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Plasma-Radiation-Induced Interface-States in MNOS of CCD Image Sensors and their Reduction Using Pulse-Time-Modulated Plasma

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1. Introduction

Charge-coupled-devices (CCD) as image sensors have been widely used in video cameras, digital still cameras and recently cellular phones. The mobile usage needs low-power consumption and small size system. Consequently lowering operating voltage and wafer-level-chip-size package are goals for development of new sensor devices. Since some image sensors have color filters and the wafer-level-packaging process that include low temperature formation of organic materials, it is necessary to develop low temperature and low damage processes. This reminds us of being hard to recover the plasma damages without heat treatment.

Some particles in the plasma such as ions, neutral particles, electrons and ultraviolet (UV) light are possible to cause damages [1]. We are focussing on the effect especially of the UV because it is easy to penetrate into the sensor devices. Thought the damages due to γ-ray, X-ray or vacuum-UV light have been previously observed using MOS devices [1] including CCDs [2], it has been not investigated whether a UV light of less than SiO_2 band gap 8.8 eV (141 nm) affects CCD characteristics or not. Because of its analog devices, the CCD is one of the most sensitive devices to detect the damages. A dark current of the CCD is strongly influenced by the plasma-induced damages because the CCD can detect a change in a few tens electrons as a dark current. Therefore, we have to be careful how we create the low damage plasma processes for back-end processes including the color filters and the wafer-level-packaging processes. On the other hand, we have reported that a pulse-time-modulated (TM) plasma causes less emission of UV lights compared with a continuous wave (CW) plasma.[3] We expected the TM plasma drastically reduced the UV-induced damages.

In this study, we show that UV irradiation in some plasmas or in air under a metal-halide lamp induces the dark current coming from interface states at SiO_2/Si boundary, not from fixed charges in SiO_2. It is also found that the TM plasma reduces increases in the dark current and the interface states. Metal/nitride/oxide/ silicon (MNOS) as CCDs must be taken into account to discuss the mechanism of UV induced damages.

2. Experimental

Applying 13.56-MHz-RF power to a one-turn antenna generates inductively coupled He, Ar, or O_2 plasma for a plasma irradiation to the CCD chips on a wafer. A microwave interferometer and a VUV spectrometer are used to measure the electron density and the light intensity, respectively. The RF power and pressure were fixed at 1 kW and 0.65 Pa gas, respectively. We irradiated UV lights to the CCD wafer using a metal-halide lamp from 230nm to 430 nm.

To detect damages in the irradiated CCD, we measured the dark current of the CCDs. The CCD has arrays of 1.3-milion-MNOS-structures that consist of 50nm-doped-polycrystalline-silicon electrode, 75 nm Si_3N_4, 62 nm SiO_2 and Si substrate. On the MNOS structures some inter-insulating layers of 4.0 μm, which consist of SiO_2 (band gap 8.8 eV) and plasma-enhanced-silicon nitride (around 5 eV), totally exist. These insulators prevent ions, electrons and vacuum-UV lights from impinging into the MNOS structures. When an UV through the interlayer degrades the insulator in the MNOS or Si/SiO2 interface, dark currents increase. Therefore, an increase in the dark currents was evaluated as degradation of the CCD devices.

A CV measurement was tried to detect fixed charges in the MNOS structure. Interface states were evaluated by charge-pumping method using MNOS-FET.

3. Results and Discussions

Effect of TM plasma

Figure 1 shows an image example of an increase in the dark current as well as a reference image. You can see the image degradation by increase in a dark current.

It was previously reported that the time modulated plasma reduced lights emitted from plasma [3]. Figure 2 shows that the TM He plasma (on time / off time = 50 μs / 50 μs) reduce an increase in the dark current compared with the CW plasma. Vertical axis represents the number of CCD chips, horizontal one is an increase in the dark current. A decrease in the UV light induces decline in the dark current. This result suggested that the TM plasma is a good solution for suppressing plasma damages in some back-end processes of CCDs.

Gas Dependence and UV flux of Dark Current

An increase in the dark current depended on gas. In case of He plasma, the dark current extremely increases. Conversely, in Ar and O_2 plasmas the currents slightly grow up, whereas electron density in Ar and O_2 plasma was much higher than that in He plasma. The UV light from the metal halide lamp also induced the dark current. Because electron-hole pairs can not be generated in SiO_2 by irradiating the UV lights ranged from 230 nm to 430 nm, these results imply the rise in the dark current strongly depends on wavelength of irradiated light.

CV Measurement and Charge Pumping Method

There is no difference of 1-MHz-CV curves among any irradiation conditions including no irradiation. (See Fig.3) This means that fixed charges in MNOS did not change due to any irradiation such as He plasma or metal-halide UV light. On the other hand, charge pumping currents increase with an increase in the metal-halide-UV-light as Fig. 4. Besides the charge pumping currents rose up when the He plasma was irradiated and the amount of increase in the currents in CW plasma is much larger than that in the TM plasma. The tendency of increase in the charge pumping currents corresponds to that in the dark currents. The interface states are sources of the dark current.

Holes generated in SiO_2 film play an important role in creating damage including interface states [1]. MNOS of the CCDs might be easy to capture holes stimulated by the UV light from the ploy-Si electrode to Si_3N_4 because of less band gap of the Si_3N_4 than SiO_2.Then the holes may generate hydrogen that related to formation of the interface states.

4. Conclusions

The UV light irradiation emitted from plasmas and from metal halide lamp generates the dark current of the CCDs. The TM plasma suppressed the growth of the dark current as a plasma-induced damage. Charge-pumping method using MNOS transistor gave us the result that the dark current comes from the interface states. We also emphasize that the UV light (less than the SiO_2-band-gap) generates the interface states of the MNOS structures of the CCDs.

References

[1] T. Yunogami, T. Mizutani, K. Suzuki and S. Nishimatsu: Jpn. J. Appl. Phys., 28 (1989) 2172

[2] J. Killiany: IEEE Trans. Components, Hybrids and Manufacturing. Tech. 4 (1978) 353

[3] S. Samukawa, Y. Ishikawa, S. Kumagai and M. Okigawa: Jpn. J. Appl. Phys., 40 (2001) L1346

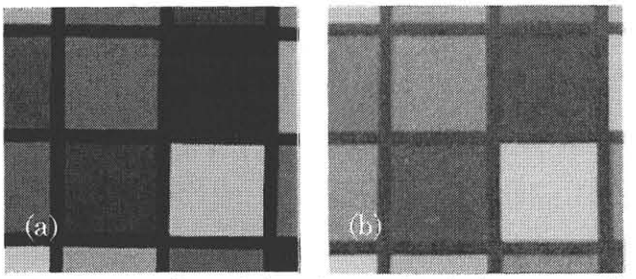

Fig.1 Image degradation due to the dark current (b). The left image is a reference (a).

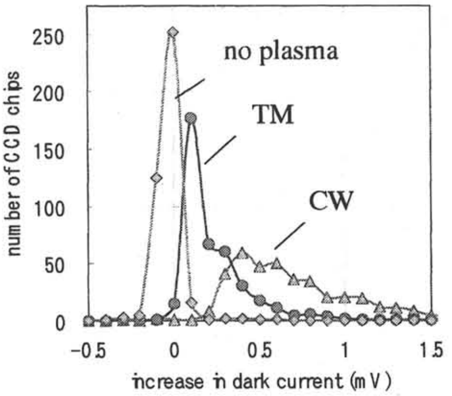

Fig.2 Number of CCD chips versus increase in dark current due to TM and CW plasma using He.

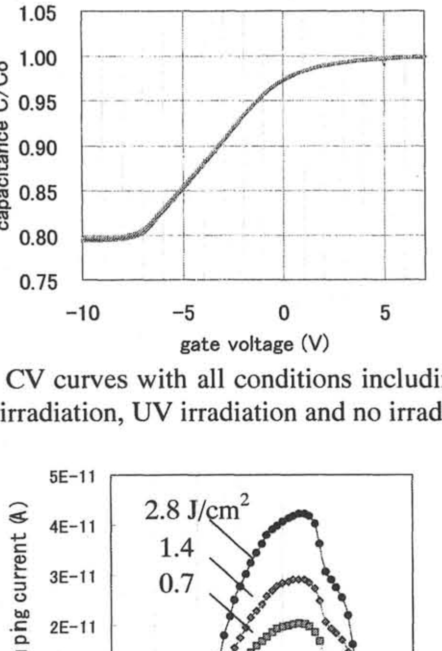

Fig.3 CV curves with all conditions including plasma irradiation, UV irradiation and no irradiation.

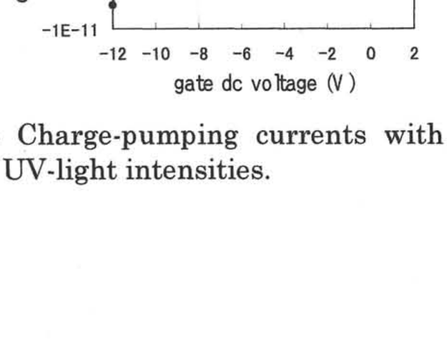

Fig.4 Charge-pumping currents with various UV-light intensities.