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AN INSTRUMENT FOR MEASURING THE ELECTRICAL RESISTIVITY OF SINGLE-CRYSTAL SILICON BY A FOUR-PROBE METHOD

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A new instrument which enables the resistivity distribution over the surface of a wafer of single-crystal silicon with a diameter of up to 200 mm to be measured is described. The measurement is based on the four-probe method.

***Key words:** resistivity, single-crystal silicon, four-probe method.*

Resistivity is one of the main parameters, monitored in single-crystal silicon. The four-probe method is recognized by the Semiconductor Equipment and Materials International (SEMI) organization for this purpose and is recommended by the Russian Standard [1].

When analyzing the quality of single-crystal silicon, it is often necessary to measure the resistivity not only at the center and at the edges of the manufactured wafers, but also to obtain information on its distribution over the whole surface. Foreign instruments are available which enable such measurements to be made automatically (see, for example, [2, 3]).

Below we describe a new instrument for automatically measuring the distribution of the resistivity over the surface of wafers of single-crystal silicon using the four-probe method, in which the requirements of the SEMI standards [4–6] are taken into account, and which is on a par with the technical characteristics of foreign instruments.

In Fig. 1, we show a block diagram of the Rometr instrument. The instrument contains a four-probe head with a linear arrangement of the probes made by Jandel Engineering Ltd. with an interprobe spacing of 1.59 mm. It ensures that a specified direct current is applied to the wafer being measured via the external probes and it also measures the potential differences on the internal probes, to which the measuring amplifier is connected. The analog signal from the amplifier output is connected to an MAX132 18-digit analog-to-digital converter. The digital code is then applied to an ATMEGA8 microcontroller, which controls the operation of the measuring system, and then to a personal computer.

In order to reduce the effect of interference on the measuring amplifier, two power supplies were used in the Rometr instrument: one for the circuit controlling the step motors, and the other for the measuring amplifier and the stabilized current source. The latter provides the following discrete values of the constant current: 0.25, 2.5, 25, and 250 μA and 2.5, 25, and 100 mA with polarity switching. The instability of the current during the time when the instrument is being calibrated and when measuring the resistivity does not exceed ±0.01%. The current strength is established automatically depending on the range of measured values of the resistivity as described in [4]. When measuring the electric current through the external probes the four-probe head is attached to the sample being measured, and during calibration it is attached to similar equiva-

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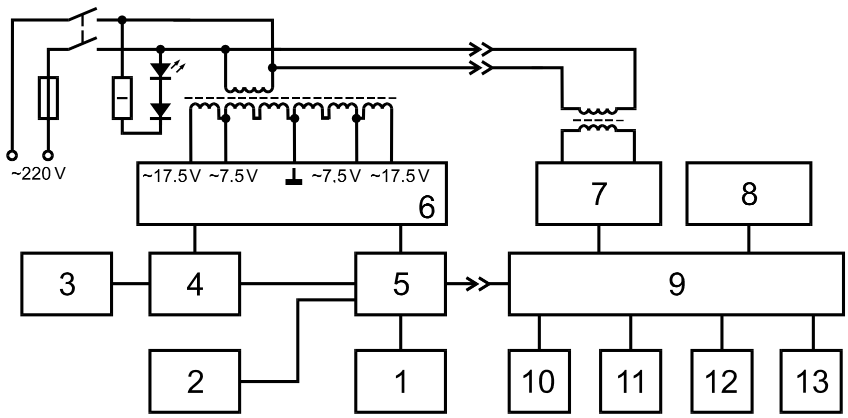

Fig. 1. Block diagram of the Rometr instrument: *1*) personal computer; *2*) temperature sensor; *3*) four-probe head; *4*) module, containing a current source and a measuring amplifier; *5*) control circuit with a microcontroller and an analog-to-digital converter; *6*) power supply for the instrument; *7*) power supply for controlling the step-by-step motors; *8*) sensor of the angular displacement of the measuring table; *9*) control circuit of the step-by-step motors; *10*) optronic sensor of the operating position of the four-probe head; *11*, *12*, *13*) motors for the horizontal displacement of the moving part of the measuring table, the vertical displacement of the four-probe head, and circular rotation of the moving part of the measuring table, respectively.

lents, i.e., to seven precision resistors with resistances of 10000, 1000, 100, 10, 1, 0.1, and 0.01 Ω. Similar equivalents in the calibration mode are connected to the current source through resistors, which simulate the transfer resistance between the tip of each probe and the silicon wafer. The resistance of these resistors is 300 times greater than the resistance of the corresponding analogous equivalents. The temperature of the wafer is monitored using a DS1820 sensor.

Supplied voltage pulses were applied to the windings of the step motors in the required sequence to ensure rotation in a straight line or the reverse direction. DShI-200-1 step motors were used. An LIR458A angular displacement sensor monitors the angle of rotation of the moving part of the table with the silicon wafer with respect to the four-probe head. Control signals are applied from the end switches of the vertical (upper and lower) and horizontal (forward and reverse) displacements at instants when the position of the four-probe head or the measuring table have reached the limiting values. A control signal is supplied from an AOT 147-A optron sensor of the working position of the four-probe head when the pressure of the sensors on the surface of the silicon wafer has reached a specified value [4].

The calibration and measurements made by the instrument are automated using a controlling program in the Borland C++ Builder system. It consists of four subroutines which enable the resistivity to be measured under four operating conditions for different samples of single-crystal silicon: wafers and ingots – at a single point a specified number of times, wafers – at six points as described in [5] (version B), its distribution over the surface of a wafer as in [5, 6], and nonstandard bulk samples.

Using the controlling program, one can calibrate the instrument using similar equivalents, measure the thickness of the silicon wafer, set the necessary current strength on the external sensors of the four-probe head, and measure the potential difference between the inner probes and calculate the resistivity using the method described in [4] taking correction coefficients on the geometry of the sample and its temperature into account. The measurement protocol is displayed in the window of the program, which enables the values of the resistivity to be monitored during measurements. Manual input of the thickness of the wafers being measured and of the current strength applied to the four-probe head is also provided.

The instrument operates as follows. After starting up the controlling program, a signal is applied from the motor control circuit to the vertical, horizontal, and circular displacement motors to set the four-probe head and the moving part of the instrument table in the initial position. The single-crystal silicon wafers to be measured are clamped so that their centers coincide with the center of the four-probe head. Automatic calibration of the instrument is then carried out. To do this,

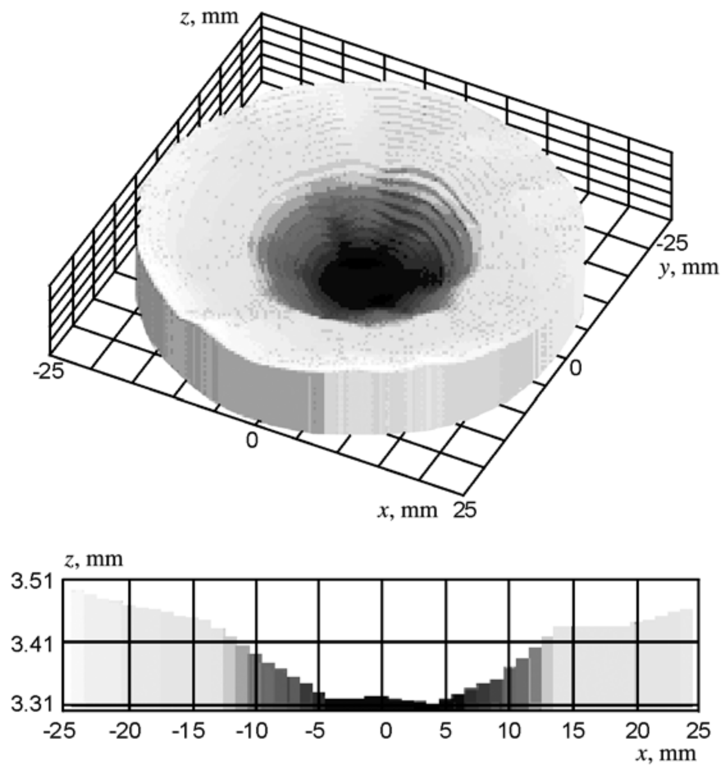

Fig. 2. Results of measurements of the resistance pattern of a wafer of single-crystal silicon.

the four-probe head is disconnected from the current source and the measuring amplifier, on a command from the controlling program, and similar equivalents are connected alternately instead of it. A corresponding current is passed through them and the voltage drop across each equivalent is measured for opposite directions of the current. After calibration, the four-probe head is automatically connected to the output of the current source and the input of the measuring amplifier instead of the similar equivalents. A vertical displacement manipulator smoothly lowers the four-probe head on to the wafer being measured until the probes make contact with its surface. Depending on the chosen mode of operation, one can measure the resistivity and temperature of the sample and take into account the temperature correction coefficient as described in [4].

To increase the accuracy with which the resistivity can be measured, the instrument incorporates a mode of operation in which, at each point where the four-probe head is in contact with the silicon wafer, a controlling program enables one to specify from 10 to 1000 resistivity measurements with alternating current polarity on the outer probes of the head.

In Fig. 2, we show the results of measurements of the resistance pattern of a wafer of single-crystal silicon. The controlling program enables the resistivity to be determined at any point of the three-dimensional image of the wafer surface by directing the cursor to this point, monitoring the data in accordance with the measurement table, and also enables one to analyze the resistivity distribution over a section of the surface (the lower figure), passing through its center.

Technical Characteristics: the range of measurements of the resistivity of wafers of single-crystal silicon is 0.001–10000 Ω·cm, the limits of the permissible fundamental relative error of the arithmetic mean of ten measurements in the 0.001–0.01 Ω·cm range is not greater than ±3%, in the range 0.011–10000 Ω·cm it is not greater than ±2%, and sample diameters of 10–200 mm (this can be increased to 300 mm), and thicknesses of 0.1–30 mm. The overall dimensions of the instrument are 560 × 320 × 410 mm and its weight is not greater than 25 kg.

The instrument is comparable in its technical characteristics with the best foreign instruments. The limits of the permissible fundamental relative measurement error, determined from the results of certification tests, do not exceed the values given in [4–6].

The instrument has been certified and approved and is registered in the State Register of Measuring Instruments (No. 35567-07).

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