Observation of Semiconductor Elements Using Scanning Electron Microscope

Hirokazu Kimura, Hisayuki Higuchi, Michiyoshi Maki
and Hifumi Tamura

Central Research Laboratory, HITACHI Ltd. Kokubunji, Tokyo, Japan

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The physical topography of semiconductor elements has been observed by using of the scanning electron microscope newly developed in Hitachi Central Research Laboratory.

The voltage topography shows the location of PN junction, the base width of planer type transistor and the voltage drop in integrated circuits. Furthermore, diffusion depth of PN junction becomes visible by the electron voltaic effects.

§ 1. Introduction

Many papers have been already reported on the resolving power and the image contrast of the scanning electron microscope, and the semiconductor elements were hitherto observed by many researchers using scanning microscope.

With the scanning electron microscope, it is possible to observe the surface topography as well as material topography utilizing the difference of the secondary electron coefficient. It is also possible to get "voltage contrast" which shows the location of PN junction in a semiconductor and voltage drop in a resistor. The primary electrons generate hole-electron pairs in the semiconductor and this enables to obtain specimen images on account of electron voltaic effects.

§ 2. New Scanning Electron Microscope

Fig. 1 shows the newly designed scanning electron microscope. The diameter of its electron beam spot is about 0.1μ which is focused sharply by the two-stage demagnification electron lens system. The scanning speed of one frame can be changed four step wise from 1 sec. to 50 sec. and the scanning lines from 200 to 2,500. At the normal operating conditions, 20 KV accelerating voltage, 10 sec. scanning speed and 1,000 lines are adopted.

The secondary electrons emitted from the specimen by the impinging primary electrons are collected by the scintillator whose light output is detected by a photomultiplier and led to an amplifier. The secondary electron beam of 10⁻¹¹ Amp. is detectable with SN ratio as large as 10 and the frequency bandwidth of the amplifier is about 30 kC. The
energy of secondary electron is analysed by a simple static electron lens and potential difference as small as 0.5 eV can be detected.

§ 3. Observation of PN Junction by Absorbed Current

Fig. 2 shows the absorbed current image of a silicon diode of the grown junction type, in which both terminals are short-circuited. The size of the crystal is about 0.3 mm × 0.5 mm × 5 mm. The central darkline shows a PN junction, the upper part is N type silicon with donor density of \(2 \times 10^{17} \text{ cm}^{-3}\) and lower part P type silicon with \(10^{20} \text{ cm}^{-3}\) accepter density. The stair at PN junction caused by the difference of etching speed is clearly recognized, because the incident angle of the primary electron beam is larger at this stair resulting the scanning image to be darker.

Fig. 3 shows the absorbed current image of the same diode, in which the terminal of N type is opened and the signal from the terminal of P type is detected. A new contrast which is caused by electron voltaic effect has appeared at the PN junction.

§ 4. Observation of Electron Voltaic Effect in PN Junction

The image of the same area as in Fig. 3 is shown in Fig. 4, in which the circuit for measuring diode current as shown in Fig. 5 is used. In Fig. 4 the dark part of the image
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Fig. 5. Measuring circuit of PN junction by electron Voltaic effect.

Fig. 6. Line analysis across PN junction.

intensity is proportional to the change of the diode current.
Accordingly, the local diffusion length of the minority carriers can be obtained by measuring the diode current. The variation of the dark band width in Fig. 4 may be caused by crystal defects. An example of the diode current value along a line across the junction is shown in Fig. 6. The mean life time $T_p$ can be calculated from the following equation in the same way as in the measurement by photocurrent.

$$L_p = \sqrt{D_p \cdot T_p}$$

where $L_p$ is the diffusion length and $D_p$ the diffusion constant of the minority carrier.

In this experiment, the value of $T_p$ is 0.45 $\mu$ Sec., since $L_p$ and $D_p$ are 15 $\mu$ and 5 $cm^2$/Sec. respectively for $2 \times 10^{17}$ $cm^{-3}$ donor density.

By means of this method it is possible to measure very short diffusion length easily and the local variation in the large area of the specimen can be observed.

§ 5. Observation of Planer Type Transistor by Secondary Electrons

Fig. 7 shows a secondary electron image of a planar type transistor. The central bright part is the emitter, the center line the lead wire, the outside dark part the collector and the bright area between both parts the base respectively. Owing to the contact potential, Fig. 7 shows high contrast notwithstanding the both connections between collector-base and emitter-base.

Fig. 8 is the photograph of the other planer type transistor etched at the angle of 5 degrees. The bright spheres and large line are the lead wires of the emitter and base respectively, and the dark area under the base lead represents the base. The lower part, the contrast of which is slightly changed is the etched area of the pellet. From the measurement of this photograph, the base width of about 1.9 $\mu$ was obtained.
§ 6. Observation of Integrated Circuits

Fig. 9 is a photograph of the integrated circuit and Fig. 10 is its connection diagram. The bright part is P type and the dark part N type silicon. The aluminum connection wires by evaporation are visible darker than N type silicon. The specimen consisting of 8 transistors and 6 resistors has been investigated. The magnified image of a resistor is shown in Fig. 11, in which the bias voltage is applied to both terminals resulting the contrast variation from bright to dark.

In this way it is possible to inspect the damages and irregularities in the integrated circuit under the operating conditions.

§ 7. Conclusions and Acknowledgement

The characteristics of the semiconductor elements using the new scanning microscope have been described.
The physical characteristics of surfaces have been imaged with high resolution and over great field depth, and the relative potentials between different areas on the surfaces have been determined.

This technique is very useful in the study and inspection of the semiconductor elements.

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References
