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Fabrication and Characteristics Evaluation of $CoSi_2$-Gate MOS Electron Tunneling Emission Cathode

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Abstract: MOS electron tunneling emission cathodes have been fabricated with $CoSi_2$-SiO_2-Si structures, and the emission characteristics were evaluated. The 10 - 20 nm $CoSi_2$ layers were formed on 10 nm SiO_2 films by the molecular beam deposition (MBD). The electron emission occurred from the gate area by electron tunneling through the potential barrier in the MOS diode. The transfer ratio, i.e., the ratio of the emission current to the total current flowing through the MOS diode, was 1.4×10^{-4}. The emission was independent of pressure in the range of 1×10^{-4} - 6×10^{-6} Torr and stable over a long period of 100 min.

Keywords: MOS electron tunneling emission cathode, Transfer ratio, $CoSi_2$

1. Introduction

High contrast flat panel displays with fine pixels will be applied to the advanced portable data acquisition systems. Field emission devices operate at a high speed and show adequate brightness, and the advanced flat panel displays with the field emission devices are being developed. Usually, Spind-type emitters are employed for the field emitter elements, though they need a high voltage for the emission. On the other hand, tunnel-emission devices operate at a relatively low voltage, and those with the metal-insulator-metal structures have been investigated by many researchers [1]. Recently, Yokoo *et.al.* have demonstrated high emission efficiency and pressure insensitivity of the emission current for Al-gate and amorphous Si gate Metal-Oxide-Semiconductor (MOS) tunnel emission devices [2),3)]. However, deterioration of the oxide in the Al-gate MOS electron tunneling emission cathode is remarkable at high field, and the emission current reduces rapidly. The amorphous Si-gate MOS electron tunneling emission cathode shows more stable emission characteristics than the Al-gate cathode.

Cobalt disilicide shows low resistivity and excellent chemical stability, thus it is expected that the $CoSi_2$-gate MOS electron tunneling emission cathode will have long term stability and high speed capability compared with the amorphous Si-gate MOS electron tunneling emission cathode.

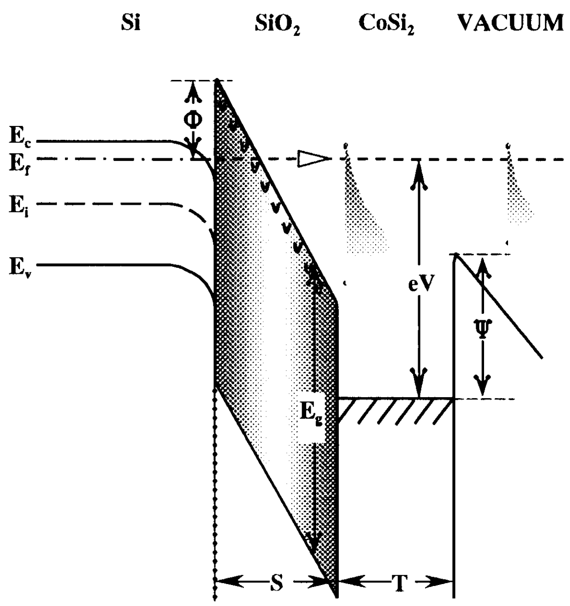

Fig.1 Energy band structure of $CoSi_2$-gate MOS electron tunneling emission cathode with applied bias, V, larger than work function of $CoSi_2$, Ψ.

In the present study, we have fabricated $CoSi_2$-gate MOS electron tunneling emission cathodes and evaluated the emission characteristics.

2. Experimental

The mechanism for the electron emission is schematically shown in **Figure 1** [2)]. With applied bias, V, larger than the work function of

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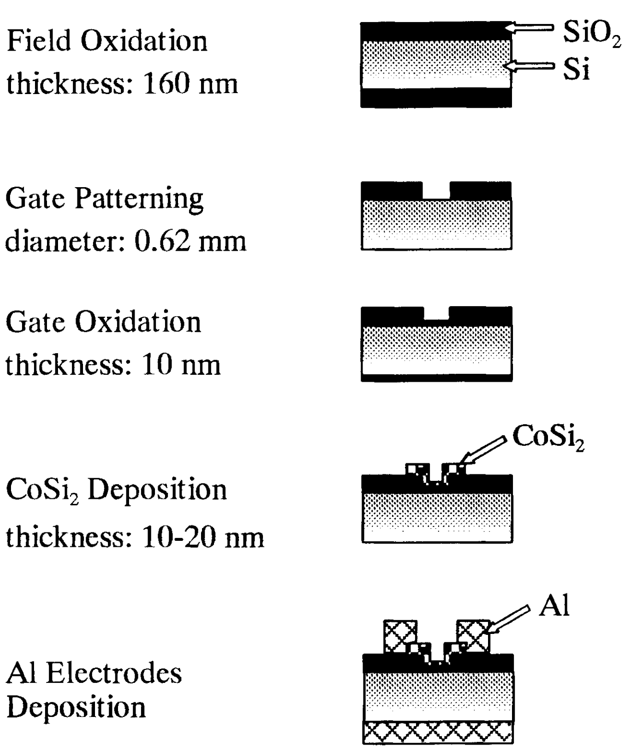

Fig.2 Fabrication procedure of $CoSi_2$-gate MOS electron tunneling emission cathode.

$CoSi_2$,Ψ, electrons in the conduction band of Si tunnel through the thin oxide films. If the gate material is thinner than the mean free path of electrons, a fraction of the electrons are emitted to the vacuum.

Figure 2 shows the fabrication process of the MOS electron tunneling emission cathode. A (100) n-type silicon wafer with 8 ~ 12 Ωcm was cut into slices of 20 mm × 20 mm. The chips were oxidized to grow 160 nm SiO_2 films in dry O_2 at 1100 °C for 2 h. After patterning the gate area, a 10 nm thick gate oxide was grown by dry oxidation at 900 °C for 24 min. Subsequently, 10 nm and 20 nm $CoSi_2$ films were deposited on the gate oxide through a Mo mask using the molecular beam deposition (MBD) method with an atomic ratio of Co : Si = 1 : 2 at sample temperature of 400 °C[4]. Finally, Al electrodes were deposited on the both sides of samples by vacuum evaporation.

Figures 3(a) and 3(b) show the measurement system and circuit of the $CoSi_2$-gate MOS electron tunneling emission cathode, respectively. All measurements were performed in a vacuum. The collector electrode was positioned above the sample by about 3 mm, and the extraction voltage between cathode and collector was 22.5 V. The current-

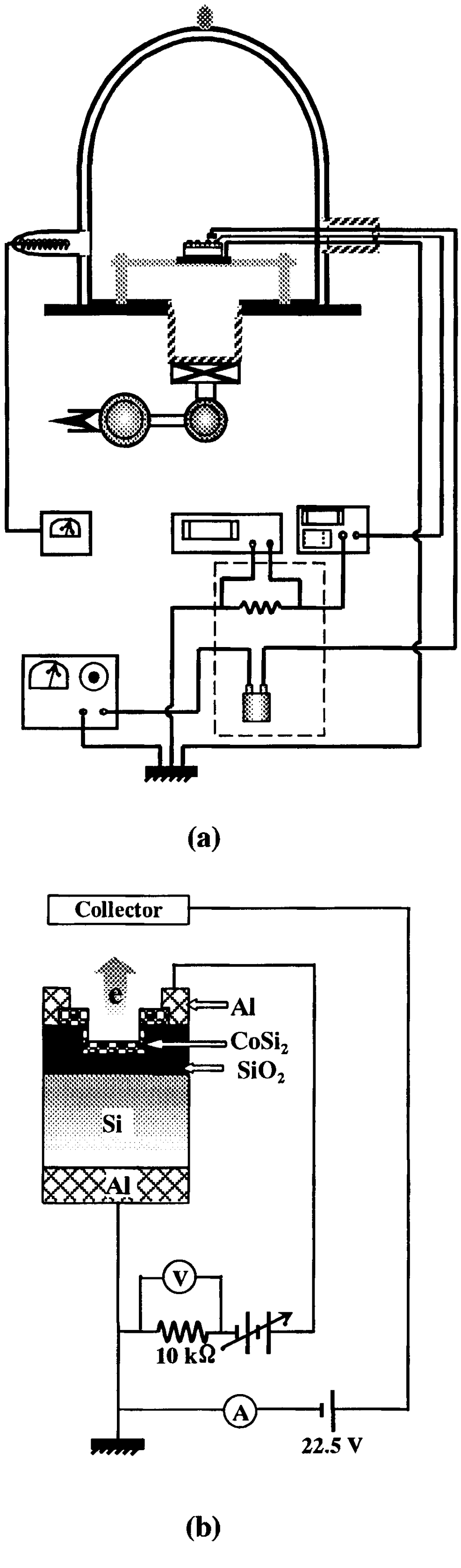

Fig.3 Measurement system (a) and circuit (b) of $CoSi_2$-gate MOS electron tunneling emission cathode.

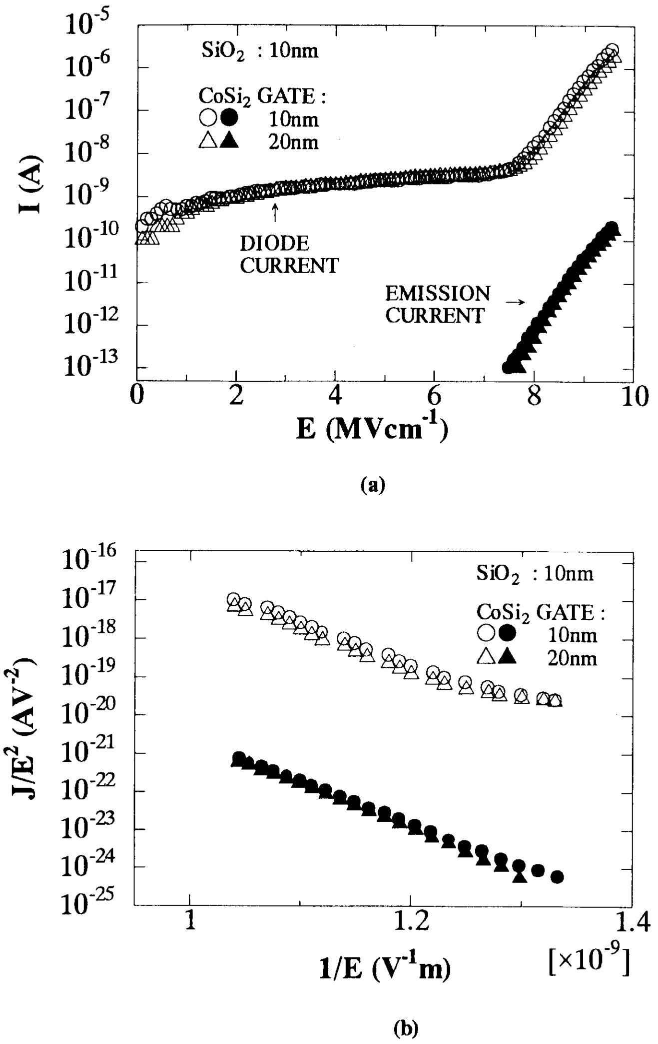

Fig.4 *I-E* curve (a) and Fowler-Nordheim plot (b) for $CoSi_2$-gate MOS electron tunneling emission cathode.

voltage characteristics were measured with increasing the gate bias. The diode current and the emission current were measured by the digital multimeter and the electronic pico-ammeter, respectively.

3. Results and discussion

We investigated the emission characteristics of the samples with oxide thickness of 10 nm and $CoSi_2$-gate thickness of 10 and 20 nm. The electric field dependence of the emission and diode currents and the Fowler-Nordheim plots are shown in **Figures 4(a)** and **4(b)**, respectively. The emission of electrons is observed at high electric field where the diode current shows the Fowler-Nordheim tunneling characteristics. The gradient of the Fowler-Nordheim plot of the diode current and the emission

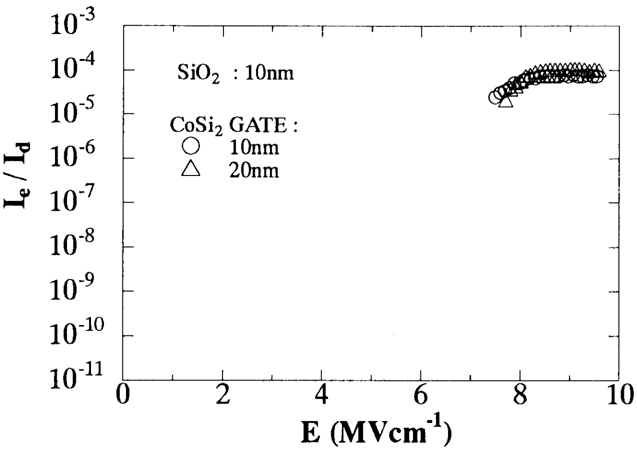

Fig.5 Electric field dependence of transfer ratio for $CoSi_2$-gate MOS electron tunneling emission cathode.

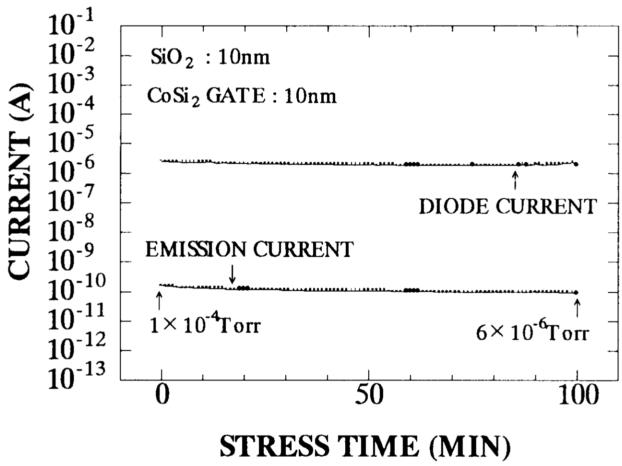

Fig.6 Stress time dependence of emission and diode currents of $CoSi_2$-gate MOS electron tunneling emission cathode.

current is almost the same for both samples, which suggests that the emission current is limited by the same barrier for tunneling as that for the diode current, and that the transfer ratio, the ratio of the emission current to the diode current, is a constant value.

The gate electric field dependence of the transfer ratio for the samples obtained from **Figure 4(a)** is shown in **Figure 5**. The transfer ratio is about 1.4 $\times$ 10^{-4} and does not depend on the gate electric field above 8 MV cm^{-1}, while the emission current changes about 3 orders of magnitude in the range of the electric field from 8 to 10 MV cm^{-1}. Thus, it is suggested that the emission current can be precisely controlled over a wide range with tuning the gate bias for the $CoSi_2$-gate MOS cathodes. Moreover, the ratio does not depend on the thickness of the $CoSi_2$-gate, as shown in **Figure 5**. On the other hand, it has been reported that the ratio for the Si-gate MOS cathodes depends on the field [3]. This suggests that the constant transfer ratio is due to the electrical property of the $CoSi_2$-gate, though the detailed mechanism for the constant ratio need to be clarified.

In **Figure 6**, the pressure and stress time dependence of the emission current and that of the diode current for the $CoSi_2$-gate MOS cathode are shown. Both oxide and gate thickness were 10 nm. The emission current was nearly independent of the pressure ranging from 1×10^{-4} to 6×10^{-6} Torr and stable over the period of 100 min. The emission characteristics is more stable than that for the Al-gate cathodes [2] and comparable to that for the Si-gate cathodes [3].

4. Conclusion

Emission characteristics of the $CoSi_2$-gate MOS electron tunneling emission cathodes have been investigated and compared with those reported for the Al-gate and Si-gate cathodes. The ratio of emission current to the total current through the diode was 1.4×10^{-4} and did not depend on the gate electric field between 8 and 10 MV cm^{-1}, while the emission current in this range of the gate electric field changes about 3 orders of magnitude. This suggests that the emission current can be precisely controlled over a wide range with tuning the gate bias for the $CoSi_2$-gate MOS cathodes. The emission characteristics were stable over 100 min under the electric field stress and did not depend on the pressure between 1×10^{-4} to 6×10^{-6} Torr. The deterioration of the oxide are suppressed and the controllability of the emission current are improved by using the $CoSi_2$-gate. Thus, it is suggested that the $CoSi_2$-gate MOS electron tunneling emission cathodes are expected to be suitable for the flat panel displays and the vacuum electronics.

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