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Microprocessor controller for EL-11D ellipsometer

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Abstract

The purpose of the microprocessor – based controller described in the present study is to enable the measurements by means of EL-11D ellipsometer system to be carried in automatic mode. The geometry of optic components of the ellipsometer system can be changed in MANUAL and AUTOMATIC modes by means of the controller. Three keys incorporated on the front panel are used for setting of the ellipsometer in MANUAL mode. The controller management in AUTOMATIC mode is possible via serial transmission link from any IBM personal computer.

1. General

The optic system of the ellipsometer consists of polarized light source, quarter – wave plate, two polarizers (hereinafter referred to as polarizer and analyser) and light beam intensity detector [1]. The detector has been incorporated behind the analyser. The sample to be tested is placed between the polarizer and analyser.

The experimental point achieved by means of the ellipsometer consists of a set of angular settings for optic active elements, polarizer and analyser being characterized by complete extinction of light beam transmitted via optic system of the ellipsometer.

In practice, any change of light polarization angle in the polarizer – sample system will result in detuning of local beam intensity minimum in the polarizer – sample system. The measurement consists in many setting sequences repeated alternatively for optic active elements in order to achieve complete extinction of light beam.

The step motors operated by means of hardware controller system have been applied by the designers for the setting of the polarizer and analyser in their positions. A/m system has been built on the basis of TTL integrated circuits.

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As a result of its serious failure, the controller has been replaced by a new system with microprocessor control.

2. Design inputs

In the phase of designing of ellipsometer operation hardware controller it has been agreed that the mechanical and electrical solution features of EL-11D ellipsometer designed by Warsaw University of Technology will be maintained. Additionally, the following target features of intended controller have been assumed:

- MANUAL – the direct control mode enabling the setting of polarizer and analyser elements in any position – to be achieved by means of the keys incorporated in the front panel of the controller,
- MANUAL – the indirect control mode enabling any setting of optical elements of the ellipsometer by means of IBM PC keypad or mouse,
- measurement execution in AUTOMATIC mode – the measurement will be controlled by means of IBM personal computer – with the ellipsometer operation controlled by means of automatic measurement program in accordance with the scheme to be selected by the user,
- the system will incorporate the features required to control two step motors and to enable easy extension in the form of two next step motors,
- the controller will be designed as a compact unit with small overall dimensions.

From the assumptions presented above, it appears that the completion of microprocessor controller including its software and the elaboration of additional program enabling the controller operation by means of IBM personal computer were necessary for project accomplishment. It has been agreed that a keypad incorporating three keys will be used for manual operation in direct mode i.e. one of the keys will be used for selection of the active motor and remaining two keys will be used to turn the shaft of the active motor. The number of active motor will be visible on LED display.

3. Description of design features of microprocessor controller of the ellipsometer

Refer to photos Nos 1a and 1b for a general view of EL-11D ellipsometer and analyser driving mechanism. The photos of the ellipsometer controller being discussed in the present study have been illustrated in photo No 2.

The electronic section of the controller has been designed as typical microprocessor solution in order to ensure data exchange with an external computer via RS232 interface. Refer to Figure 1a for the Block Diagram of ellipsometer controller. The micro-controller and I/O systems are provided with ports in order to operate the keypad and LED indicators as well as the photodetector system and step motors control circuits. The controller has been constructed on the basis of micro-controller AT89C52 [2] and customized elements of I/O ports: 81C55 [3], MAX232 [4], PCF8591 [5].

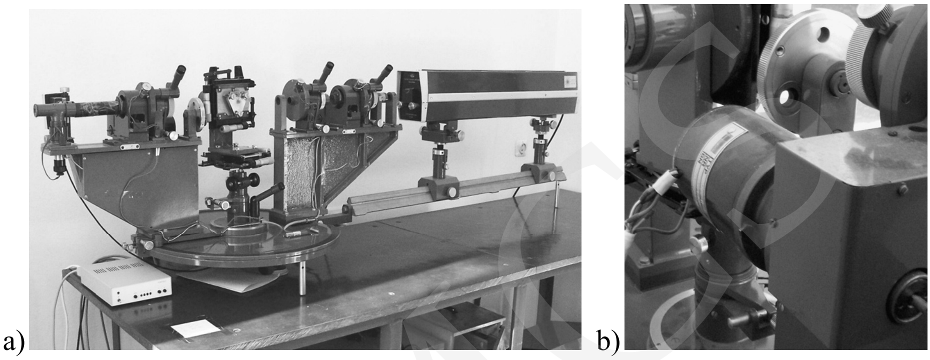

Photo 1. Ellipsometer EL11D: general view (a) and step motor with gearbox (b)

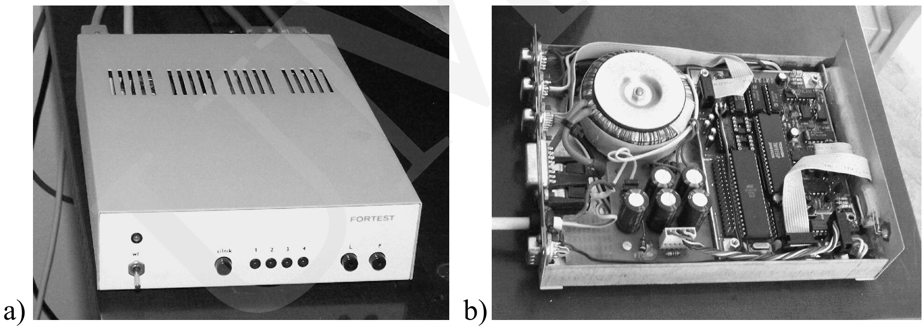

Photo 2. Controller of ellipsometer EL11D: general view (a) and interior (b)

Refer to Figure 1b for the Block Diagram illustrating one of the controller modules which is associated with direct operation of step motor. That module had to be built of discrete elements, because any integrated circuit enabling four – phase step motor of ellipsometer (type EDS-10) was unavailable in the market. The configuration of the module is similar to typical architecture of integrated systems designed for step motor operation control [6,7].

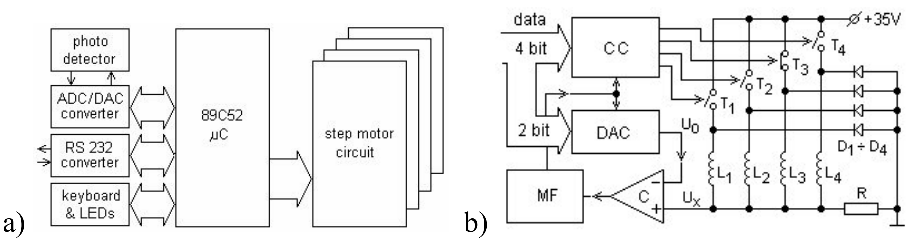

Fig. 1. Block Diagram for ellipsometer controller (a) and motors control system (b)

The purpose of step motors control module is to ensure the passage of current on one of the motor windings and self-adjustment of the maximum value of that current. Therefore any stabilized supply voltages sources are not necessary for the motor. The method of self-adjustment of the maximum current value has been illustrated in simplified manner in the Figure 2.

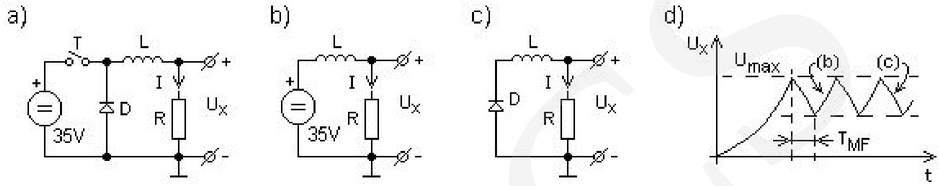

Fig. 2. Power supply for step motor and the use of self-induction phenomenon

Refer to Figure 2a for the diagram of electric circuit operated by means of the transistor switch T and to the Figures 2b and 2c for the equivalent circuit diagrams illustrating two cases i.e. with current passing through T transistor (2b) and without current passing through T transistor (2c). In the case illustrated in Figure 2b, the energy from supply source is transferred to the magnetic field of the coil and partially dissipated on the resistance R. In the case illustrated in Figure 2c, the energy accumulated in the magnetic field of the winding is dissipated on the resistance R. The passage of current is possible in that case owing to the presence of D diode. The transistor shall be controlled in manner causing the generation of voltage drop U_x along the resistance R in result of current variations in the circuit as shown in the Figure 2d. Therefore the oscillating magnetic flux with non-zero average value being generated by the motor winding will be sufficient to maintain the motor shaft in determined position.

The step motor control module illustrated in Figure 1b, consists of transistor keys set T1 – T4, CC transistors control system, C winding current detector system, DAC voltage source and MF monostable flip – flop system. The motor shaft local position is determined by means of microprocessor system in form of indication of the keying transistor. After activation of the transistor, the current value in selected winding of the motor increases and voltage drop U_x along the resistance R also increases. When the voltage threshold of the voltage drop U_x determined by DAC is exceeded, the MF monostable flip – flop system is released by the comparator. The enabling of MF flip – flop system will result in interlocking of T transistor for the period T_{MF} (refer to Figure 2d). During the period T_{MF} the energy accumulated in the magnetic field of the winding is transmitted to the resistor R (Figure 2c) and the voltage drop U_x along the resistor R decreases. After elapsing of period T_{MF} the current passage through the transistor T is restored and the sequence described above is repeated.

4. Light beam detector system

The light beam detector system has been designed as an external element incorporating the photo-electric sensor situated directly at the optical axis of the ellipsometer. Owing to the fact that the zero intensity of the light beam is the criterion to be achieved, “detuning” of optical system results in very intensive change of photodetector illumination intensity. The change of sensor current even by several magnitude orders is possible. The current output from the photodetector will be transformed in the ADC converter system in order to obtain its digital form. The application of at least 16-bit ADC converter (with 4 or 5 processing decades) seems to be an obvious solution in that case. However any extremely high precision of ADC processing is not required in order to determine the correct position of the analyser or polarizer owing to a/m significant change of photodetector current resulting from “detuning” of the optical system. In that case, 7 or 8-bit ADC processing range is sufficient to determine the settings for step motor in a correct manner. The problem consisting in seemingly conflicting requirements referring to the selection of ADC converter has been resolved in the present study in the form of common application of 8-bit ADC and DAC converters (integrated system PCF8591). DAC converter has been used to compensate the static component of the photodetector output.

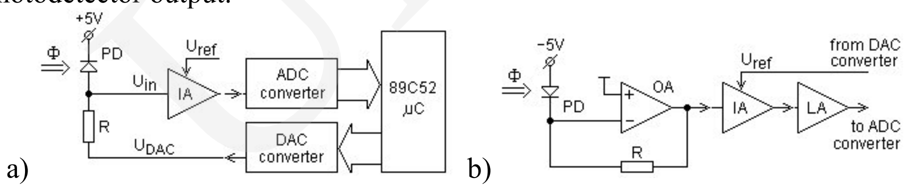

Fig. 3. Schematic diagram for light beam detector: a) – version 1, b) – version 2

Two light beam detector systems have been built in the framework of the project. Version No 1 of that system is illustrated in Figure 3a. Under the influence of illumination, the diode PD generates the current passing through the resistor R and causing corresponding voltage drop $I*R$. The latter is added to the voltage U_{DAC} originating from DAC converter. The voltage $U_{in} = I*R - U_{DAC}$ is transmitted to the instrument amplifier system IA and, after the amplification, to ADC converter. The formal 16-bit resolution of that system is reduced owing to non-linear variability of the signal U_{in} for various values of flux intensity of light beam (R_{PD} R for high value of luminous flux Φ and $R_{PD} >> R$ for low value of luminous flux Φ; where R_{PD} – the equivalent resistance of photo-element).

Another light beam detector system is illustrated in Figure 3b. The photodiode PD generates the current passing through the resistor R. The voltage U_{in}, proportional to the intensity of passing current is generated on the output of operational OA amplifier. The voltage U_{in}, is transmitted via instrumental amplifier to the logarithm system incorporating temperature compensation. After the logarithm finding operation U_{in} voltage is transmitted to ADC converter. The voltage U_{ref} obtained from DAC converter is used to shift the level of U_{in} voltage being subject to the logarithm finding operation. Therefore the effective ADC processing is possible for the component of U_{in} pulse which is included in the vicinity of its minimum.

The light beam detector systems are characterized by some advantages and disadvantages. The simplicity of the solution illustrated in Figure 3a will be emphasized. However, its disadvantage consists in significant engagement of the microcontroller program required to achieve correct intensity of light beam. The advantage of the solution illustrated in Figure 2b is associated with the simple programming code of the microcontroller and its disadvantage consists in complex architecture (logarithm system incorporating temperature compensation). The additional advantage of a/m solution is associated with the emphasized range of low voltages U_{in}, which is most useful for determination of active motor shaft position. Finally, the version illustrated in Figure 3b has been found better.

5. Controller operation supervising programs

As mentioned above, the controller described in the present study has been built as a processor – based device. Two software sets have been created in order to enable the correct operation of the controller in an independent (autonomous) mode or in a controlled mode.

The first software package is used as the operation program for the micro – controller in order to enable the basic testing and controlling functions in the controller system and to ensure data exchange between the controller and IBM PC.

In the course of operation in the independent (autonomous) mode, the controller keypad is directly operated by the program in a manner enabling the selection of active motor and rotation of its shaft. Every pressing of directional key results in change of position of the shaft of selected motor by one step. Maintaining of directional key in the depressed position will result in adding of next steps with gradually increasing frequency. The measurement of light beam intensity is continued by the program simultaneously with the motors operation process.

In the course of operation in the controlled mode, the controller keypad is interlocked by the micro – controller program in order to prevent any accidental disturbance of the settings of ellipsometer optical elements. The controller operation supervising is handed over to another software package to be installed in an external computer (for instance IBM PC). The data exchange between the controller and IBM PC is carried out by means of serial transmission interface, RS232. The motors operation consists in corresponding command (to be sent to the controller) including the information on motor number, direction of rotation and number of steps to be performed. In the course of operation in the controlled mode, the information on current value of light beam intensity is continuously transmitted to the supervising program.

The graphical interface for the controller operation supervising program has been presented in Figure 4. The program is designed for operation in WIN 95/98/XP environment. The operation of ellipsometer controller is possible in so called "MANUAL" and AUTOMATIC modes. The settings of ellipsometer motors can be controlled in "MANUAL" control mode by means of several screen pushbuttons and options. Such a method is equivalent to the direct controller operation mode being possible by means of the keys incorporated on the front panel of the controller. The photodetector output vertical indicator, type 'ProgressBar' has been incorporated in the program dialog box in order to enable continuous monitoring of light beam intensity and to determine the position of the motors associated with the light beam extinction. The determination of the parameters associated with the method of automatic measurement execution, ellipsometer calibration data and the entry of experiment describing text are also possible by means of the program. After starting of automatic operation process, the step motors operation will be controlled in accordance with the settings performed previously. After measurement completion, the measurement data can be recorded in the results file. The data file format is identified by typical spreadsheets.

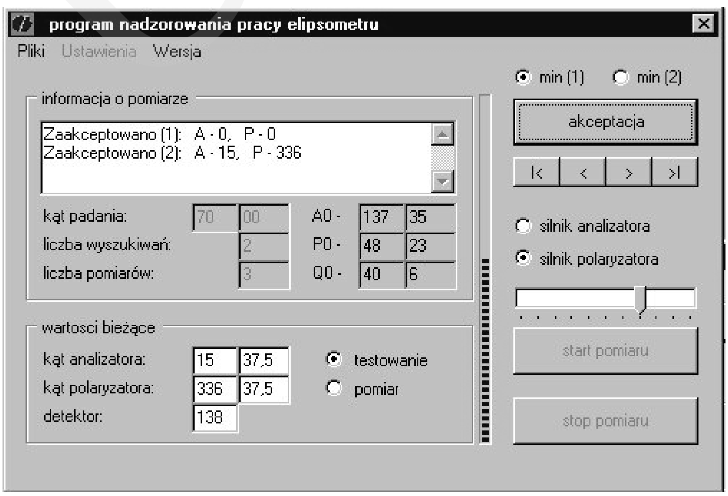

Fig. 4. Ellipsometer operation management program – graphical interface

The determination of step motor shaft position associated with the minimum value of light beam intensity is the most important task to be performed in the course of automatic measurement control. The shape of the curve illustrating the light beam intensity in its vicinity is similar to parabola. Therefore it is possible to calculate the position of the shaft using the parameters of the parabola inscribed into the points obtained from experiments. However the efficiency of that method was insufficient in the case of absolute extinction of light beam. It was associated with the noise in the signal from photodetector prevailing in that case. Therefore the method illustrated in Figure 5 was used for determination of the motor position. Insignificant "detuning" of ellipsometer optical system results in quick increase of light beam intensity and significant suppression of noise component of the signal. After measurements of light beam intensity which have been performed in the vicinity of minimum, the correct position X_0 for minimum has been determined as the arithmetic average of the positions X_1 and X_2. Similar operation was carried out for several other levels of signal from the photodetector. Finally, the minimum position X_0, has been determined as the arithmetic average from all previous calculations. The results of practical application of that method were excellent.

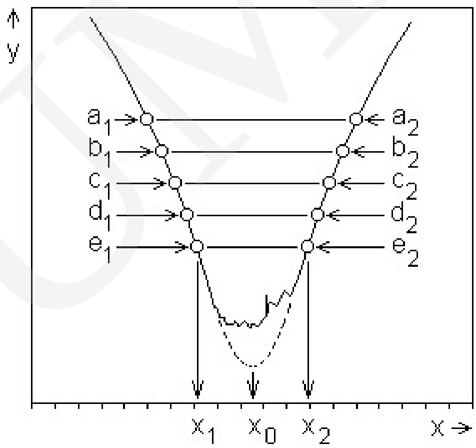

Fig. 5. Method of function minimum determination

The errors contributed by mechanical clearances in the mechanical transmission systems incorporated between the motor shaft and polarizer and analyser have been considered for step motors control. In order to eliminate the errors, each change of motor shaft position has been executed as the movement in one direction only. The movement in opposite direction was carried out in the form of 20 steps more than required and correction of the shaft position by 20 steps in the proper direction thereafter.

6. Summary

The correct and failure free operation of EL-11D ellipsometer controller system has been carried on since 2000. The electronic components of the system described in the present study have been designed to control for EDS-10 step motors. The controller system enables the connection of 2 additional motors provided that corresponding power supply systems will be installed (Fig.2b).

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