INSPECTION OF SURFACE BY THE MOIRÈ METHOD

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Abstract: *A moirè method is one of the optical methods which are suitable for measurement of length, angle of rotation and also contactless surface shape deviation evaluation. The article is concerned on the possibilities of application this method by the evaluation of plane surface deviation of the semiconductor wafers.*

Key words: *grating, moirè fringes, measuring system*

1 Introduction

The word moirè is coming from the name of silk texture in which at the reloading and smooth shifting layer to layer dark and light fringes appear. The moirè fringes arise in consequence of the coincidence of two periodical structures-gratings (rasters). Generally, by the coincidence of two periodical processes a third one arises with longer period (Fig.1). The interference phenomenon is typical for the interaction of two mechanical and acoustical oscillations, for two electromagnetic and light waves.

The moirè interference was firstly described 1874 by Lord Rayleigh*, who predicated that this interference can be used as the test of irregularity ruling of grating or deflection of one grating to second, i.e. the reference grating [1].

Contemporary the moirè interference is used as the:

a) Impulse dial gauges for linear measurement of length or for digital measurement of rotation movement. Such measuring systems are IAL Zeiss, Langenmessysteme Haidenhain, OMT Optics Limited, Universalkomparator 200 Leitz, etc.
b) Moirè inspection systems of surface
    - for locating missing or misaligned parts in an multicomponent assemblies [2],
    - for analysis of dynamic processes (vibrations) [3],[4],
    - for optical contour mapping of surfaces the method of moirè topography [5],[6].

The moirè topographic system was subject of our research at the finding of a suitable method for testing the surface flatness of semiconductor wafers and photomasks.

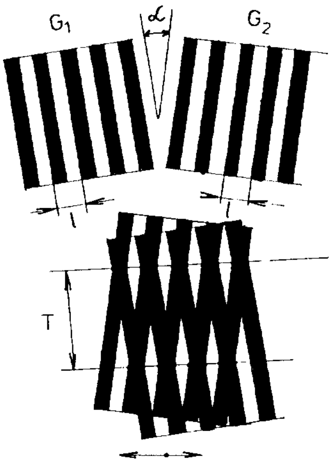

Fig.1
l – grid constant, raster period
angle between gratings
T- ***period of moirè fringes***

2 Moirè topography – evaluation of the shape

The basic principle of moirè effect is in superposition of two identical gratings G_1 and G_2 with a grid constant *l*. When they are exactly parallel (if α is zero), no fringe is observed (only dark or light field). When there is a small angle α between gratings, the moirè pattern of fringe spacing T is observed (Fig.1). It follows:

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* LORD RAYLEIGH: On the Manufacture and Theory of diffraction Gratings. Scientific Papers 1, 209, Phil. Mag. **47,** 1874, p.81-83 and 193-205.
Lord Rayleigh (John W. Strutt 1842-1919)

$$T=\frac{l}{2\sin\frac{\alpha}{2}} \tag{1}$$

A grating strips (lines) displacement on width l causes the perpendicular transposition of the moirè fringe pattern T. For small angle α = 1' is $T = l/\alpha$. This principle is applied in impulse dial gauges.
The moirè fringes pattern arises also when one grating is projected to the plane of second. When the image of first grating G_1 is distorted in the plane of second G_2 the moirè fringes to be curved (Fig.2).

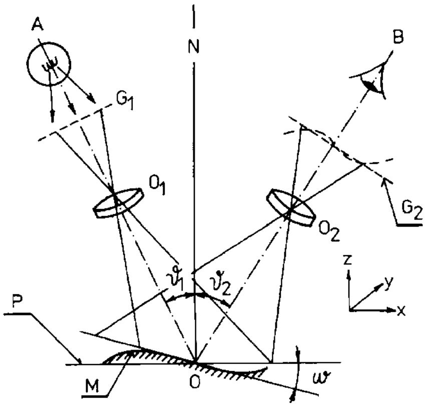

Fig.2
Scheme of moirè topographic system

It can be used for the evaluation of the surface form. The strips of the first grating G_1 projected on the measured surface M are rearranged, which is caused by the local deviations of the measured surface M from the plane P. A moirè shifting C across of one moirè fringe depends on the grid constant $l'=\beta.l$ (where β is the magnification of the projection system O_1), on the incidence angle ϑ_1, on the viewing angle ϑ_2, on the angle of inclination ω (angle between the plane of projection P and the measured surface M) and angle φ between the normal NO and the plane AOB. C is given by the expression [7]:

$$C=\beta.l\frac{1+\tan\omega\tan\vartheta_2\cos\varphi}{\tan\vartheta_1+\tan\vartheta_2} \tag{2}$$

If C is known, the deflection (rebound) of moirè fringe $N_3 - N_4$ (Fig.3) gives the information about local vertical deviation Δz from the plane.

$$\Delta z = C\cdot\frac{N_3-N_4}{N_1-N_2} \tag{3}$$

where $N_1 - N_2$ is the distance between two neighbouring fringes.
In the case when angles ω and φ converges to zero and for $\vartheta_1=\vartheta_2=\vartheta/2$. In arrangement on the Fig.4 ϑ is apperture of the objective. It follows:

$$C=\frac{\beta.l}{2\tan(\vartheta/2)} \quad \text{and} \quad \Delta z=\frac{\beta.l}{2\tan(\vartheta/2)}\cdot\frac{N_3-N_4}{N_1-N_2} \tag{4}$$

3 Moirè measuring system

Arrangement of our moirè system (Fig.4) consists of the photographic objective NIKON S, Auto 1:1,2, f = 55 mm (asymmetric anastigmat), two gratings (product of KFKI Budapest) with line density 200 lines/mm and TV camera with monitor. When the gratings were placed on the distance a = 2f (110 mm) from the back principal plane of objective O, then the magnification of optical system was β =1. In this case the measured object plane M lays on the same distance from the front principal plane of objective O and angle of opening was ϑ = 11°56'. Since l = 5 μm, then C = 24 μm. When we consider that we are able to determine the fringe deflection $N_3 - N_4$= 1/6($N_1 - N_2$), then system made possible to determine Δz_m= 4 μm, which is minimum of measurable high difference.
Sensitivity increasing is possible by the change of magnification of optical system or by application of the grids with higher density of lines. E.g when β =1/3, then ϑ = 17°46' C = 5,3 μm and Δz_m= 0,88 μm. This magnification can be reached if a = 4f (220 mm), i.e. by the change of dimension of the all system. Such a system is suitable for the flatness measurement of silicone wafers which were used for the production of surface standards, since flatness of substrates must be smaller as 3 μm according to the technological prescription. For acquisition of the higher contrast of moirè

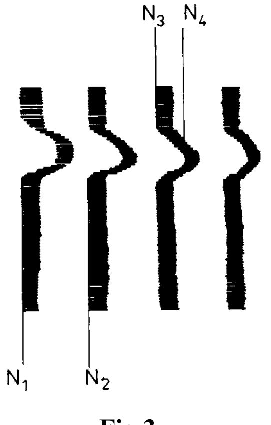

Fig.3

patterns the gratings can be vibrated in perpendicular direction to the grid strips [7],[8]. Then strips are scattered (dissipated), but moirè fringes are stationary by the simultaneous moving of both gratings. The realisation of such moirè system requires the precise mechanical construction. It is very important that angle $\alpha = 0°$ between gratings cannot be changed at the vibrations. The arrangement with TV camera and monitor was suitable for our application. But the computer evaluation of video signal from TV through can be useful for practical application.

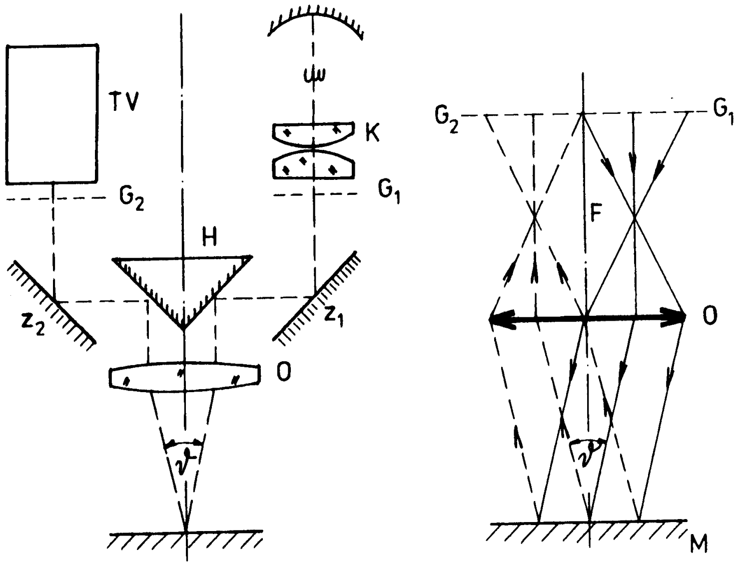

Fig.4
Opto-mechanical arrangement of moirè system

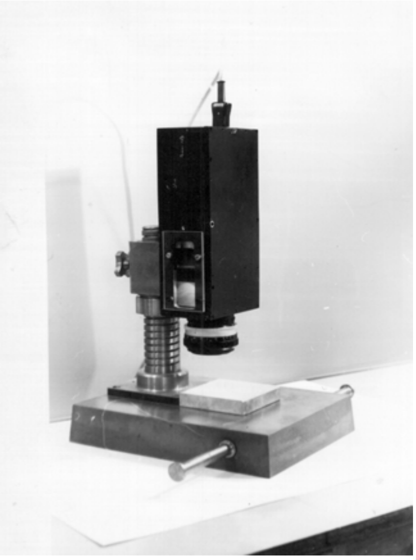

Fig.5
View on the device

4 Conclusion

A modernisation of a mechanical engineering put the higher emphasis to the accuracy of the serial production. The 3-D surface control gets step by step more exact if the profile measuring of complicated form is realised by the mechanical means (also e.g. by the CMM). The moirè interference methods which started to be applied at the beginning of seventies as the impulse dial gauges were also applied for the measuring of small mechanical deformations, changes of positions and also for the evaluation of the living body deformations [9],[10] (sickly defects of figure, scoliosis of spine). A present method and its realisation gives also the information about the higher vertical differences. This type of moirè for an out of plane deviation is given by [3]:

$$z = \frac{N\beta.l}{\tan\vartheta_1 + \tan\vartheta_2} = C.N \tag{5}$$

where N is moirè fringe number.

In our arrangement

$$z = \frac{N\beta.l}{2\tan(\vartheta/2)} \tag{6}$$

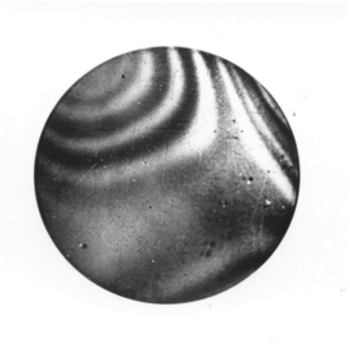

Fig.6

On the Fig.6 is snap of moirè pattern on the polished silicon substrate before superfinishing. The substrates were prepared as the circular wafers of the diameter 37 mm and 3 mm thickness. The fringe number is N= 4 on the above left side of the Fig.6, it means that this side of substrate exceeds the central part about 21 μm (C = 5,3 μm).

In this article we intended to present our small contribution to this problem.

5 Acknowledgement

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