Makyoh-topography for study of mirror-like surfaces

PhD theses

Lukács István Endre
Research Institute for Technical Physics and Materials Science

Consulant: Dr. Ferenc Riesz
Senior Research Fellow
Research Institute for Technical Physics and Materials Science

University consulant: Dr. László Jakab
Associate Professor
Technical and Economical University of Budapest
Department of Atomic Physics

Budapest
2006

1 Attecendents of the research

I have begun my work in 2000 at Department of Device Physics of Research Institute for Technical Physics and Materials Sciences. As a new associate I joined to a running research work, which dealed with a new analyse method of topography of mirror-like surfaces.

The stock of integrated circuits is fail save, oriented, perfectly flat Si crystalline wafer. The deviation from flatness of wafers can inhibit some of the following processing steps (for example polishing) or it can worsen the parameters of the process, so thus it can worsen the quality of the fabricated integrated circuits. Such failure can manifest itself in the amount of refuse products. By the progress of the miniaturization the specification of the geometrical property of the wafers are more and more strict, but the performance of this specification more and more problematical, if we consider the increasing diameter of the wafers. To our days the all of the leader microelektrical componys ground its manufacturing on 300 mm waferdiameter technology, whereas the deviation from the flatness of these wafers can not be more than few microns.

Hence both the wafer producers and the customers are intrested in such non-contact, high precision, clear and fast methods, wherewith the geometrical, topographycal errors of the Si wafers can be detected at the earliest possible moment – hopefully before the use –, so the wafer can be extacted from the producing process, and it can be sent back for reclaim. By this step the customers can spare a lot of heavy and expensive steps.

Several other industries require the study of mirror-like surfaces. It is indispensable in the course of the manufacturing of optical elements, that the manufacturer qualify the surface of these elements and perform the specification demanded by the order exacly. The other side the manufacturer can recognize failure of the producing process by continous controlling, so they can spare yield a lot of wrong product. In addition the topographycal features and flatness of the stocks are very important at the aspect of the maufacturing of optical and magnetic disks and magnetic magnetic heads used in information technology and the quality and lifetime of the product.

At the begining of the eighties a new topography study method called Makyoh topography came up as an adaptation of an aicent technik, the Makyoh, which is capable to observe the microdeformation of mirror-like surfaces. Its principle is the following: The surface is illuminated by well known property – practically collimated – inkoherent light beam. The reflected beam is detected on a screen, which is fixed a given distance from the studied surface. In praktice CCD camera, lenses, mirrors and other optical adjustments are used of course. It is able to deduce the surface topography by qualitative methods from the intensity distribution produced on the screen. The quantitative evaluation is very limited. There are two ideas to solve this problem at the moment, which were realised. These are: the approximation of the surface topography by several iterative methods and using of projected mask onto the sample.

2 Aims

The subject for my dissertation are study of the property of Makyoh imaging, the development of the quantitative methods and analysis theirs accuracy mentioned above, in addition verifiing and demonstration my analytical results by measurements and simulations. In addition the subject for my dissertation are the study the deformation generated under production of micromechanical devices and realisation the measurement of several material constans of thin layer, and finally development other topographical adaptations.

I devided my paper accordingly to my aims as follows: The title of the first chapter is: *Makyoh systems*. In this part I summarize the used results of the bibliography, I give exact definition for the Makyoh systems, I review the basic connection of Makyoh imaging and theirs limit, I show the most important published measuring methods, and finally I show the device used in our institute. I review my results from the second chapter, which's title is: *The imaging effect of the apertures in Makyoh systems*. I show the effects of apertures in Makyoh systems using my theoretical results and I verify them by experimental observations. In the third chapter titled *Quantitative Makyoh-topography* I discuss the developed methods for reprodution the Makyoh images in deatails. I deal with the several iterative methods and the "projected grid" method, I review the developed realisating algoritms and I show the advantages and disadvantages of these methods. In the last chapter titled *Makyoh technik in practice* I show the other scientifical results gained by practical using of Makyoh-topography. I show the capability of the method for in-line control the Si wafer process and process optimalisaton by Makyoh-topography study of the process of several membran structures and study of the deformation issued under removal of the layers of processed CMOS and NMOS Si wafer. My dissertation closes by summarize and conclusion together with the itemised enumeration of my thesises. My dissertation contains two appendix as well.

3 Examination methods

Under my research I studied the properties of imaging by analitical evaluations, computer simulations and several measuring adjustment as well. The Makyoh images for measurements and demonstration were made by Makyoh system located at MFA. The light source is a pigtailed LED with $\lambda = 829$ nm wavelength, which serve a very small size (only 50 μm diameter), but enough high intensity (200 μW), enough homogenious sight source.

The generated Makyoh image is detected and recorded by a 640×480 pixel resolution black and white CCD camera (with several ojectives and spacer rings) and a PC based image processing system. An 80 mm diameter and 500 mm focal length lens is fixed few centimeter above the sample holder and it serve as a collimator of the illumination light.

It is possible to place a structured mask between the magnifiing lens and the light source. The light beam impinging on the sample surface goes through the magnifiing lens again, and gets into the camera. The system is oriented in perpendicular, so the sample get into its horisontal, special formed, moveable in plane, and spinable round two axle sample holder. Either the camera, the light source, the mask and the collimating/magnifiing lens are fixed onto a perpendicular suporting pillar, so they can be fixed in optional distance from each other. I wrote my simulation computer algorithms in standardised C programing language, they was run in a 500 MHz AMD-Athlon computer under Linux operation system.

4 New scientifical results

The topography of an unknown surface can not be evaluates anatically from its Makyoh image.

1. *I have worked out an iteration algorithm for the quvantitative interpretation, which determines the topography of a surface given by one variable in Descartes frame of reference with a good approximation by using only its simulated Makyoh image and the known parameters of the Makyoh system. [T5, T6, T7, T15].*

Since the apertures affects to the generated image in an optical system, it is neccesary to know well the effects of the apertures in Makyoh systems. I determined the matematical equations of the limiting effects of apertures in the temple modell and in the camera and lens system. Based on above there are three benchmarks: (i) The aperture limit the detectable area of the sample; (ii) the aperture limits the area of the image; (iii) the angle of the reflected ligth beam is limited. In general case the character of the limiting effects is mixed.

2. *I analised that when the kamera is fixed at the focal point of the lens placed above the sample the aperture of the camera determines a maximal gradient value with the following statement: the points of the sample, in which the surface have higher gradient than the limit determined by the aperture, can not be imaged and appear as dark spots on the Makyoh image, or rather the points of the sample, in which the surface have lower gradient than this limit, can be imaged. I confirmed my analitical result by experiments [T1, T4].*

The speed of the method and the accuracy of the evaluation are first class question at industrial use. I studied the accuracy of the recovered topography by the "projekted grid" method analitically and by the help of computer simulation to built a new, more sensitive and larger Makyoh equipment [T2, T3, T17].

3. *I evaluated the recursive formula of the average of the numerical integral summation in all least step path of the „projected grid" method. Based on above I developed a new evaluation algorithm. The atvantage of this method is its rate.*
   I proved that the error of the evaluation mainly comes from the finite pixel resolution of the camera at relative small L value, its character is $1/L$*-like. In addition I proved that the value of the error is independent from the density of the grid and the shape of the studied surface in this range. But at relative large L value the error of the evaluation is practically independent from the L value itself. In this range the error of the evaluation is mainly the numerical error of the integral approximate summation. I made proposal for the optimal working parameters of Makyoh systems using my theoretical results [T9, T10, T16].*

The disadvantage of the "projekted grid" method is the low lateral resolution of Makyoh method. Manifest aim is the increasing of the lateral resolution.

4. *I have made foremost high lateral resolution Makyoh measuring procedure by the „projected grid" method. The measurement is based on the projected grid shifting and sequential recording of images. The resolution depend on the resolution of the used camera and the magnitude of shift step of the projected grid. At the realised measurement I increased the lateral resolution up to 7 fold compared to the original projected grid method of the Makyoh topography. I compared my results to the results measure by interferometry, and I got better accordance than wavelength.*
   I used first the recursive method for evaluation the „projected grid" Makyoh topography. I proved that we get the poisson equation by derivation the Makyoh imaging given $\mathbf{r} \rightarrow \mathbf{f}(\mathbf{r})$ *equation, which can be evaluated by the relaxation method [T8, T15].*

The reclaim of silicon wafers is a dynamically advanced area of silicon industry in these days. It is crucial to know and control the deformation changes during the reclaim process to improve the technology. I applied the Makyoh-topography fo study the deformation of the surface of processed CMOS and n-MOS circuits after the individual steps of wafer reclaim. I determined that the tension due to the metal layer, the much higher compressive stress due to the oxid layer and the changes in geometry and stress during the reclaim process can be shown by our method.

5. *I established in the course of experimental using of Makyoh topography that the relative flat originally processed circuits wafers remain relative flat, the relative uniformly curved wafers remain relative uniformly curved after the remove of layers, grinding and polishing. The originally strongly deformed wafers get new deformation on whole or part of their surface. This new deformations have no correlation to the old shape. The deformation due to the etching steps did not depend on the initial shape. The pattern of the integrated circuits remain viewable in the case of using larger granule slurry, the reason is analogous to the origin of the microdeformation*

of the ancient Makyoh mirror. In additional dimples appeared on the surface, I correlated this phenomenons to the fault of polishing [T11, T15].

The geometrical property of MEMS structures, the different material constants of the component of the structure and the parameters of the fabrication processes affect to theirs operation strongly. I applied first the Makyoh-topography method for observation the fabrication processes of membrane structures and for measuring the material constant of the component of the membranes.

6. *I used first the „projected grid" Makyoh method for determine the thermal expansion coefficient of non-stochiometric silicon nitrid thin layer by measuring the shape of the produced membranes on silicon bulk. The measured shape of the membranes were compared to the computed results by simulation. The thermal expansion coefficient was got* $2,62 \cdot 10^{-6}$ K^{-1}*, which suits to the literal range of values.*
   I studied first the effects of the electrochemically stopped alkaline etch used for fabricating the Si-SiN$_x$ *membranes and effects of the following steps: removal of* SiN$_x$ *annealing and etching of oxid layer by measuring of the shape of the membranes by "projekted grid" Makyoh method. Our method can show the stress due to the electrochemically stopped alkaline etching. The stress drastically increases further during annealing. The mechanical stress of the structure decreases slightly during the etching of the oxide layer. [T4, T12, T13, T14, T15].*

5 A tézispontokhoz kapcsolódó tudományos közlemények

T1 István E. Lukács, Ferenc Riesz: *Imaging-limiting effects of apertures in Makyoh-topography instruments*, Measurement Science and Technology **12**(8) pp. 29-33 (2001), IF: 0,859

T2 Lukács István Endre (23%), Dr. Makai János (24%), Dr. Pfitzner, Lothar (5%), Dr. Riesz Ferenc (34%), Dr. Szentpáli Béla (14%), Patent Application: *Apparatus and measurement procedure for the fast, quantitative, non-contact topographic investigation of semiconductor wafers and other mirror like surfaces*, applicant for all designated States except US, Internetion Application No.: PCT/EP 02/11011, International Filing Date: 01.10.2002

T3 Lukács István Endre (25%), Dr. Makai János (25%), Dr. Riesz Ferenc (35%), Dr. Szentpáli Béla (15%), Nemzetközi szabadalmi bejelentés: *Mérési elrendezés és eljárás félvezető szeletek és más tükörjellegű felületek érintésmentes, gyors kvantitaív topográfiai vizsgálatára*, szabadalmi oltalom kívánt területe: Magyarország, ügyszám: P0104057, bejelentés napja: 2001 október 2.

T4 F. Riesz, I. E. Lukács, Cs. Dücső, K. Hjort: *Makyoh topography: Instrumental Aspects and Quantitative Study of Deformation of Semiconductor-based Dielectric Membrane Structures*, 2nd Workshop "Micromechaniched Circuits for Microwave and Milimetersize Wave Applications", 27 October 2000 Budapest, Extended Abstracts pp. 18-19

T5 I. E. Lukács, F. Riesz: *A Simple Algorithm for the Reconstruction of Surface Topography from Makyoh-topography Images*, VIth Polish Conf. on Crystal Growth, 20-23 May 2001, Poznan, Poland; Crystal Research Technology **34**(8-10) pp. 1059-1064 (2001), IF: 0,536

T6 F. Riesz, I. E. Lukács: *Possibilities of Quantitative Makyoh Topography*, Proceedings of 3rd International EuroConference on Advanced Semiconductor Devices and Microsystems 16-18 October 2000 Smolenice Slovakia, pp. 215-218

T7 I. E. Lukács, F. Riesz: *Surface Topography Measurement of Semiconductor Wafers by the Makyoh Method: A Simple Algorithm for the Reconstruction of Surface Profile*, XXXth Iternational School on Physics of Semiconducting Compounds, 1-8 June 2001, Jaszowiec, Poland, p. 98

T8 I. E. Lukács, F. Riesz, Z. J. Laczik: *High Spatial Resolution Makyoh Topography Using Shifted Grid Illumination*, 6th Intl. Workshop on Expert Evaluation and Control of Compound Semiconductor Materials and Technologies, 26-29 May 2002 Budapest; Phys. Stat. Sol. (a) **195**(1) pp. 271-276 (2003), IF: 0,95

T9 I. E. Lukács, F. Riesz: *Analysis of Errors of Makyoh-topography Surface Height Profile Measurements*, XXXIInd International School on the Physics of Semiconducting Compounds, 30 May-6 June 2003, Jaszowiec, Poland, p. 153

T10 I. E. Lukács, F. Riesz: *Error analysis of Makyoh-topography surface height profile measurements*, 10th International Conference on Defects - Recognition, Imaging and Physics in Semiconductors (DRIP-X), 29 Sept. - 2 Oct. 2003, Batz-sur-Mer, France; Eur. Phys. J. - Appl. Phys. **27** (1-3) pp. 385-388 (2004), IF: 0,745

T11 I. E. Lukács, F. Riesz: *Makyoh-topography Assessment of Etch and Polish Removal of Processed Circuits for Substrate Re-use*, Microelectric Engineering, **65**(4) pp. 380-386 (2003), IF:0,9

T12 I. E. Lukács, P. Fürjes, Cs. Dücső, F. Riesz, I. Bársony: *Process Monitoring of MEMS Technology by Makyoh Topography*, Micromechanics Europe, 6-8 October 2002, Sinaia, Romania, pp. 283-286

T13 I. E. Lukács, Zs. Vízváry, P. Fürjes, F. Riesz, Cs. Dücső, I. Bársony: *Determination of Deformation Induced by Thin Film Residual Stress in Structures of*

Millimeter Size, Spring Meeting of the MRS, 5-8 June 2002 Strasbourg, France; Advanced Engineering Materials **4**(8) pp. 625-627 (2002), IF: 0,901

T14 F. Riesz, I. E. Lukács, Cs. Dücső, B. Szentpáli, K. Hjort: *Makyoh Topography Studies of the Deformation of Micromachined Membrane Structures*, Micromachined Microwave Devices and Circuits, pp. 93-101 (2002), IF: 1,299

T15 Riesz Ferenc - Lukács István Endre: *Kvantitatív Makyoh-topográfia tükörjellegű felületek simaságának vizsgálata*, Bányászati és kohászati lapok. Kohászat. 2.sz pp. 45-50 (2005)

T16 F. Riesz I. E. Lukács: *Sensitivity and Measurement Errors of Makyoh Topography*, 7th Expert Evaluation & Control of Compound Semiconductor Materials & Technologies, 1-4 June 2004 Montpellier, Phys. Stat. Sol. A, **202**(4) pp. 584-589 (2005), IF: 0,86

T17 I. E. Lukács, J. P. Makai, F. Riesz, I. Eördögh, B. Szentpáli, I. Bársony, I. Réti, A. Nutsch: *Wafer flatness measurement by Makyoh (magic-mirror) topography for in-line process control*, Proc. 5th European Advanced Equipment Control / Advanced Process Control, 14-16 April 2004, Dresden, Germany, p. 514.