Optica Applicata VIII/2, 1978

*Barbara Oleś, Andrzej Kisiel**

Ni-Ge Schottky diodes in application to the electroreflectance measurements**

The Schottky diode technique for obtaining surface barrier electroreflectance spectra has been used successfully on *n*-type Ge. The fabrication process, I–V characteristic of the Ni–Ge Schottky diode and electroreflectance spectra of Ge in 2.1–2.3 eV region using Schottky barrier technique are reported.

The electroreflectance is an efficient method in investigations of not only spectroscopic aspects of crystals but also of other interactions. Since it has been shown [1, 2] that in low-field region the quantitative electroreflectance spectra can be obtained without the modulating from flat-band condition electroreflectance measurements can be performed by using the Schottky barrier technique [3]. Low-field electroreflectance line shapes are scaled quadratically with the applied modulating field, the invariant line shapes being determined entirely by the intrinsic properties of the crystal itself [1]. These line shapes are closely related to the third derivative of the dielectric function [1, 2], consequently they are characterized by the presence of strongly enhanced critical point structures and strongly suppressed background effects. The critical point energies and broadening parameters can be, moreover, obtained directly from experimental data without data reduction by Kramers–Kronig analysis [4]. The metal-semiconductor configuration is ideal for high-resolution spectroscopy of semiconductor materials having distinct advantages with respect to other surface-barrier techniques [3–6]. Schottky diodes can be applied to a wide variety of semiconductor materials, and permit to take the measurements over wide ranges of temperature, surface field and photon energies.

The Ni-*n*-type germanium Schottky barriers have been obtained in our laboratory by the following procedure: Before metal evaporation the reflecting surfaces of the wafers of 1.8 Ω cm and 12 Ω cm *n*-type germanium were mechanically polished and etched in CP4-A and in HF. It has been found [5] that nickel is particulary well suited for electroreflectance applications, because of a relatively uniform transmittivity over a wide spectral region. The barrier-metal evaporations were carried out in a liquid-nitrogen-baffled oil pumped vacuum system. The pressure during evaporation was not higher than 7.5×10^{-6} Torr. The metal thickness was monitored by measuring the resistance between two contacts at the ends of a glass slide adjacent to the sample. The single-pass transmittance of the Ni films prepared in this manner was typically of the order of 65%. Ohmic contacts to the wafers were fabricated by evaporating a layer of Au+1% Sb on an appropriate face of the sample and then by heating the sample under vacuum to a temperature 500°C for 5 min. Electrical connections to the barrier and sample were made via silver paint.

Current-voltages characteristics were plotted, and the extrapolation of the semilogarithmic plots of forward I–V characteristics to zero bias voltage gave values for the saturation current I_s. For a sample of resistivity 1.8 Ω cm a typical I–V characteristic corrected for the series resistance effect [7, 8] is shown in fig. 1. The barrier height Φ_b, estimated from the value of $I_s = 4.4 \times 10^{-4}$ A was equal to 0.51 ±0.02 eV, whereas according to **Thanailakis** and **Northrop** [9] $\Phi_b = 0.44 \pm 0.02$ eV for the resistivity

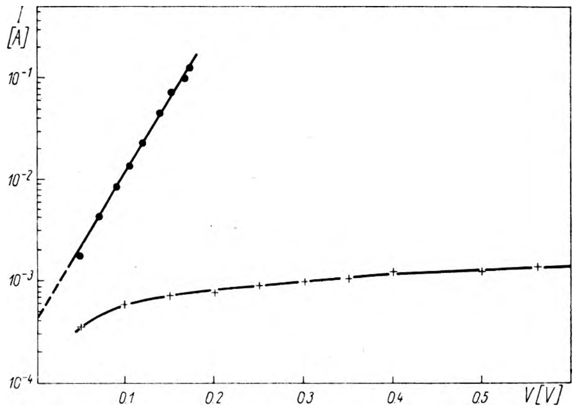

Fig. 1. Characteristic of Ni–Ge (1.8 Ω cm, *n*-type) Schottky diode

—·—·—·— forward bias
—x—x— forward bias

---

*) Institute of Physics, Jagiellonian University, Cracow, Poland.

**) This work was partly supported by the Institute of Physics of the Polish Academy of Science (MRI. 4. II-7).

ranging between 0.1–1.0 Ω cm. The discrepancies in results may be caused by different barrier fabrication processes. THANAILAKIS and NORTHROP [9] obtained their Ni–Ge barrier by electron bombardment. The value of barrier height Φ_b [10, 11] is also slightly increased by the natural-oxide layer present between the semiconductor and metal film, inevitable in the fabrication process used in our experiment. This oxide, however, being sufficiently electrically and optically transparent neither influences the basic metal-semiconductor nature of the junction nor disturbs electroreflectance measurements [5].

We have examined the ageing process of the Ni–Ge contacts and stated that this process is very slow and the contacts are good for electroreflectance purposes even after four weeks. The ageing process could be observed on saturation current values I_s which slightly decreased. The saturation current extrapolated from I–V characteristic (see fig. 1) measured several hours after evaporation process was $I_s = 4.4\times10^{-4}$ A and after two weeks it decreased to the $I_s = 4.0\times10^{-4}$ A, but this change in I_s value did not give a significant increase in barrier height. It is supposed that the effect connected with ageing process of silver paint electrical contact is more significant and limits the period of time in which Schottky barrier diodes are good for electroreflectance measurements.

The block diagram of the measuring system used to measurement of the electroreflectance spectra is shown in fig. 2 and is similar to the systems previously described in [12, 13]. The light source was a 150 W halogen lamp. Monochromatic light was directed to the Ge sample and the reflected beam was focused onto a photomultiplier. The electronic diagram [13] is also shown in fig. 2. To obtain the electroreflectance spectra the specified energy range was divided into the required increments and then the monochromator was adjusted to the appropriate point of the spectrum. The output of the phase-sensitive detector with the constant wavelength was then sampled, perforating the required number of data which were next averaged by computer. Then the averaged ΔR data were divided through the R data which were obtained also by phase-sensitive detection using signal from the chopper as reference signal. The electroreflectance spectrum of germanium obtained in the 2.1–2.3 eV region by using Schottky diode from fig. 1 is shown in fig. 3. During the experiment the value of 120 Hz square-wave modulation voltage was 2.8 V and the value dc bias was 0.2 V.

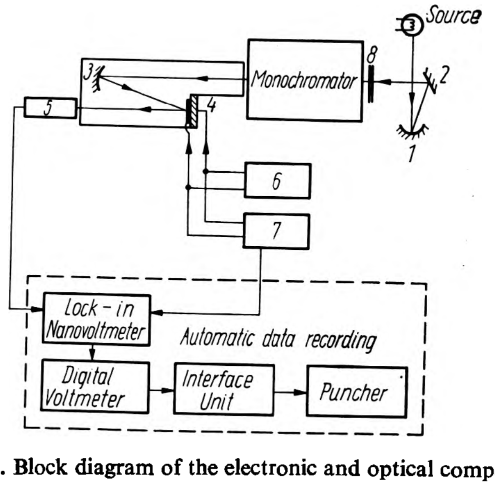

Fig. 2. Block diagram of the electronic and optical components of the measuring system

1, 2, 3 — mirrors, *4* — sample, *5* — photomultiplier, *6* — dc bias, *7* — square wave generator, *8* — chopper

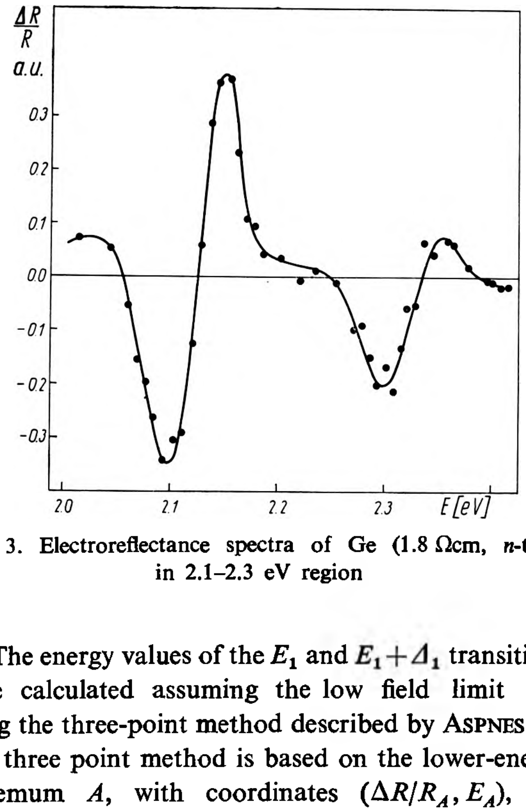

Fig. 3. Electroreflectance spectra of Ge (1.8 Ωcm, *n*-type) in 2.1–2.3 eV region

The energy values of the E_1 and $E_1+\Delta_1$ transitions were calculated assuming the low field limit and using the three-point method described by ASPNES [4]. The three point method is based on the lower-energy extremum A, with coordinates $(\Delta R/R_A, E_A)$, the higher-energy extremum B, with coordinates $(\Delta R/R_B, E_B)$, and the baseline $\Delta R/R = 0$. Let

$$\varrho = -(\Delta R/R_B)/(\Delta R/R_A) > 0$$

be the asymmetry parameter. Then the energy gap E is given by

$$E = E_A + (E_B - E_A) f(\varrho)$$

where $f(\varrho)$ is a function of asymmetry ratio, ϱ, plotted in [4]. The energy values of transitions E_1, $E_1+\Delta_1$ are equal to 2.12±0.02 and 2.31±0.02 eV, respectively. They are in good agreement with these reported by Aspnes [4].

Unfortunatelly a sufficiently high barrier for electroreflectance measurements on 50 Ω cm *p*-type germanium has not been prepared as yet. We had, however, no difficulties in measuring electroreflectance spectra of *p*-type germanium by means of electrolyte technique [14].

Применение диодов Ni–Ge Шоттки для измерения электроотражения

Применена техника диодов Шоттки для получения электроотражения с поверхностным барьером на Ge типа n. Описаны изготовление, характеристика I–V диода Ni–Ge Шоттки и, в качестве примера, спектр электроотражения переходов E_1 и $E_1+\Delta_1$ в области энергии 2.1–2.3 эВ, полученный для диода Шоттки Ni–Ge.

References

[1] Aspnes D. E., Rowe J. E., Phys. Rev. **B5,** 4022 (1972).

[2] Aspnes D. E., Phys. Rev. Letters **28,** 168 (1972).

[3] Aspnes D. E., Phys. Rev. Letters **28,** 913 (1972).

[4] Aspnes D. E., Sur. Sci. **37,** 418 (1973).

[5] Aspnes D. E., Phys. Rev. **B7,** 4605 (1973).

[6] Studna A. A., Rev. Sci. Instrum. **46,** 735 (1975).

[7] Beguwala M., Crowell C. R., J. Appl. Phys. **45,** 2792 (1974).

[8] Manifacier J. C., Fillard J. P., Solid St. Electron. **19,** 287 (1976).

[9] Thanailakis A., Northrop D. C., Solid St. Electron. **16,** 1383 (1973).

[10] Peckerar M., J. Appl. Phys. **45,** 4652 (1974).

[11] Peckerar M., Lin H. C., Kocker R. L., Int. Electron Devices Meeting, Washington 1973.

[12] Cardona M., *Modulacionnaya Spectroskopiya,* Izd. Mir, Moskva 1972.

[13] Kisiel A., Pukowska B., Acta Phys. Polonica **A45,** 923 (1974).

[14] Kisiel A., Oleś B., phys. stat. sol. (b) **83,** K35 (1977).

Received, September 28, 1977