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Nondestructive Internal Observation with High Resolution Using Metal-Oxide-Semiconductor LSI Chip as a Specimen

Mutsuo KOBAYASHI*, Hiroshi TAKENOSHITA** and Masahiro OKUDA***

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A metal-oxide-semiconductor (MOS) LSI as a specimen was observed by electron-acoustic microscopy (EAM) with high resolution. EAM is a method of nondestructive internal observation. Our EAM system was operated with electron beam chopping frequency (f) of 1 MHz, duty ratio of 50% (which were fixed) and acceleration voltage (HV) was variable.

In the previous study, an electron acoustic image (EAI) obtained with oblique lines which were caused by noises of the power source. In this study, we succeeded in excluding noises of our EAM system. For this reason, we achieved to obtain EAIs clearly with high resolution. The resolution (r) of EAM was estimated to be r≦0.8μm at HV of 19 kv. The observable depth well matched with the our previous reports.

1. Introduction

Electron-acoustic microscopy (EAM) has been studied for nondestructive observation of internal phenomena using chopped electron beam since 1980[1-2]. The EAM system was constructed of an ordinary scanning electron microscope (SEM) attached to an electron beam chopping unit, a piezoelectric transducer attached to the back of the specimen and a lock-in amplifier (LIA) synchronized to the chopping frequency of an electron beam.

On the EAM system, a specimen is repeatedly heated or cooled by irradiation or nonirradiation of a chopped electron beam. Within the specimen, repetition of elastic expansion and contraction generates a thermal wave[2-4]. During propagation of the specimen, the thermal wave is converted to an acoustic signal which is called an electron acoustic (EA) signal. The EA signal reached the reverse side of the specimen is detected by a piezo-electric detector (PZT transducer) attached to the back of the specimen. The signal amplified by a LIA is displayed as a video signal on CRT in synchronization with the scanning of an electron beam, namely, an electron acoustic image (EAI) is obtained.

The observation area is selected from SEM-mode images and then,the mode is switched to the EAM-mode, EAIs can be obtained nondestructively at the fixed area selected from SEM-mode images.

Using various bipolar transistor chips, EAM studies have been made. In the papers, the following have been reported. (1) EAI is related to the the electron beam induced current (EBIC) image, but not the same[5-7]. (2) The contrast of EAI increases under reverse bias voltage and decreases under forward. (3) The observable depth (tx) corresponds to approximately 60% of the electron range (Re) as a function of an acceleration voltage (HV)[8]. (4) Dislocation lines in the base layer are observable by EAM[9-12].

We have attempted to observe metal-oxide-semiconductor (MOS) LSIs by EAM. On the previous studies, the following have been found. (a) The adjustment of the irradiation power of the electron beam should make it possible to achieve nondestructive internal observation of MOS-LSI specimens. (b) When HV=15, 17 and 19 kv, tx were estimated as about 0.8, 1.1 and 1.5μm[15], respectively. (c) tx corresponded to approximately 40% of Re as a function of HV[15], whereas the ratio of previous report was about 60% of Re[8]. (d) The resolution (r) of our EAM has been improved to be r≦0.8μm[16].

We have achieved improvement of r to be r≦0.8μm, but not sufficient for MOS-LSI specimens. We attempted to obtain nondestructive internal observation of MOS-LSI specimens by EAM, more clearly.

* Mitsubishi Electric Engineering Co., Ltd.
** Faculty of Education, Nagasaki University.
*** Department of Physics and Electronics, College of Engineering.

2. Experimental

In order to observe MOS-LSI specimens, we must conquer problems as follows. (i) MOS-LSI devices are highly susceptible to damage due to irradiation by an electron beam. (ii) Electron beam-induced damage to MOS-LSI by the case of EAM is larger than by the case of SEM. (iii) The r value of EAM must be improved moreover because the scale of integration has further advanced for MOS-LSI devices.

To solve problems (i) and (ii), the absorption current (Is) for the beam was reduced to the comparable levels with SEM-mode images[5-12], and the power of the chopped electron beam (Pe) was reduced. With this effect, the electron beam-induced damage to MOS-LSI specimens could be diminished. At the same time, improvement of r (problem (iii)) could also be achieved to some extent[13-16]. Moreover, the passivation film on the chip was removed, and the substrate of the chip was grounded. For these reasons, the charge due to the irradiated electron beam flowed out to the ground, and the chip was not electrified. The amounts of damage and charge-up of the chip by the beam were small.

By improvement of the signal detector and the amplifier for our EAM system, the signal to noise ratio (S/N) was improved. Moreover, a new power source of the electron beam chopping unit was fabricated. For above reason, we succeeded in improving r (problem (iii)), compared with the previous level[16].

In the operation of EAM, the chopping frequency was fixed at 1 MHz, duty ratio was 50% and HV was variable. The Is for the beam was about 8×10^{-10} A (measured with DC)[14].

A MOS-LSI chip specimen was mounted in a ceramic package and the substrate of the chip was grounded. The cover of the package was removed, but the chip was kept on the package. And then, we carried out nondestructive internal observation of MOS-LSI as a specimen.

3. Experimental Results

Figure 1(a) is a backscattered electron image (BEI) of SEM-mode showing surface information of the selected area. Figure 1(b) shows the arrangement of the surface electrode. In Fig. 1(b), ①denotes the array of contact holes (about $0.8\times0.8\mu m^2$ in size). Figure

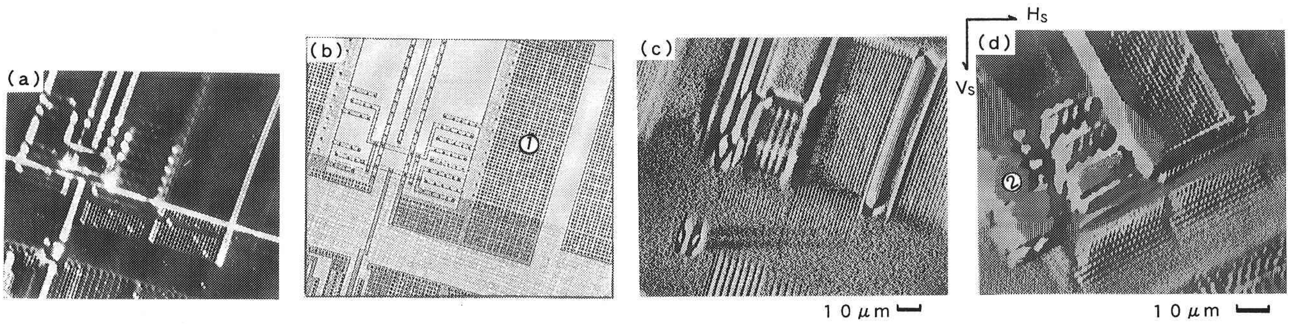

Fig. 1 Surface electrode view of the MOS-LSI chip near the observation area and the comparison of EAIs between old unit and new unit with the same operational condition.
①: arrays of contact holes (size: $0.8\times0.8\mu m^2$ square and ~$1.0\mu m$ depth from the surface). ②: oblique lines by noises of the power source which drived an electron beam chopping unit. Hs: direction of horizontal scan, Vs: direction of vertical scan. (a) BEI (SEM-mode), (b) arrangement of surface electrodes, (c) EAI of old unit (HV=19 kv) and (d) EAI of new unit (HV=19 kv).

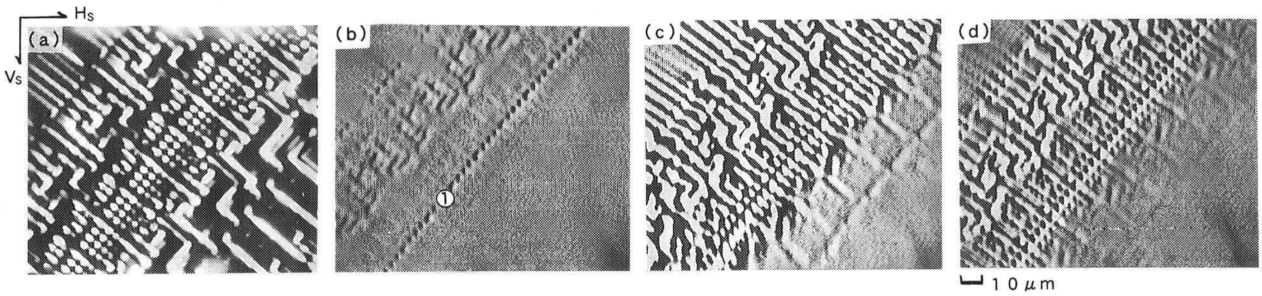

Fig. 2 EAM micrographs (EAIs) under various HV conditions. HV increases toward the right.
(a) SEI (SEM-mode), (b) HV=16 kv, (c) HV=18 kv and (d) HV=20 kv.

1(c) is the last observation of EAI, and Fig. 1(d) is the present observation of EAI under the same operational condition.

Comparing Fig. 1(d) with Fig. 1(c), Fig. 1(d) was obtained more clearly than Fig. 1(c). But in the left side of Fig. 1(d), oblique lines existed (see ②). Those lines were caused by noises of the power source which drived an electron beam chopping unit. In this study, the noises were excluded.

Figure 2(a) shows a secoundary electron image (SEI) of SEM-mode showing surface information. Figures 2(b)～(d) show EAIs obtained from the fixed area selected from SEM-mode images under HV=16, 18 or 20 kV, in which the area was different and the magnification was larger, as compared with those in Fig. 1. When HV=16 kv, there were few information as shown in Fig. 2(b). Increasing HV, diffusion layer was observed with 1.7μm depth. The tx values well matched with the previous report[15]. When HV=18 or 20 kv, tx of the specimen observable by EAM were estimated as about 1.3 or 1.7μm, respectively. Nondestructive internal observation could be performed clearly with high resolution as shown in Fig. 2(c) or (d). In Fig. 2(d), ①indicates the array of contact holes (about $0.8 \times 0.8 \mu m^2$). The image of the squares was observed sharply right angle. From above results, the resolution (r) of our EAM apparatus has been estimated to be $r \leqq 0.8 \mu m$.

4. Discussion

The observation area was selected from SEM-mode images and then, the mode was switched to the EAM-mode, EAIs could be obtained nondestructively.

In order to observe MOS-LSI specimens, we attempted as follows.

(1) The power of the chopped electron beam (Pe) was reduced. Especially, the absorption current (Is) for the beam was decreased. (2) The passivation film on the chip was removed. (3) The substrate of the chip was grounded for a defence of charge up. (4) By improvement of the signal detector and the amplifier for our EAM system, S/N of the system was improved. (5) A new power source of the electron beam chopping unit was fabricated. (6) The relationship between tx and HV well corresponded with the previous report[15].

For above effects, EAIs could be obtained clearly. These techniques are useful for nondestructive internal observation of MOS-LSI devices with high resolution by EAM.

5. Conclusions

A MOS-LSI chip specimen mounted in a ceramic package was observed with high resolution by EAM. EAIs were obtained without oblique lines which were caused by noises of the power source.

In this study, we succeeded in excluding noises of our EAM system. For this reason, we achieved to obtain EAIs clearly with high resolution ($r \leqq 0.8 \mu m$).

The observable depth (tx) of the specimen by EAM is controllable using HV as a parameter. The relationship between tx and HV well corresponded with the previous report[15].

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