ACdTe X-ray Imaging Device Using Vertical Thin Film Field Emitter Array

Yuki Tsunekawa, Masashi Nakagawa, Yoichiro Neo, Hisashi Morii, Toru Aokia, Hidenori Mimura, Masayoshi Nagao, Tomoya Yoshidab, Seigo Kanemaru

Abstract:

We have demonstrated the novel CdTe X-ray imaging device that consists of a Schottky CdTe diode and a Vertical Thin Film Field Emitter Array (VTF-FEA). The Schottky CdTe diode was fabricated by deposied indium (In) thin film on a Cl-doped p-type (p-type) CdTe substrate and Sb_2S_3 on the opposite side of the CdTe substrate. VTF-FEA was fabricated by ion induced bending (IIB) and etch-back method. The signal current was successfully detected by the recombination of the stored on the surface holes with the emitted electrons from FEA, and it was clarified that it depended on the X-ray intensity. And the imaging device succeeded in obtaining the Cu plate transmission image.

Keywords: *Vertical Thin Film Field Emitter Array, Schottky CdTe diode, ion induced bending, etch-back method.*

1. Introduction

A photon-counting mode X-ray imaging device has a lot of interests, such as high-sensitivity and energy-discrimination. We have studied about photon-counting mode X-ray image sensor, which was constructed with CdTe and already developed for the line sensor [1]. To realize the imaging devices with high spatial resolution, it is important to reduce the pixel size and to arrange the pixels in high density array. However, it is difficult to make CdTe device miniaturized, because the fineness of the process significantly degrades the device performance. Therefore, the imaging device that could detect X rays by using FEA was proposed. In this method, it reads the signal of each pixel one by one with the electron beam. The signal charge generated by X rays is recombined by the emitted electron from FEA. Therefore, the resolution of the image is decided by the spot size of the electron beam. It is unnecessary to make CdTe detector small. It is demanded to fabricate the detector with high resolution. In this report, VTF-FEA was fabricated by using an Ion Induced Bending (IIB) process [2]. And we have constructed an imaging device with VTF-FEA and the CdTe detector. And the principle inspection was performed.

2. Operation principle

Figure 1 shows operation principle of the CdTe X-ray image sensor using a VTF-FEA. Sb_2S_3 is a landing material for the electron beam and acts as the electron blocking layer. The In side of the CdTe diode was positively biased with respect to the FEA. When an electron beam irradiates the Sb_2S_3, the Sb_2S_3 layer is charged up and the CdTe diode is reversely biased by the bias voltage. Then, when X-ray irradiates the Schottky diode, electron-hole pairs are generated in the CdTe diode. The holes were drifted by applying field and are stored on the Sb_2S_3 surface. Electrons emitted from FEA recombine with the holes on the Sb_2S_3 surface, and simultaneously the output current, which is proportional to the amount of the stored holes, flows in the output circuit. X-ray images are obtained by addressing the FEA in sequence. In the case that the electron beam irradiates the Sb_2S_3 without X-ray irradiation, the dark current of the CdTe diode flows in the output circuit.

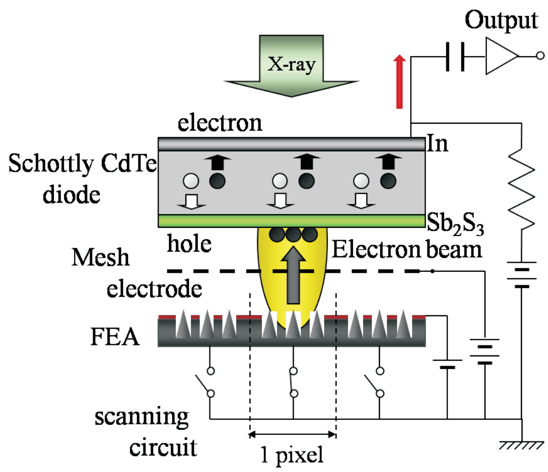

Fig. 1. Operation principle of the CdTe X-ray image sensor using a FEA.

3. Experiments

The Schottky CdTe diode was fabricated by depositing In on a CdTe substrate and Sb_2S_3 on the opposite side of the CdTe substrate. Figure 2 shows a current-voltage characteristic of the Schottky CdTe diode. The dark current was less than 10 nA at a reverse bias voltage of 100 V.

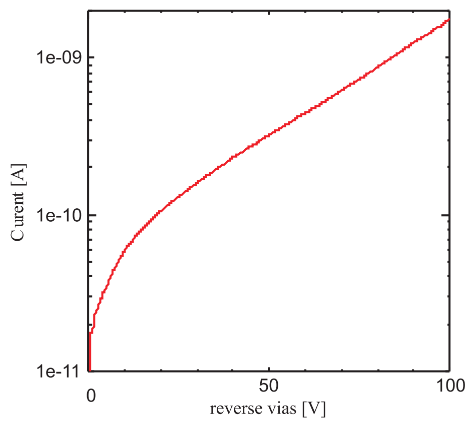

Fig. 2. Current-voltage characteristic of the Shottky CdTe diode.

The VTF-FEA was fabricated by using IIB process and etch-back method [3]. Figure 3 shows the fabrication process of the matrix-structured VTF-FEA. Mo thin film of 20 nm was used as emitter and was irradiated with 25 keV Ar ion, 3.0×10^{15} ion/cm^2. 100 nm thickness Nb film was used as the gate electrode. Gate electrode was opened by the etch-back method. Figure 4 shows SEM images of a one-pixel and an emitter tip of VTF-FEA. Table I described the specific of VTF-FEA. Figure 5 shows an electron emission characteristic of one the VTF-FEA. They were measured at high vacuum around 10^{-6} Pa. Threshold voltage was 25 V, and anode current of 500 nA achieved at a gate voltage of 70 V.

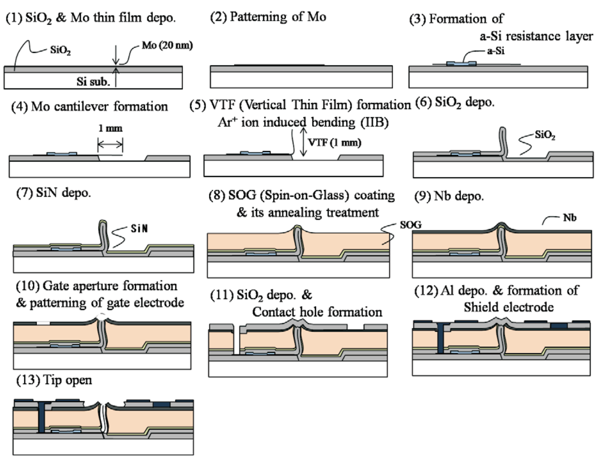

Fig. 3. Fabrication process of the matrix-structured VTF-FEA.

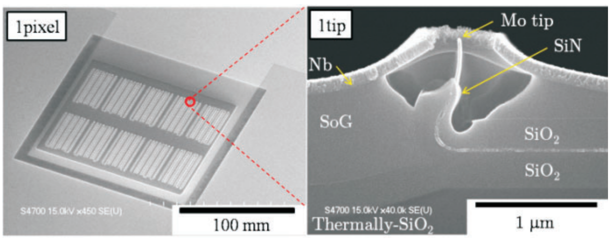

Fig. 4. SEM images of a one-pixel and emitter tip.

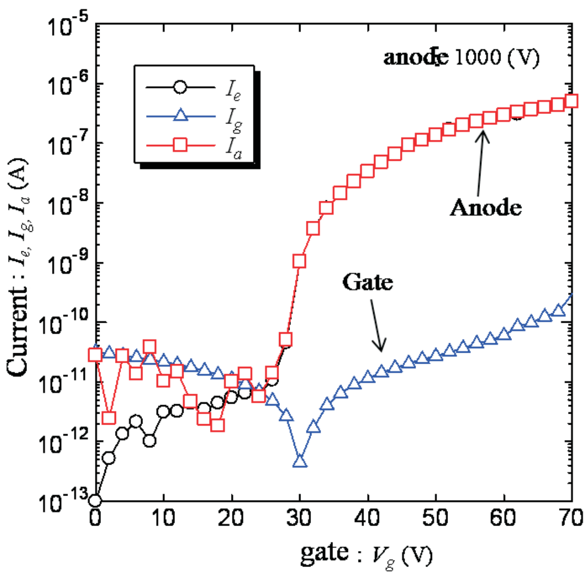

Fig. 5. Electron emission characteristic of the VTF-FEA pixel.

Table 1. The specific of VTF-FEA.

Substate size	7.5 mm x 7.5 mm
Pixel number	10 x 10 pixels
Size of 1 pixel	150 mm x 150 mm
Pixel pitch	0.4 mm
Emitted number	2000 tips/pixel

Figure 6 shows a schematic of the experimental setup for the CdTe X-ray imaging device. The VTF-FEA and CdTe diode were set in the center of a vacuum chamber. All experiments were carried out under an ultrahigh vacuum below 10^{-6} Pa. X-ray was irradiated on the CdTe diode through the glass viewing port.

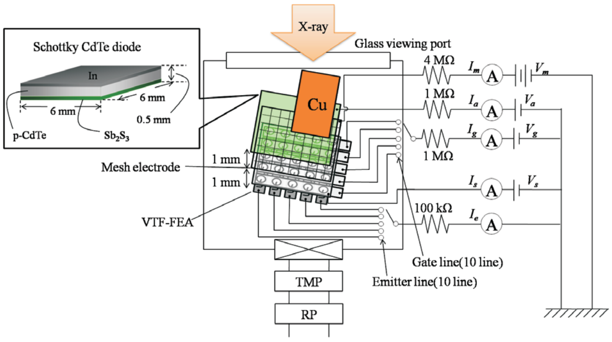

Fig. 6. Schematic of the CdTe X-ray image device.

3. Results and discussions

Figure 7 shows the output current characteristics under the exposure of electron beam with and without X-ray irradiation. The matrix-structured VTF-FEA and CdTe diode were set in the center of a vacuum chamber. A 1 mm thick Cu plate was set in front of the CdTe diode. And Cu plate beclouded the half area of VTF-FEA. The voltage of the mesh electrode was 500 V. The voltage of the cathode electrode, extraction gate and focus electrode were 0 V, 55 V, and 0 V, respectively. The anode voltage was 30 V.

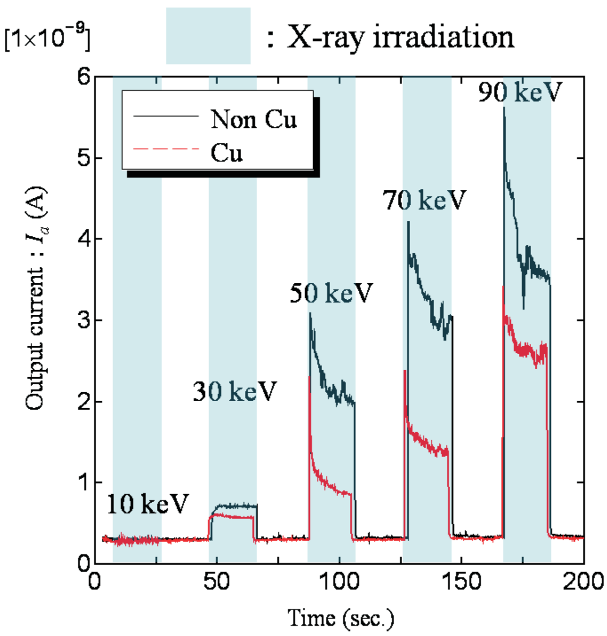

Fig. 7. Output current (IA) characteristic under the exposure of electron beam with and without X-ray irradiation.

The X-ray tube voltage was changed from 10 kV to 90 kV by 20 kV step. The X-ray tube current was kept 40 μA constantly. As shown in Fig. 6, the output current was obtained only with X-ray irradiated. Then the output current depended on the X-ray tube voltage, and it indicates that the output current is promotional to the X-ray intensity. Thus, the presence of the copper sheet can be detected, and the principle operation of X-ray imaging was demonstrated. Figure 8 shows the X-ray transmission image for Cu plate. The X-ray tube voltage was 30kV. And the X-ray tube current was 40 μA. As shown in Fig. 8, the two areas were successfully divided by reading output signal.

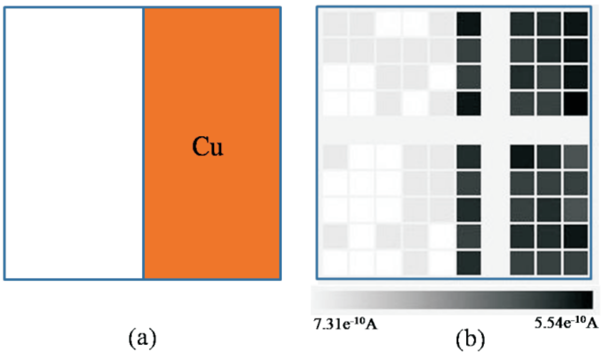

Fig. 8. (a) a schematic of the transmission objects and FEA setup and (b) obtained transmission image of Cu plate with 1mm thickness.

4. Conclusion

We have demonstrated the novel CdTe X-ray imaging device that consists of a Schottky CdTe diode and a VTF-FEA. The VTF-FEA was fabricated by Ion Induced Bending (IIB) process and etch-back method. The output current was successfully detected by the recombination of holes with electrons from the FEA, and clearly depended on the X-ray tube voltage, indicating that the output current |is promotional to the X-ray intensity. Furthermore the transmission image was successfully obtained.

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