Extended height resolution in 3D deflectometry

Konrad Szwedowicz*, Stefan Bäumer**, Wim van Amstel***

*Philips Applied Technologies, TU Eindhoven
** Philips Applied Technologies, Eindhoven, ***WimOptik, Geldrop
mailto: Konrad.Szwedowicz@philips.com

During the last years Philips Applied Technologies developed laser deflectometry for fast and accurate topography measurement of various industrial surfaces. This paper describes recent improvements of the deflectometry set-up for inspections of "slightly unflat" surfaces. Evidence for the performance of the deflectometer will be presented in form of measurements on silicon wafer, where high spatial resolution is combined with a large dynamic range in height resolution.

1 Introduction

One of the global technology trends driving many technologies advance is miniaturization. Miniaturization drives the need for shrinking dimensions, making components and processes more accurate. Therefore, there is a clear need for advanced manufacturing processes. For developing advanced manufacturing processes, good metrology is needed. Parts can only be made to high precision, if they can be measured with precision as well. Therefore metrology should form an integral part of the product creation process. In this article a new and advanced metrology method for mainly flat and slightly curved surfaces will be introduced: laser deflectometry. The basic principle will be explained and measurement results on semiconductor wafers will be presented. Laser deflectometry combines high spatial resolution with a large dynamic range in height.

2 Basic principle and implementation

Deflectometry is based upon optical slope measurement. A focused laser beam falls onto a reflective surface under test, where it is deflected. Following the law of reflection, the local slope of the surface under test (SUT) at that particular point, can be indicated precisely by measuring variation of the deflection angle. The deflection angle is measured by a position sensitive detector, located in the focal plane of a lens. This is possible, due to basic properties of a lens; the angular information is transformed into position at the focal plane. Furthermore, in first approximation, the beam angle is measured independently on the distance of the object from the objective. Hence the measurement accuracy is not influenced by vertical vibrations or mechanical drift of the object during the measurement. Using a two-dimensional detector, both coordinates of the local slope vector are measured at once. This basic principle can be implemented in various ways, depending on application. One of possible application is a topography measurement. Therefore, the object's surface is scanned (mechanically or optically) and the surface slope-data are integrated numerically to retrieve topography information from the measurement.

The set-up invented at Philips Applied Technologies is designed for fast and accurate topography inspection of "slightly unflat" surfaces, like Silicon wafers. It is based on so-called Fast Optical Scanning (FOS), which is a combination of laser scanning and deflectometry. In result, the inspection of complete wafer surface can be done with very high lateral resolution, short measurement time and high slope/height accuracy. The basic implementation of FOS is presented schematically in figure 1.

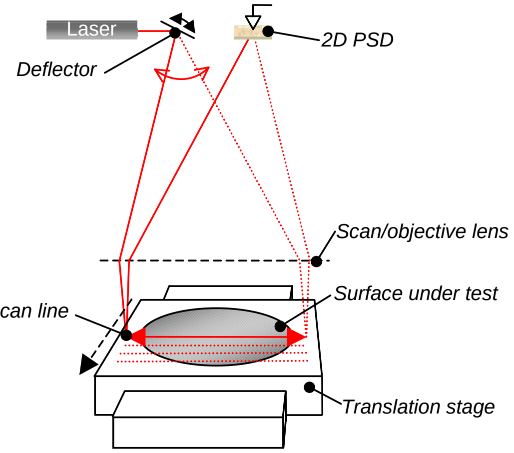

Fig. 1 Basic layout of 3D deflectometer, based on Fast Optical Scanning

In this configuration the light beam, probing the surface, performs an optical line scan. The scan is realized by an optical deflector (a scanning mirror) placed in the in the focal plane of a large scan lens. Hence, the angular deviation of the deflector is converted by the lens into a telecentric lateral scan on the SUT. The light reflected from the SUT, is focused by the same lens onto a two-dimensional position sensitive diode. Following the deflectometry principle, the angular deviation of the surface along the under test is registered as a position variation on the PSD. For generating 3D topography, the sample under test needs to be translated mechanically, perpendicular to the optical scan

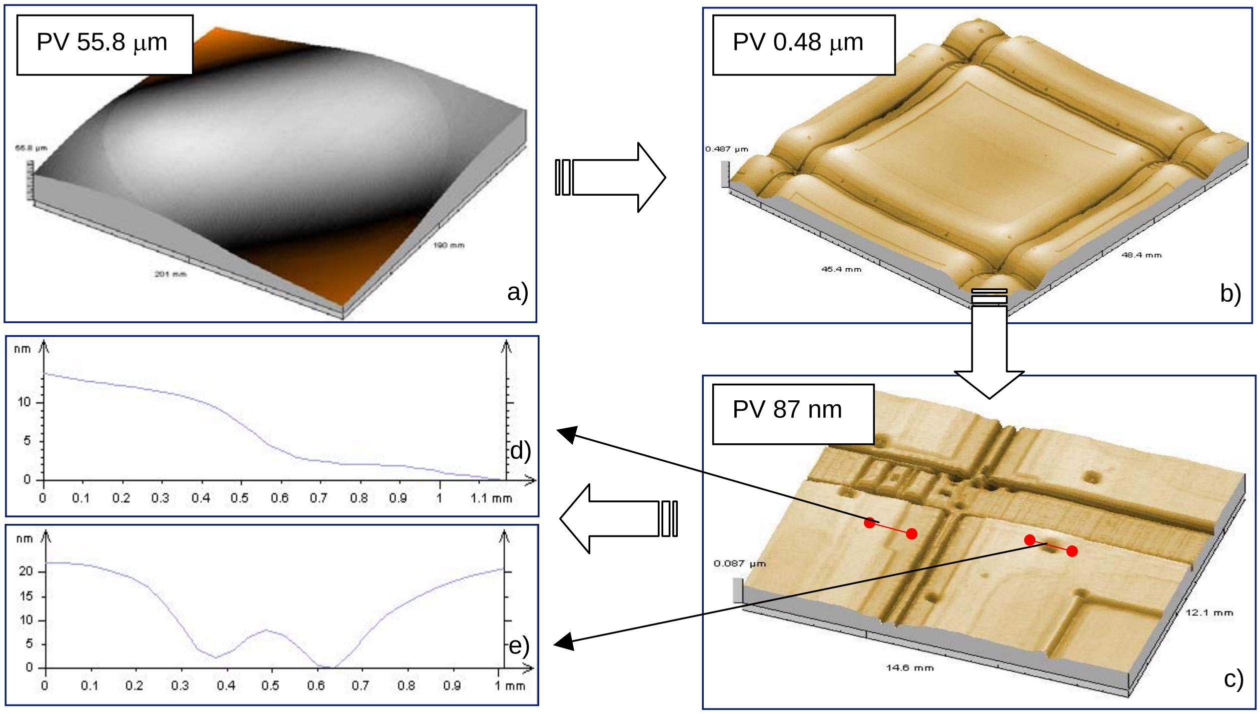

Fig. 2 A patterned silicon wafer (200mm diameter) measured by a 3D deflectometer.

direction. This way, line by line, the complete wafer surface can be inspected. Having gathered all the surface slope data, the 3D topography of the surface under test can be generated using advanced surface reconstruction algorithms.

The advantage of FOS is that the optical scan can be done a lot faster than by any mechanical scan. Furthermore, large industrial surfaces can be measured easily; using a fast PSD, a complete wafer surface can be inspected within a couple of minutes, with sampling distance in order of 0.1 mm. A long focal length of the objective makes the instrument extremely sensitive for local slope variations; the slope resolution of the current system at Philips Applied Technologies is below 1 μrad. Eventually, using a high-resolution PSD and geometrical properties of slope, very high dynamic range in the height domain can be reached.

3 Results

An example of results from wafer measurement by 3D deflectometry is given in figure 2. In the figure, a 200 mm a patterned silicon wafer is shown, which was put on a flat support without a vacuum chuck. The figure presents the complete wafer surface (fig. 2a), as well as zoomed-in small surface details (fig. 2 b,c,d,e). The wafer in the example is strongly deformed, due to the material stress from the processing, with the peak-to-valley (PV) height deviation of about 60 μm. By zooming in, however, small features with height of a few nanometres only can be captured. The zooming was done purely in software, by applying spatial filtering and smaller field of view on the same set of topography data; all the high resolution information given in fig 2 b,c,d,e is present already in the global shape picture (fig. 2a). Clearly, 1:10000 dynamic range in height is reached in that particular measurement

4 Summary

It has been shown, that FOS deflectometry can be used as an advanced metrology tool. One of the advantages of this new metrology tool is that a high spatial resolution is combined with fast optical scanning. Therefore even large surfaces can be measured in reasonable measurement times. Due to a large dynamic range in spatial- and height resolution, a single deflectometer can be applied for the global shape measurement as well as for the surface profiling. Another advantage of deflectometry is, that in first approximation the vertical position of the surface under test with respect to the deflectometer is does not have to be very accurate. Since deflectometry measures angles, not heights, even though nm vertical resolution can be achieved, the vertical position of the test object during the measurement, only needs to be within a millimetre. In results, the measurement noise due to environmental influence, like ground vibrations or mechanical drift, is practically eliminated.