Optical Electronic Microdisplacement Gage

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Abstract – **Developed were a model, a design and software of a precision device for measuring microdisplacement values, which can be used during automated control of geometrical parameters of various microobjects, and in particular in microelectronics**

I. Introduction

During manufacture of integrated circuits and complicated solid-state devices (LSI, VLSI, microwave transistors, power microelectronics devices with good prospects etc.) having specific dimensions of layout elements of less than 1 μm, including herein 0.5 – 0.13 μm, it is necessary to measure the period, width, thickness, position and quality of their peripherals. LSI elements of submicron dimensions, as well as those of nanoelectronics devices, are generated in layers of different materials (metals, dielectrics, semiconductors) which have 0.05 – 1 μm thickness and significantly differ regarding optical and emission properties [1]. Specific feature of such three-dimensional profile of a transition area of different shape, and the knowledge of geometrical structure of the area is necessary for high precision linear measurement at submicron level. At present for controlling geometrical parameters of such microobjects SEM methods are typical, but they are expensive and mostly used for failure analysis, and their use during routine inspection in LSI and VLSI technology is inefficient. A substantial problem in submicron technology is assurance and control of planarity and parallelism of surfaces of semiconductor wafers of big diameters, and these purposes SEM methods are also inapplicable [2, 3].

II. Model of Optical Electronic Transducer for Measuring Microdisplacement Values

As shows analysis of possible errors of an interferometer, which is run within optical range of wave lengths, when selecting and substantiating its optimal pattern it is possible to obtain the discreteness of reading at the level of 4 – 5 nm. Really, due to optical interpolation the reading discreteness is $\delta = \lambda/16$, and at $\lambda = 640$ nm $\delta_{opt} = 40$ nm.

As the basis for making the model a diagram of optical triangulation was used [5-7]. Simulation of triangulation diagram starts from selecting initial values for basic parameters [8] (Fig.1): free space h, between an object and a sample, $\angle\alpha$ и $\angle\beta$ and aperture f_E of the main lens.

After establishing basic parameters other ones are calculating: $F'F''$ sensor length, common range of $D'D''$ measurements and $\angle g$, which establishes the angle to which the sensor shall be adjusted per the main lens. If the obtained results are satisfactory, then we start a more precise adjustment of the circuit which consists of repeating calculations with initial values and of finding the optimal alternative.

To make up the model we use Fig.1, trigonometrical functions and lens formula for the thin lenses:

$$\frac{1}{a} - \frac{1}{b} = \frac{1}{f},$$

where a is the distance from an object to the lens; b is the distance from the lens to an image; f is a focal distance.

Simulation was carried out using a computer in Mathcad package according to Fig. 1.

The following equations were obtained:

$$DE = \frac{h}{\cos\alpha}. \quad (1)$$

The essential task of a mathematical modelling is selection of the measurement limits. We have determined them as the following equations connected with the Fig.1:

$$D'D'' = h\, tg\alpha\left(\frac{1}{tg(\alpha-\beta)} - \frac{1}{tg(\alpha+\beta)}\right). \quad (2)$$

Segment

$$D''_{DE}E = D''_{DE}D + DE = h\left(\cos\alpha\left(\frac{tg\,\alpha}{tg\,(\alpha-\beta)} - 1\right) + \frac{1}{\cos\alpha}\right) \quad (3)$$

and segment

$$D'_{DE}E = DE - DD'_{DE} = h\left(\frac{1}{\cos\alpha} - \cos\alpha\left(1 - \frac{tg\,\alpha}{tg\,(\alpha+\beta)}\right)\right). \quad (4)$$

This work has been carried out within the Belarusian State Scientific Program "Electronics".

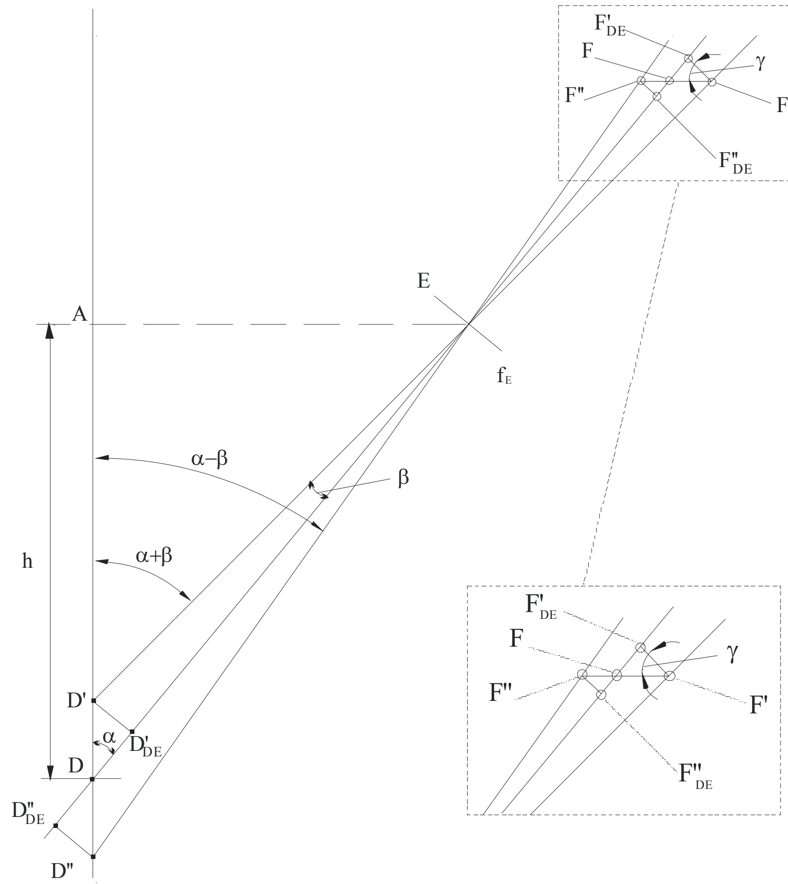

Figure 1. For developing the mathematical model

Let us present the lens formula like this:

$$\frac{1}{D''_{DE}E}+\frac{1}{EF''_{DE}}=\frac{1}{f_E} \quad (5)$$

or

$$\frac{1}{DE}+\frac{1}{EF}=\frac{1}{f_E} \quad (6)$$

and

$$\frac{1}{D'_{DE}E}+\frac{1}{EF'_{DE}}=\frac{1}{f_E}. \quad (7)$$

On the photodetector side we obtain the following equations for the segments

$$F''_{DE}F = EF - EF''_{DE} \quad (8)$$

and

$$F''F''_{DE} = EF''_{DE}tg\beta. \quad (9)$$

Then γ angle of the photodetector setting per the main lens axis is

$$\gamma = arctg\left(\frac{F''F''_{DE}}{F''_{DE}F}\right) = arctg\left(\frac{EF''_{DE}tg\beta}{EF-EF''_{DE}}\right), \quad (10)$$

and the photodetector length is

$$F''F' = \frac{tg\beta}{\sin\gamma}\left(EF''_{DE}+EF'_{DE}\right). \quad (11)$$

Thus, the system of the obtained analytical equations (1-11) is a mathematical model of an optical electronic transducer, and it assures a link between spatial position of an object, analysing lens and photodetector at optimal conditions of selecting location of the focus of laser beam in the measurement area and the type of photoelectric response.

III. DESIGN OF THE DEVICE FOR MEASURING MICRODISPLACEMENTS

Based on the developed model an optical electronic device for measuring microdisplacements was designed for contactless measurement of dimensions, displacement, position, surface profile and deformation of parts in microelectronics. The above device can be regarded as a laser triangulable micrometer (LTM). It is shown in Fig. 2.

LTM is mounted on a stand with micrometrical feed of a microscope stage and includes:

- 5 mW semiconductor laser with irradiation wave length λ = 670 nm,
- condenser lens for focusing a laser beam on the surface of a measured object,

– reproduction lens with the focal distance of 16 mm,
– correcting mirror,
– CCD ruler, and
– microprocessor for processing measurement data and controlling CCD ruler and semiconductor laser.

LTM is connected to a standard port to which software of measuring data presentation is also loaded.

The basis of the micrometer operation is optical triangulation explained in Fig .3.

Figure 2. Picture of the microdisplacements measuring device

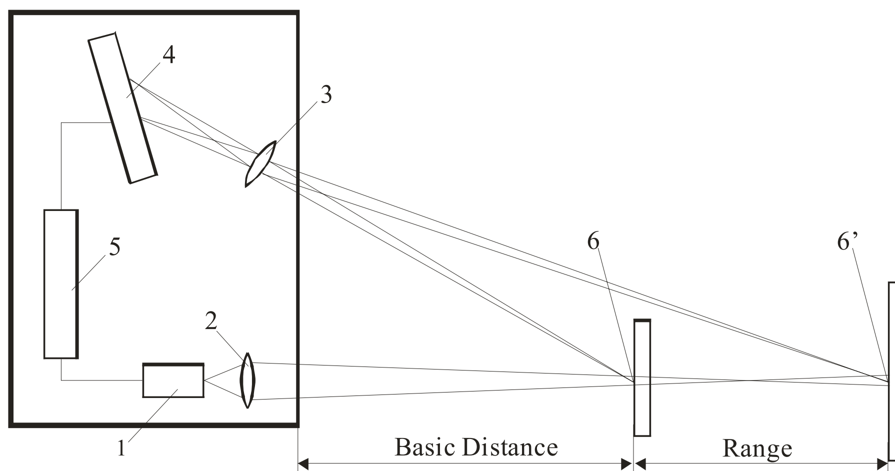

Figure 3. LTM optical diagram

Irradiation of the semiconductor laser 1 is focused by lens 2 to an object 6. Dissipated on an object irradiation by lens 3 id concentrated on CMOS ruler 4. Displacement of object 6 – 6' causes relevant displacement of image. Signal processor 5 calculates the distance to an object per position of illumination spot image on ruler 4.

IV. Data Processing

A special software called "RF60X-SP" was developed for:

– testing and demonstration LTM operation of RF603 series;
– tuning of LTM parameters;
– receipt and storage of data.

After starting the software there comes the window shown in Fig. 4.

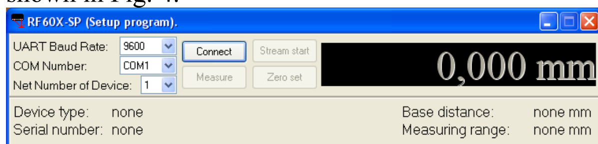

Figure 4. Operational software window

Sequence of running the software is the following.

In "UART Baud Rate" line we choose the rate of LTM operation (initial setting is 9,600 bit/s).

In "COM Number" line we choose number of RS232 port of computer to which LTM is connected.

"Net Number of Device" line determines LTM's network address (initial setting is "1").

When pressing "Connect" RF60X-SP tries to establish connection with LTM with parameters set up in the above lines. If the connection is not established a message of the fact is produced.

If the connection is successful:

1) In "Device Type" line LTM type is indicated;
2) In "Serial Number" line LTM number is indicated;
3) In "Base Distance" line LTM's basic distance is indicated;
4) In "Measuring Range" line operational range of LTM is indicated, and the window transforms.
5) Pressing "Stop"/"Stream stop" stops data transmission.
6) Data coming from LTM are accumulated and stored in a circular buffer of 10000 measurements.
7) With a left key of the mouse one can change a chart scale, and with a right one – move a chart for viewing. Pressing a right key brings about "Data saving in a file" menu.

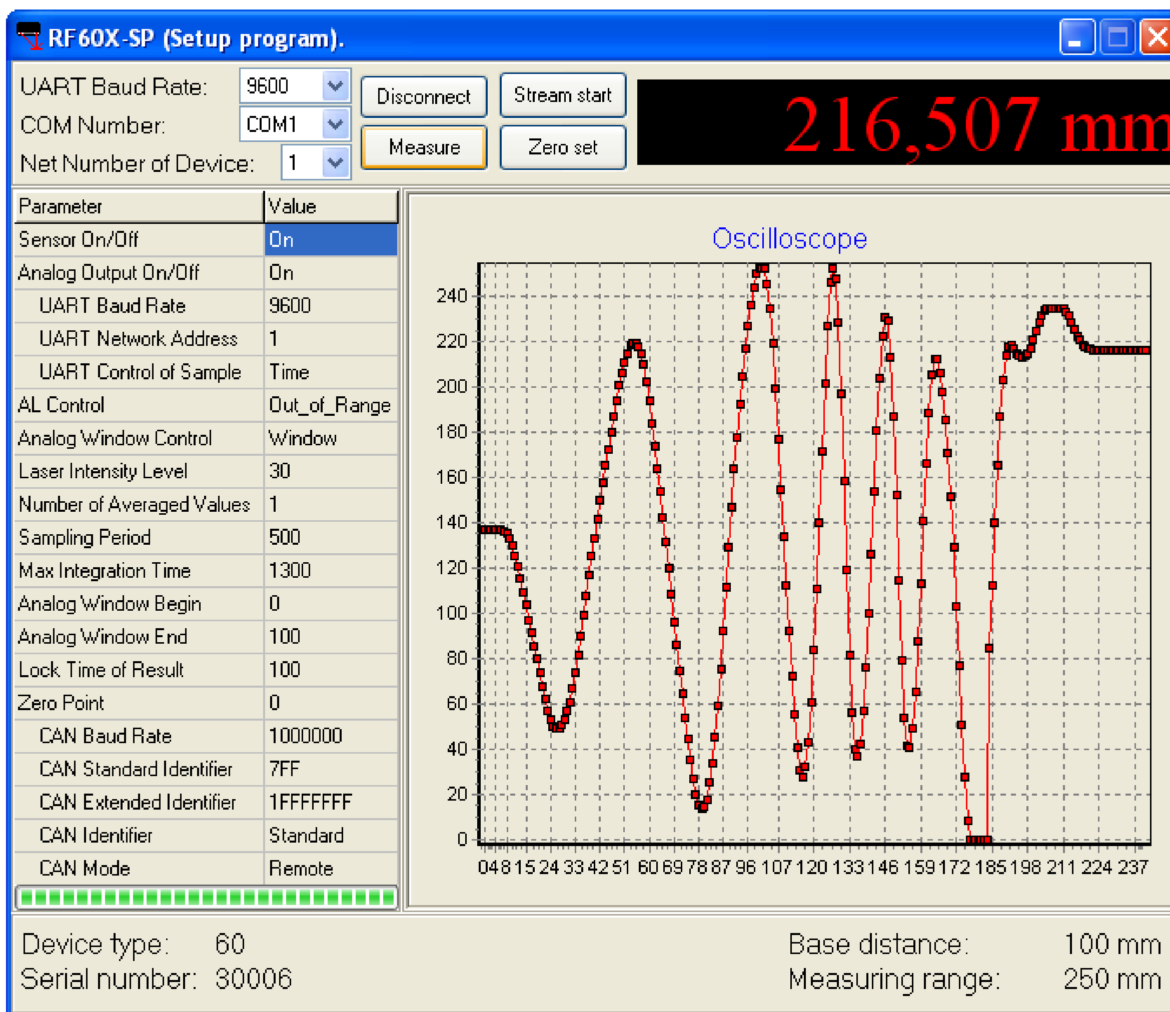

Figure 5. Full-scale operational window with an oscilloscope

For an example Fig. 5 shows an operational window with an oscilloscope. But initially in the right top corner a zero value comes which corresponds to the basic distance setting.

After successful link connection we check device's performance.

An object is positioned in LTM's operational range.

Pressing "Measure" key displays an indication panel and "Oscilloscope" panel results of measuring an object's position. X axis is time (time mode), or number of reading (mode of sampling per external input), Y – coordinate. In this case 06h call type is realized.

Pressing "Stream start" key activates measurements in time sampling mode according to set up Sampling Period parameter. Then 07h call is realized.

Moving an object in the operational range area we can see changes in values.

V. Test and Calibration

As a result of calibration and test of the laser micrometer we obtained a chart of distribution of a measurement error on the operational range which is given in Fig. 6. The chart shows that the measurement error is not more than ± 3,3 µm, which meets modern requirements for basic microelectronics processes, for instance regarding packaging.

Conclusions

The designed optical electronic gage of microdisplacements, based on laser triangulation, assures low errors of contactless measurements and possibility to automate control of geometrical parameters of objects in microelectronics.

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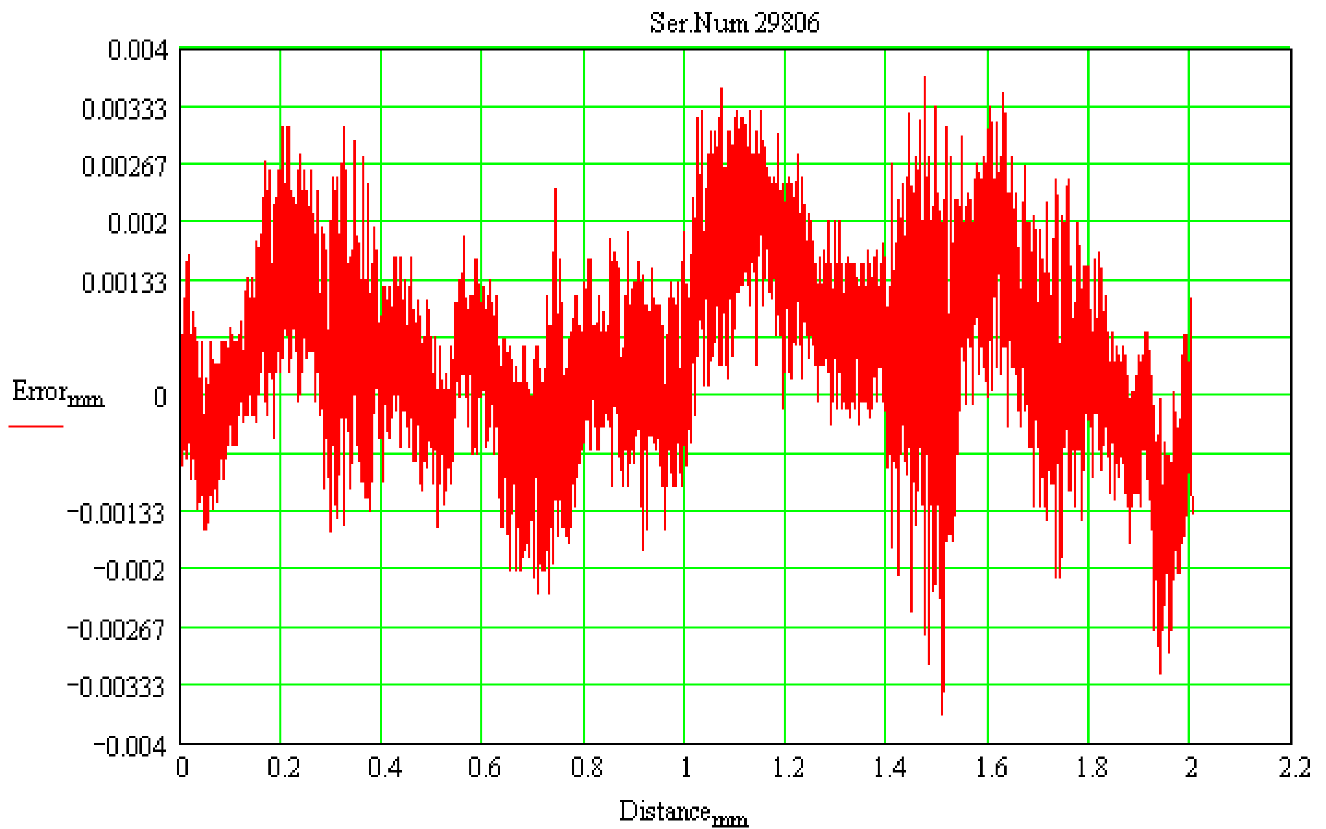

Figure 6. Dependence measurement error on the operational range

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