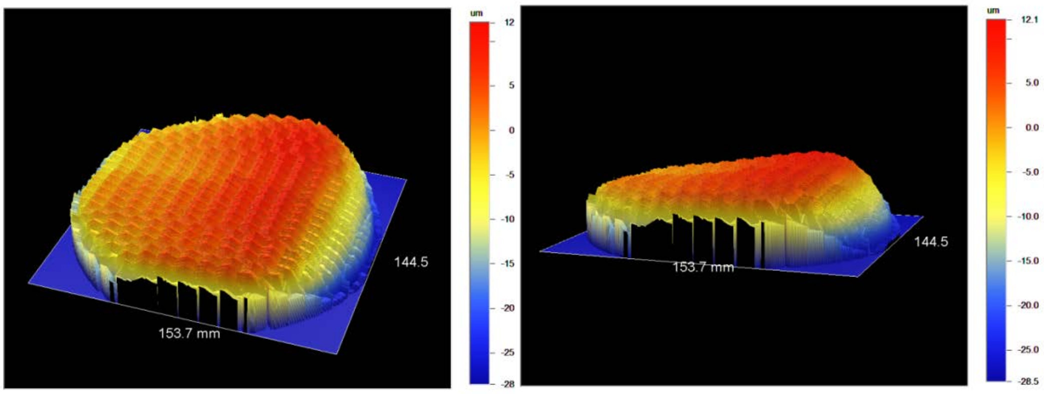

Figure 6. Restored surface map-3D.

A feature of this technique is the unevenness of the resulting image of the surface. Characteristic "saws" are present on 2D and 3D maps (Figures 7, 8). This artifact is related to the data extraction feature and cannot be removed using the Veeco Wyko NT9300 optical profilometer software. However, after recovering the data and saving the profile (Figure 7) in .txt format, this sawtooth distortion can be easily removed using software, for example, Matlab.

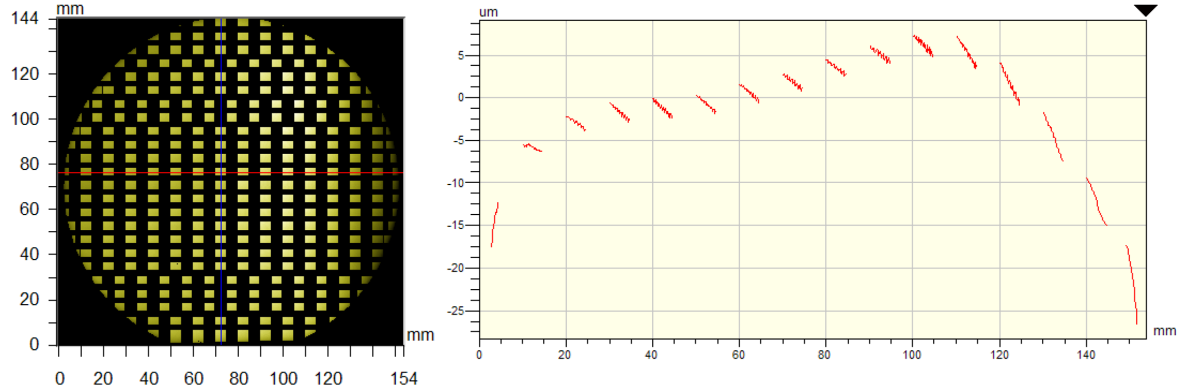

Figure 7. Surface profile of surface along the red line.

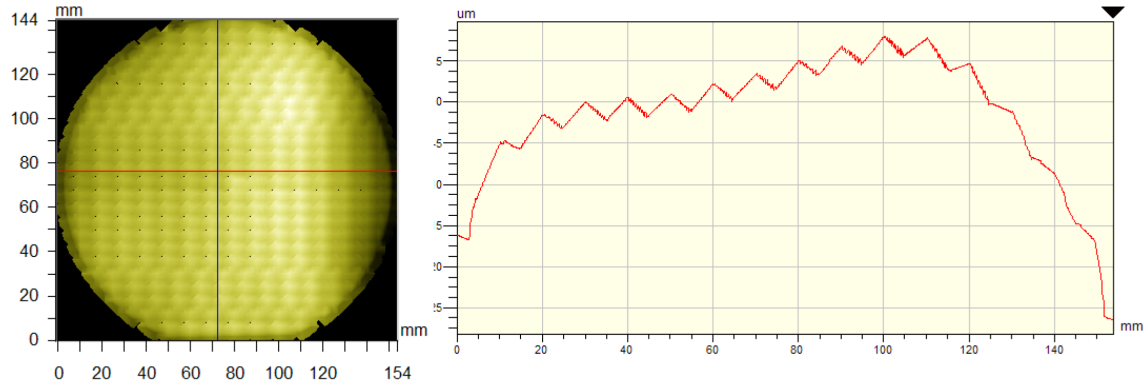

Figure 8. Reduced profile of surface along the red line.

4. Estimation of the accuracy of measurements of mechanical stresses

We are estimated technique on the basis of experimental data obtained by the authors in the previous paper [5]. The thickness of the materials is determined by the contactless method by means of an ellipsometer. The thickness of the silicon oxide film is 0.6 ± 0.05 (um), the thickness of the silicon substrate is 670 ± 20 (um). The value of curvature of the surface is calculated from geometrical location of the points determined by means of a contactless profilometer and is 0.0015 ± 0.0010 (1/m). Let the biaxial modulus of elasticity of the silicon substrate is 1.8×10^{11}(Pa) [6]. Previously, the average value of the mechanical stress in SiO_2–210 (MPa) is determined. Taking into account the variation of the measured values across the plate, the measurement error is -16.2 (MPa), i.e. 7.7%.

5. Conclusion

The developed technique for mapping the surface of structures makes it possible to obtain information about the entire surface of the plate and to localize the irregularities. In the process of applying this technique it is possible to obtain accurate and visual information about the surface of samples with a diameter of about 150 mm or more, which is inaccessible by most other methods. The accuracy of determining the value of mechanical stresses according to the Stony formula increases due to non-destructive measurements of the set of parameters (curvature of the surface, film thickness and substrate thickness) in the local areas of the investigated structure increased by 7.7%.

Acknowledgments

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References

[1] Astashenkova O N Physico-technological basis of management mechanical stresses in thin film compositions of micromechanics, Thesis, Ph. D., 2015.
[2] Gusev E E, Gryazneva T A, Negencev A V, Makhiboroda M A 2017 *Proceedings of the 2017 IEEE Russia Section Young Researchers in Electrical and Electronic Engineering Conference, ElConRus 2017* 1397–1400 doi: 10.1109/EIConRus.2017.7910831
[3] Wu Q,Wang J, Hou Y; Zhu F 2016 *Method for changing curvature of silicon wafer by stress of silicon dioxide* Patent CN №105448666
[4] Johnson T, Darwin M 2013 *Local Stress Measurement* Patent USA №8534135
[5] Djuzhev N A, Dedkova A A, Gusev E E, Makhiboroda M A, Glagolev P Y 2017 *IOP Conference Series: Materials Science and Engineering* 189 012019 doi: 10.1088/1757-899X/189/1/012019
[6] Chen K S 2006 *Handbook: Techniques and Applications* (Springer Science & Business Media), pp. 263 – 340