The measurement of p-n junction depth by SEM

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Abstract—In this paper, the p-n junction depth with nondestructive method by using scanning electron microscopy (SEM) is determined and conformed. By measuring the critical short circuit current on the p-n junction which induced by electron beam and calculating generation range, the diffusion depth can be obtained. It can be seen that values destructively measured by constant angle lapping and nondestructively by this study almost concur. As this result, it is purposed that diffusion depth of p-n junction can be easily measured by non-destruction. This nondestructive method can be recommended highly to the industrial analysis.

I. INTRODUCTION

At the present time, lots of industrial fields have concerns on nondestructive measurement. If we can find earlier information on device's defects and properties, we can easily solve difficult problems on subsequent events in system. The nondestructive measurement methods on defects occurring at inner part of integrated circuit are radioactivity penetration inspection, ultrasonic investigation inspection, LASER nondestructive measurement, liquid penetration inspection, and so forth. At among them all, the most widely used measurement method is to check material's defect, size and distribution by penetration of radioactive rays. At the semiconductor industry, the nondestructive measurement inspects performance by penetration of radioactive rays for verifycation of actual function. In 1970, K Kanaya and Okagama presented electron penetration and energy law in solid material. In 1972, B.F.Bress published current theory on electron beam in inside of silicon planar p-n junction and it's application was published by Harry C Gatos. At recently, lots of papers was published including a paper of Tsuyoshi. Electron Beam-Induced Current (EBIC) Analysis, as its name implies, is a semiconductor analysis technique that employs an electron beam to induce a current within a sample which may be used as a signal for generating images that depict characteristics of the sample, e.g., the locations of p-n junctions in the sample, the presence of local defects, and doping non-homogeneities. Since a scanning electron microscope (SEM) is a convenient source of electron beam for this purpose, most EBIC techniques are performed using a SEM. In this paper, on the basis of this theory, the emitter and base diffusion depth of n-p-n transistor is measured by scanning electron microscopy (SEM). We conform that by destructive method and verify this theory.

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II. THEORY AND MEASURING METHOD

If we adjust the focus and flash electron beam at a semiconductor, at inside of semiconductor the beam energy is converted to radiation signals of various kinds, that is, backed scattered electrons, auger electrons, X-ray and cathode-luminescence are occurred. The SEM we used in this paper can increase energy of beam. When the primary electron beam of the SEM penetrates the semiconductor itself, holes and electrons that are free to move around are created by the impact. In a material that's free of any electric fields, these holes and electrons will be in random motion that allows them to find each other and recombine. If electric fields within the semiconductor device do exist, however, these fields can influence the holes and electrons to move in a non-random manner, i.e., the holes and electrons will be separated and swept off to differently-charged areas. These electric fields may either come from external sources, or local to the sample such as those exhibited by p-n junctions. With proper electrical contact with the sample, the movement of the holes and electrons generated by the SEM's electron beam can be collected, amplified, and analyzed, such that variations in the generation, drift, or recombination of these carriers can be displayed as variations of contrast in an EBIC image. EBIC imaging is very sensitive to electron-hole recombination, which is why EBIC analysis is very useful for finding defects that act as recombination centers in semiconductor materials. A typical EBIC system consists of the following: 1) a scanning electron microscope (SEM); 2) an external (i.e., located outside the SEM's high-vacuum chamber) low-noise current amplifier; 3) high-vacuum electrical feed-throughs that electrically connect the external current amplifier to the sample inside the SEM chamber; and 4) a sample holder with the required electrical contact points to facilitate the electrical connection of the sample to the feedthroughs.

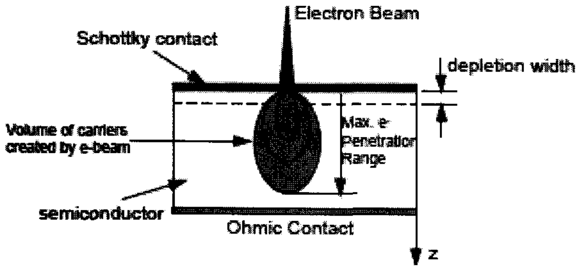

Fig. 1 The creation of Carriers by e-beam

Fig.1 shows the creation of Carriers by e-beam.

When the device gets the beam, electrons and holes are generated to globular shape in the inner of device. They induce current and we can find the diffusion depth by measurement of the electric current. When electron beam penetrates inside of semiconductor, electrons and holes are generated to globular shape in the inner of the semiconductor. At that time, the dimension of electric current generated in p-type, n-type neutral semiconductor region without p-n junction is different from the dimension of electric current generated in depletion region of p-n junction. If we can find the gap of two electric current, we can know the diffusion depth of p-n junction. When electron beam of SEM shines surface of semiconductor device, electrons and holes are generated to globular shape with R radius in the inner of device.(Fig.2) If the electron beam is moved to interface of p-n junction, it infiltrates to depletion region and gives its own energy to peripheral atoms and electrons and holes are generated.(Fig.4) If we compare p-type, n-type neutral region and depletion region, electrons and holes are generated over twice in depletion region and give rise to lots of current. If the power of electron beam is continuously increased, R radius increases in size and depletion region possesses lots of region inside R radius. Therefore, outside current increases.(Fig.5) If the power of electron beam is increased and reached into a critical point, the depletion region crossed by R radius at interface of p-n junction (x=0) and R radius are equal in length (r1=r2=R). (Fig.5, 6) Maximum R radius of electron beam is as follow.

$$R \cong \frac{1}{\rho X 2.76 X 10^{-11} X A Z^{-\frac{8}{9}} X E_o^{\frac{5}{3}}} \qquad (1)$$

where,

ρ : density, A: atomic mass, Z: atomic number, Eo :energy

Also, the centre diffusion depth is concerned with generation range.

$$\frac{Z_d}{R} = \frac{1}{(1+\gamma)} \qquad (2)$$

$$\gamma = 0.187 Z^{\frac{3}{2}} \qquad (3)$$

Where,

Silicon density (ρ)=2.33 g/cm^3

Atomic mass(A)=28

Atomic number(Z)=14

Therefore, Z_d=0.48 (4)

So, the centre diffusion depth is 0.48 time of maximum exciting range.

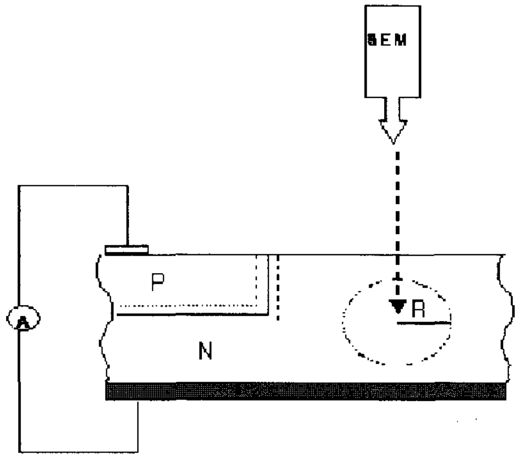

Fig. 2 Diagram of SEM scanning

III. EXPERIMENT AND RESULTS

At the front section, we referred that electrons and holes are generated and give rise to lots of current in interface region of p-n junction by radiation energy. This measuring current is called to EBIC(Electron Beam Induced Current). This current is changed by electron beam energy. If the electron beam scans from n-type to p-type like figure 1, EBIC changes from nearby p-n junction and is described to function of distance. The figure 3 is scanning electron microscopy (SEM) using in this paper.

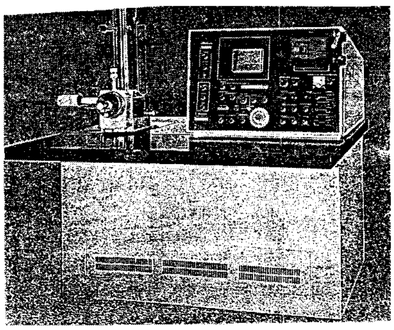

Fig. 3 SEM (SUPER III A-ISI)

First, we install the sample for measurement inside of SEM and adjust the sample to zero position. At this time, as a matter of convenience we selected Tr. (2N2222) for commercial small signal. This device used planar diffusion layer.

We connect separately lead line of emitter, base, collector terminal for measuring of EBIC and fix the sample over holder of SEM and evacuate SEM and adjust the focus of electron beam and put mode over spot. At next, we move x-position knob from left to right while scanning and read chart record, c-current meter.

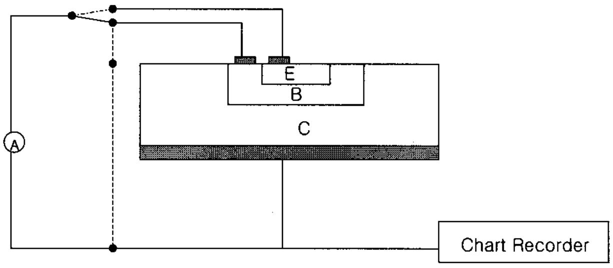

Fig. 4 Diagram for EBIC measuring

The curve line showed in this chart record is EBIC curve. If we read an energy value corresponding to critical value, we can calculate diffusion depth by equation (1). Also, we will conform by destructive method (sectioning, bevel lapping, polishing, chemical treatment) of sample for verification of this result. As a result of measuring, EBIC shows a peak value in interface region of p-n junction by electron beam scanning of low power P1 like figure 5.

As power intensity of electron beam increases, magnitude of peak value decreases. If a peak value of EBIC disappears by increasing power of electron beam, the depletion region crossed by R radius at interface of p-n junction (x=0) and R radius are equal in length (r1=r2=R). As a result of substitution the equation by this measuring, we can obtain a result of table 1.

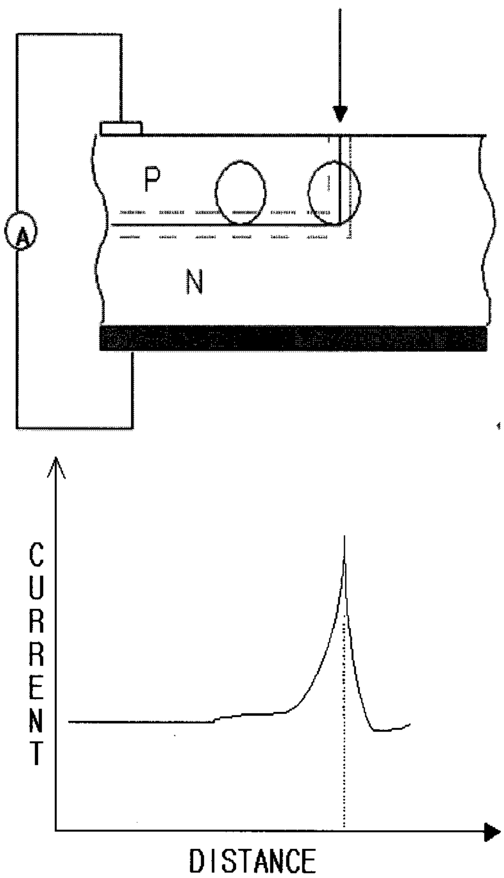

Fig. 5 (P1) EBIC of low SEM energy

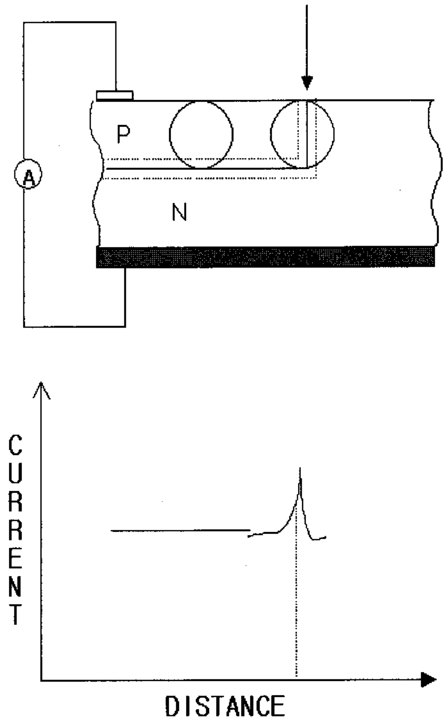

Fig. 6 (P2) EBIC of medium SEM energy

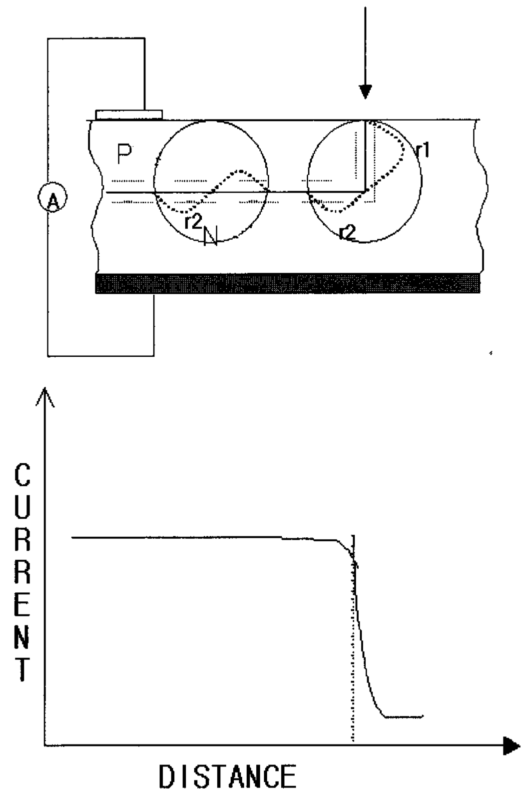

Fig. 7 (P3) EBIC of high SEM energy(P1<P2<P3)

Table 1 The results of measuring on Tr. (2N2222)

Junction	Critical energy(KeV)	Maximum exciting range(μm)	Depth(μm)
Base/Collector	30	9.27	4.45
Emitter/Base	26	7.25	3.46

IV. CONCLUSIONS

In this paper, the p-n junction depth with nondestructive method by using scanning electron microscopy (SEM) is determinated and conformed. As a matter of convenience we selected Tr(2N2222) for commercial small signal. This device used planar diffusion layer. We measured EBIC value correspond-ding to a critical value and calculated diffusion depth by a penetration range of electron beam. As a result measuring change of EBIC value on electron scanning beam energy of SEM, generation rate in interface region of p-n junction increases a lot of more. Considering these results, we can conform this idea that diffusion depth of p-n junction can be easily measured by non-destruction. So we can recommend highly this nondestructive method to the semiconductor industry.

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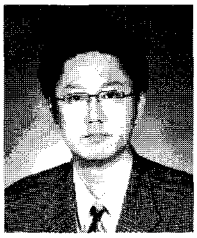

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