Express Measurements of Electrical Properties of Semiconductors in a Pulsed Magnetic Field

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Abstract *The progress of electrical engineering and electronics has demanded the application of new materials in device design. New technological processes allows to obtain thin films, monocrystal and policrystal samples of modern semiconductor materials. Electrical parameters of semiconductors should be tested constantly to provide the high quality of semiconductor devices. In this area express methods for testing electrical properties of semiconductors are successfully used. The main requirement for devices using for express testing is a short time of measurements. Testing large batches of semiconductor samples, the simple operation of the device and the quick replacement of tested samples are very actual. Sometimes the compromise is done to obtain a quick testing of semiconductors instead precise measurements. Relative errors of ± (10 to 20) % are acceptable for express measurements in most cases of non-destructive testing. Often high frequency resonators and microstrip lines are applied for express measurements of electrical properties of semiconductors because of their simple operation. A high frequency field of these devices is interacted with charge carriers of semiconductor sample and contactless measurements of resistivity, concentration, mobility of free charge carriers of semiconductors can be realized.*

1. Introduction

Last time much of the attention has focused on semiconductor and semi-metal thin films. Thin films of Bi and BiSb can be applied as pressure transducers. Electrical properties of BiSb and Bi are strongly depended on alloying technology and concentration of Sb in the alloy. Therefore the testing electrical properties of films is demanded. The application of high frequency resonator for testing electrical properties of thin films with relatively high resistivity is known. Semi-metal thin films were not testable. The improvement of resonator construction allows to use above mentioned device for measurements of electrical properties of semi-metallic thin films of Bi and BiSb [1].

2. Subject and Methods

The block diagram of the resonator equipment for testing resistivity of thin films of Bi is shown in Figure 1.

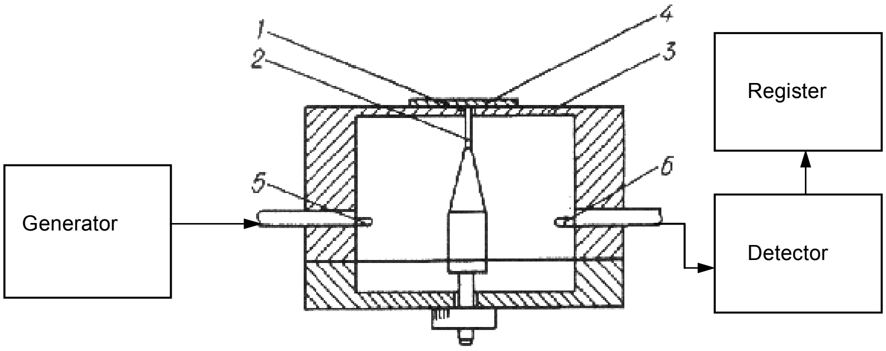

Fig. 1. Block diagram of the equipment for testing resistivity of Bi films.

The quasistatic resonator has a measuring hole 1 in the face. Alignly with the hole a inducting post 2 is placed. A face of the resonator 3 as positioning table for the semiconductor sample 4 is applied. The exciting coil 5 is connected with high frequency generator. An output signal by receiving coil 6 is detected by the detector. A experimental data is registered by the register. An electrical field of the resonator is localized between the induction post and the measuring hole. Electrical field of the resonator interacts with the bulk of semiconductor sample. Losses of the resonator are depended on electrical properties of the tested semiconductor. The resistivity can be determined by measurement the transmission coefficient of the resonator . Thin films of Bi and BiSb are materials with low resistivity and the condition $\omega\varepsilon_p\varepsilon_o\rho$ <<1 is valid. In this equation ω is exciting frequency, ε_p , ε_o is relative dielectric permittivity of semiconductor and vacuum respectively, ρ is resistivity of semiconductor. The value of resistivity can be determined by equation [2]

$$\rho = \left(\frac{2\pi\left(\left(\frac{P_{tr}{}^{0}}{P_{tr}{}^{p}}\right)^{2} - 1\right)}{k_n C_3 Q_{n0} \omega_m \sqrt{\omega_m \mu_o}\, \ln\frac{b}{a}} \right)^{2} . \qquad (1)$$

where $P_{tr}{}^{0}$ is transmitting power of the resonator without semiconductor sample, $P_{tr}{}^{p}$ is transmitting power of resonator with semiconductor sample, C_3 is the capacity of measuring hole, ω_m is resonance frequency of the resonator with semiconductor sample, *b*/*a* is ratio of measuring hole and the post diameter respectively. The quality Q_{n0} can expressed as

$$Q_{n0} = \left(\frac{1}{Q_r} + \frac{1}{Q_1} + \frac{1}{Q_2} \right)^{-1} . \qquad (2)$$

where Q_r is quality of the resonator with semiconductor sample, Q_1, Q_2 are input and output qualities of the resonator. A resonance frequency of the resonator ω_m can be determined experimentally by following equation

$$k_n = 1 - \frac{\omega_m{}^{2}}{\omega_0{}^{2}} . \qquad (3)$$

where ω_0 is resonance frequency of the resonator without semiconductor sample, k_n is connection coefficient of the sample.

3. Results

The equation (1) can be used for drawing of standard curves of resistivity. But the same information can be obtained more easier by measurements of standard samples with known resistivity. Standard curves obtained by measurements of Ge samples are shown in Figure 2.

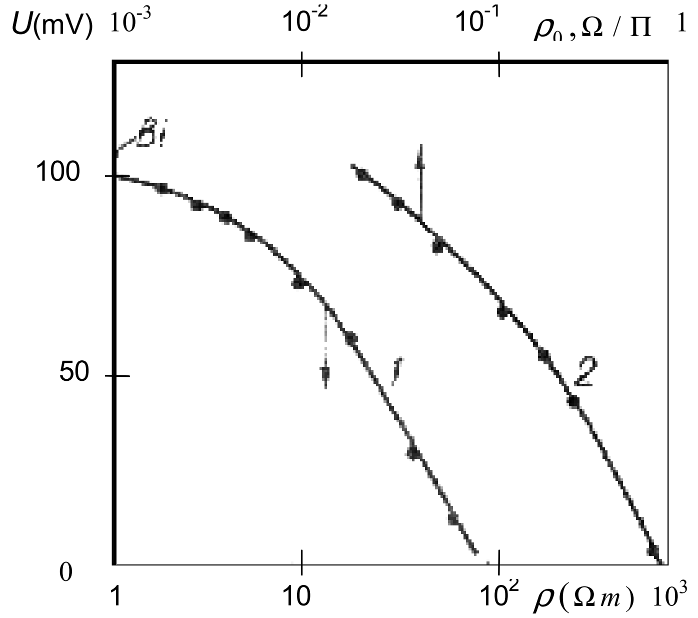

Fig.2. Standard graphs of resistivity measuring by resonator method

Curves 1 and 2 are obtained experimentally measuring samples of Ge, Bi and thin films of Bi respectively by four probe method. A relative error of standard curves is about 5 %. Measuring resistivity of thin films of semiconductors the losses of the resonator are determined by the thickness of the semiconductor film. The value of losses can be expressed as resistance r_n

$$r_n = \frac{\rho}{2\pi d} \ln \frac{b}{a},. \tag{4}$$

where d is thickness of tested film.

Therefore the application of value $\rho_0 = \frac{\rho}{d}$ is more favorable.

The quality of the resonator should be great as much as possible to provide the high sensitivity of the resonator. Therefore inside surfaces and all inside details of the resonator were coated with Au. The thickness of the coating is $3 \cdot 10^{-6}$ m. The inside diameter of the resonator is 60 mm, the highness 24 mm. The diameter of measuring hole is 1,2 mm, diameter of inducting post is 1 mm. The quality of the resonator is exceeded 1500 in resonance frequency of 2,4 GHz.

The locality of measurements of offered resonator is determined by the size of measuring hole at the resonator face [46]. In our case the locality of measurements is 1,2 mm. This means, that the resonator can be applied for investigations of non-homogeneity of electrical properties of semiconductors and semiconductor films.

Experimental results of measurements of resistivity of Bi films are offered in Figure 3.

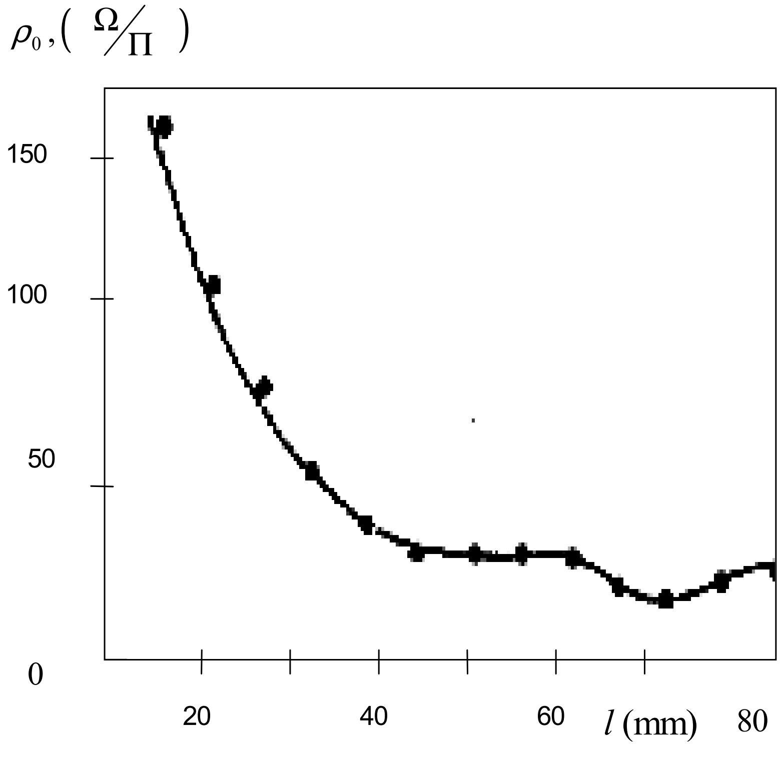

Fig. 3. The resistivity of Bi film.

The non-homogeneity of the investigated sample was formed technologically to test the possibility to control the non-homogeneity of resistivity of thin films by high frequency resonator. Obtained results were compared with measurements of four probe method. Measured resistance by resonator method has a good coincidence with measurements by four probe method. The total relative error of measurements does not exceed ± 10 % using standard apparatus for signal registration as HF detector (relative error ± 3 %), memorized oscilloscope (relative error ± 4 %). The range of measurements is (10^{-2} to 10^{2}) Ω/Π. The design of the resonator allows to replace tested samples very quickly and express measurements of resistivity of semiconductors can be executed. By the application of pulsed magnet in offered resonator the measurements of mobility can be executed in addition.

4. Conclusions

High frequency resonators and microstrip lines can be used in design of devices for express testing electrical properties of semiconductors and semi-metals in pulsed magnetic field. Resonator devices with a pulsed magnetic system provides the testing of semiconductor resistivity and mobility of free charge carriers in wide range of measurements with good accuracy and a convenient replacement of samples. Semiconductor samples and thin films can be tested successfully. The application of pulsed magnet in measurements of mobility of free charge carriers of semiconductor and semi-metal thin films expands the measuring range per an order as minimum and materials as Bi can be tested. Offered microstrip equipment for express testing concentration of free charge carriers of semiconductors in a pulsed magnetic field has the high productivity of measurements by an arrangement of exciting and receiving probes in the one plane with the end face of pulsed solenoid. Moreover a microstrip design of these probes provides a minimum distortion of magnetic field inevitably arising at presence of conducting elements in pulsed magnetic field. The microstrip equipment is applied for the express testing of a concentration of free charge carriers in narrow-gap semiconductors as InSb, CdHgTe, GaAs. Also offered equipment can be used successfully for testing another semiconductors and semimetals due to the universality of the device construction and wide range of measurements.

References

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