Compact Algorithm of Extrema Count in the Interference Measurement of Transparent Film's Thickness

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ABSTRACT
In this paper, we describe the solution of the problem of automation of quick count of thickness method developed by Oyama and Mori, and the implementation of an efficient algorithm for the automatic calculation of the interference extremums.

Categories and Subject Descriptors
D.3.2 [**Programming Languages**]: Language Constructs and Features – graphical structures*, control structures.*

General Terms
Algorithms, Experimentation, Measurement.

Keywords
Thin film, measurement, ADC, algorithm, contactless methods, automation

1. INTRODUCTION
To control the thickness of the dielectric layers (films), which are transparent in the visible or infrared region, it is convenient to use laser interference methods. One of the methods developed for measuring the thickness of the so-called "thick" films (10-1000 um) is a laser-interferometric method proposed by Oyama and Mori [1]. The film thickness can be determined by counting the number of extrema m, occur when the angle of incidence of the laser beam θ on the film in a predetermined angular range from θ_1 to θ_2 The refractive index n of the film material must be known.

$$d = \frac{m\lambda}{2\left(\sqrt{n^2 - \sin^2\theta_2} - \sqrt{n^2 - \sin^2\theta_1}\right)}$$

The method proposed by Oyama and Mori was realized with the help of a pantograph, on which the laser and photoelectric detector were placed on adjacent shoulders. The surface of the controlled sample was at the axis of the hinge connecting the shoulders. The laser beam, which is incident to the previously specified point on the sample surface, will hit on the photoelectric detector at any angle of incidence on the sample. In the opinion of Japanese researchers the main disadvantages of this implementation method is the long duration of the measurement (10 seconds) and the lack of precision in a number of applications.

In the works [2-5] optical-mechanical schemes have been proposed, which allowed increasing the rate of change of the angle of incidence of the laser beam at a given point on the surface of the sample significantly and reducing the time of a single measurement from 10 seconds to 0.02 seconds. One of them [2, 3] contains a rotating flat mirror and two fixed ellipsoid mirrors. The laser beam, which is reflected by a flat rotating mirror from one focus of an ellipsoid, after reflection from the elliptical surface, hits its second focus, which coincides with a predetermined point on the sample surface. Changing of the angle of incidence of the laser beam on the sample is set by rotating a plane mirror. Subsequently, the ellipsoid mirrors have been replaced with spherical [4] or with spherical lenses [5]. When calculating the thickness according to the formula (1), the main task is to count the number of extrema m. To automate the calculation and reduce the time of receipt of the thicknesses we have applied digital signal processing and specially designed software.

2. ALGORITHM
2.1. Description of the algorithm
The chain of receiving and processing information about the interference in the sample is shown on Figure 1.

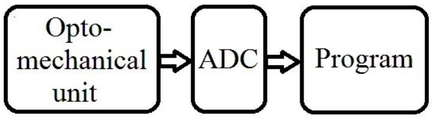

Figure 1. The signal processing chain to obtain values of thicknesses of the films studied.

Signal containing information about the interference in the sample is converted by a photodetector into an electric and goes from the output of the optical-mechanical unit performing a scan of the laser beam on the surface of the film, to the analog-to-digital converter (ADC).

Once converted to digital form from the output of ADC we get the flow of information in an array of data. The data, which contains information about the interference is coming from the optical-mechanical unit with a periodicity of 50 times per second, because, conventionally the whole data stream can be divided into 50 frames. Every frame contains information about the interference pattern in the film. The frames are different one from another because of different disturbing factors - noise superimposed on the useful interference signal. For getting the finite values of the thickness of the analyzed film, each frame is processed on the fly by software. The result of processing - the value of the film thickness, is displayed graphically on the screen of a hardware and software complex.

Some of the information contained in the data stream does not carry information about the interference, so, to reduce the amount of processed data we implement the ability of selection and manual adjustment of the useful part of the information flow. This will allow us to get rid of redundant data and we increase the precision of calculations the number of local extremes without loading the CPU with too much information. Next, the selected data in the one-dimensional array enters the main processing unit - the cycle (with a nominal delay) with a count supplied by all elements of the array. For convenience, the program counts the required number of iterations carried out in the main body of the program automatically.

Previously [7] we have proposed a version of the software processing of the signal of the optical-mechanical unit. The same way in [8, 9], we proposed to combine the methods of optical measurements to repeatedly increase the precision. The current version of the data processing program has rather simple implementation of the algorithm. This will allow us, if necessary, to implement the extrema detection algorithm in the form of a separate electronic circuit and the microcontroller for embedded ADC.

The basic idea of the new algorithm is a sellection of the incoming stream from the ADC at each iteration of the cycle of the three elements of the data array, making the detector differences and their subsequent comparison and verification of conditions of extreme detection.

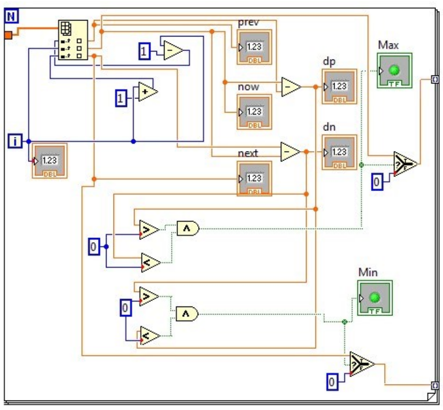

Figure 2. Algorithm for the detection of interference extremes.

Consider the bulk of software implementation of the interference extremes detection unit (Fig. 2): On each loop iteration via subdevice of index selection elements from the incoming data stream, we extract three elements. For convenience, let us call them the previous, current and next element. After that, we create and calculate the intermediate differences between selected items (On the picture marked, respectively, dp и dn). It is used to set up a sign comparison of the differences, followed by verification of the interference extremes detecting conditions. Under these conditions, to produce the differences we form the following data stream and write it to an array of amplitude values for all elements in the special way. When the “different sign” conditions specified by us for detecting peaks are met (in a similar way to the lows), the current element for this iteration is written in the formed array and, when failed to fulfill the conditions, zero is placed in the array. Thus, now the array generates information about the minima and maxima of interference. Further processing does not represent any difficulties and can be solved in any convenient way. We, in turn, form, for solution of the problem of counting interference extrema from the resulting array, additional array containing zeros and ones, putting ones in an element place in the array, if it is the interference extremum and zero - otherwise. Next, the finding of the number of the interference extrema is a trivial task. Due to the implementation of the proposed extrema detection algorithm, film thickness can be determined with a precision of half-cycle interference.

2.2. Problems, solved for the practical implementation of the algorithm

After digitizing of the signal from the optical-mechanical unit, we receive digital data array that carries the information of the amplitude envelope of the output signal taken from the photodetector unit. The array includes detailed information about the interference in the measurement sample. Information from the opto-mechanical unit is supplied periodically with a frequency of 50 times per second (50 fps), and only a tenth of the time of each frame contains the necessary information. The rest of the analog information from the optical-mechanical unit does not bear information about interference and to free up CPU time for useful for us computations, we must get rid of it. In order to implement calculation of thickness, we solved the problem of the selection of that frame, which carries the interference pattern formed by the sample. For clarity, in the data processing part of the program we provided graphic display of data from the ADC.

The interferences superimpose on the interference pattern formed by the test sample superimpose, and these interferences are distorting information about the interference. One of the confounding factors - the unevenness of rotation of the engine, carrying out a scan of the laser beam. The second factor - unevenness of the samples of the oscillator of analog-digital converter (ADC). The third factor, the most significant - is electromagnetic interference arriving at the input of the ADC together with the signal from the photodetector carrying useful information. All three of the above factors affect the measurement precision of the proposed method of calculation of the digital interference maxima. To deal with them we had to complicate the algorithm of the software processing of measurement results, and namely: to allocate a certain margin on the leading and trailing edges of the frame carrying the interference pattern. So the algorithm developed by us of extremum detecting has been further complicated and includes a cut-off unit of redundant information, which does not carry the information about interference, with the possibility of manual adjustment of the allocated frame block. Furthermore, to eliminate errors in extrema detection caused by noise imposed on the signal, we allocate additional subarray of data from the stream received from the ADC by sampling every n-th element (in this case, tenth). Additional processing of the subarray level allowed us to avoid errors associated with noise, the frequency of which affect the information within one half-cycle of the interference pattern.

In addition, we applied the algorithm for calculating the interference extrema, which allows us to solve the problem of determining the thickness of the film by the method of Oyama-Mori with the precision up to half period of the interference pattern, which is coming from the sample. We have following conditions: the wavelength of a helium-neon laser, λ = 628 nm, the refractive index of the polyethylene sample n = 1,54, the sampling frequency of used by us twelve bit ADC NI-5122 and 300 kHz and sweep range of the laser beam 35 ° (from 25 ° to 60 °), provided by the optical-mechanical unit. When detecting 17 of the interference maxima, the measured thickness of the selected sample of the film was 26.49 μm ± 0,76 μm. In case of counting the whole number of periods of interference, the variation of thicknesses would be ± 1,51 μm.

2.3. The precision of the measurement method

When increasing film thickness within a range of angles of the sweep of the laser beam, increasing number of interference periods will be placed and each period will fit inside the smaller angular range sweep of the laser beam. Since precision is characterized by taking into account one half period of interference, increasing the thickness of the sample, relative tolerance range of calculated thickness will decrease (at constant absolute tolerance range). This will increase the precision of determining the relative thicknesses. However, when increasing the amount of interference extrema in the given range of the laser beam sweep, the amplitude span between maximum and minimum interference would be reduced due to scattering effects in the real non-plain-parallel sample. In addition, the current peak values of the interference and noise while reducing the useful amplitude swing of the electrical signal will have a more significant impact on the analyzed signal, hence the risk of error of detecting amount of extrema increases. These factors will reduce the precision of the method of measurement of thick films. Using our optical-mechanical unit, we were able to measure the maximum film thickness of 105.95 μm.

Limitation for small thicknesses can be determined from the fact that within a range of sweep of the beam fit one interference period. Then, as referred to the article's parameters of the measuring system and the refractive index of the sample, the minimum thickness measured by unit was 1.51 μm ± 0,76 μm. It is understood that the relative accuracy of the measurement in this case is low.

A compromise solution will be an artificial restriction of the range of measured thicknesses both above and below, all other constant parameters of the system, such as: the range of the beam sweep, carried out by opto-mechanical unit, the wavelength of the used laser and the refractive index of the sample.

2.4. Advantages of the algorithm

The software module has a simple structure, which allows us to implement it in simple programmable complexes. Local extremes are counted precisely: in most raw data the results of program extrema counting is identical with the calculation of the waveform manually. Compact software system coupled with the ease of implementation does not require large amounts of CPU computing time and allows us to implement his work on a single chip with integrated ADC.

2.5. Disadvantages of the algorithm

The relative simplicity of the proposed algorithm is both an advantage and a disadvantage, because of the influence on the result of counting of the thickness of noise and disturbances superimposed on the useful signal. These disturbances manifest themselves and cause minor error in extrema detection that are not handled with the proposed algorithm. About 20% of the values of the thickness are differ from the bulk of values of thicknesses on half-period interference. Increasing the accuracy of counting of the interference extrema requires further complicating of data processing algorithms, and as well usage of statistical processing of the values of thickness;

3. ACKNOWLEDGMENTS

Our thanks to National Instruments for allowing us to use their licensed product LabView 8.5 that they had developed. In addition, we thank The National Mineral Resources University for providing us with all the hardware equipment and with all the experimental tests, where they used modern facilities and some software and hardware equipment made by their best specialists.

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