PS-7-11

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp242-243

Photosensing in MOS(p) and MOS(n) Photodiodes

Chang-Tai Yang[1] and Jenn-Gwo Hwu[1]

[1] Graduate Institute of Electronics Engineering /
Department of Electrical Engineering,
National Taiwan Univ.
No. 1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan
Tel: 886-2-33663646, Fax: 886-2-23671909 E-mail: jghwu@ntu.edu.tw

Abstract

Metal–oxide–semiconductor (MOS) photodiodes of p-type (MOS(p)) and n-type (MOS(n)) were examined under illuminations of 3, 5, and 7 mW/cm^2. By measuring devices with different gate oxide thicknesses (*dox*), we found that the light current from MOS(p) increases as *dox* increases. Conversely, the light current has irradiance-dependent minimum between *dox=23* Å and *dox=29.5* Å for MOS(n). We suggest that the light current of MOS(p) is related to edge Schottky barrier height modulation and that of MOS(n) is affected by the energy of electrons. Under irradiance of 7 mW/cm^2, the sensitivity of MOS(p) with *dox=23* Å is up to 4020 and that of MOS(n) is up to 3460 with *dox=29.5* Å.

1. Introduction

In recent years, increasingly silicon based optoelectronic devices are investigated ; one of them is metal–oxide–semiconductor (MOS) . Still many photodetectors are fabricated by other semiconductor materials, such as germanium. In silicon-based MOS photodiodes with nontransparent metal gate, it has been reported that the electron–hole pairs are generated in the depletion region at the edge below the metal gate . In this work, the gate current behaviors of MOS capacitors of p-type (MOS(p)) and n-type (MOS(n)) with ultrathin SiO_2 are investigated. We demonstrate novel current mechanisms of both photodiodes with oxide thicknesses from 23 Å to 29 Å. By observing the experimental results, we suggest that MOS(p) mainly utilizes the mechanism of edge Schottky barrier height modulation of holes, while MOS(n) is related to the voltage drop in oxide and the energetic electrons.

2. Device Fabrication

A 3-in boron-doped (100) p-type silicon wafer with a resistivity of 1–10 Ω·cm was used for the substrate of MOS(p) in this work. After the standard RCA clean process to remove the organic particles, ions and native oxide, the ultrathin SiO_2 was grown on the surface of tilted wafer by anodic oxidation in D.I. water with DC voltage 15 V for 8 minutes. Postoxidation annealing was carried out in 20-torr N_2 ambient at 950 °C for 15 seconds. And then, 99.99% pure aluminum film with 2000 Å was thermally evaporated as the gate electrode. The gate electrodes of D1, D2, and D3 with areas of 150 μm×150 μm, 300 μm×300 μm, and 600 μm×600 μm were determined and patterned by photolithography. Finally, after removing native oxide by a buffered oxide etchant, aluminum back contact of 2000 Å was deposited by thermal evaporation. In the interim, the ultrathin SiO_2 was also grown on a 5-in phosphorus-doped (100) n-type silicon wafer with a resistivity of 1-10 Ω·cm for the substrate of MOS(n). The rest processes were the same as p-type device. Current–voltage (*I–V*) curves were measured by Agilent B1500A Semiconductor Device Analyzer. The illumination was performed by several incandescent lamps, whose intensity was measured by a Newport 841-PE power meter.

3. Results and Discussion

Fig. 1(a) and 1(b) show the gate current versus gate voltage (*I–V*) curves of MOS(p) and MOS(n) respectively. It is found that when *dox* increases, the saturated gate dark current under inversion region of MOS(p) (gate voltage $VG > 0$ V) increases. On the contrary, the current under inversion region of MOS(n) ($VG < 0$ V) decreases. When it comes to the saturated gate light current under inversion region under light intensity of 7 mW/cm^2, the current of MOS(p) tends to increase as long as *dox* increases. But it is more complicated in MOS(n); the current meets its minimum at *dox=24* Å, and it increases no matter *dox* increases or decreases. Furthermore, if *dox* becomes thicker, the light current will saturate slower or even not saturate.

Fig. 2(a) and 2(b) show dark current (I_{dark}), light current(I_{light}), and sensitivity(I_{light}/I_{dark}, $VG=2.5V$ for MOS(p) and $VG=-2.5V$ for MOS(n)) versus gate oxide thickness of both types. MOS(p) and MOS(n) have almost inverse results of currents. Hence, it is not surprise that while *dox* increases, the sensitivity of MOS(p) decreases but that of MOS(n) increases. What is interesting is the minimum of the light current of MOS(n) depends on luminance. When irradiance is low (3 mW/cm^2), the minimum of the light current is at *dox=26* Å; on the other hand, the minimum under higher light intensity (7 mW/cm^2) is at *dox=24* Å.

From the results above, we suggest two different mechanisms for both types of photodiodes. When the electron–hole pairs are generated in the quasi-neutral region, the significant change of minority carriers (electrons) concentration in MOS(p) leads to extra lateral electron diffusion current and can supply additional electrons into the edge inversion region. In contrast, the change of diffusion

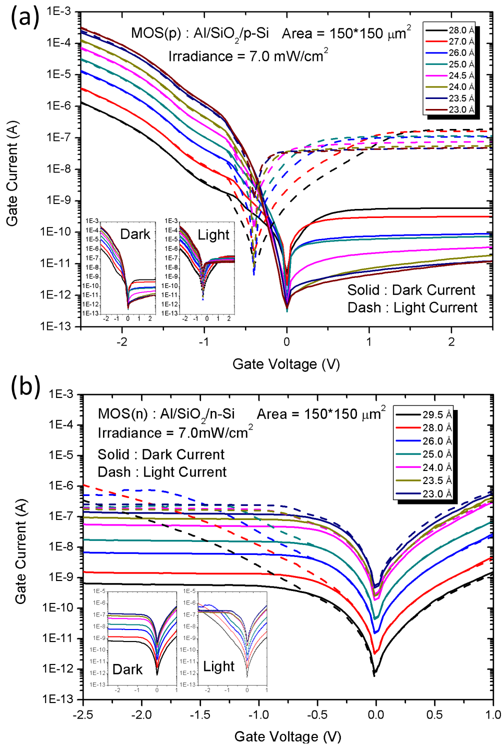

Fig. 1 Complete *I–V* curves for dark and light current at a light intensity of 7 mW/cm^2 of (a) MOS(p) with eight oxide thicknesses and (b) MOS(n) with seven oxide thicknesses.

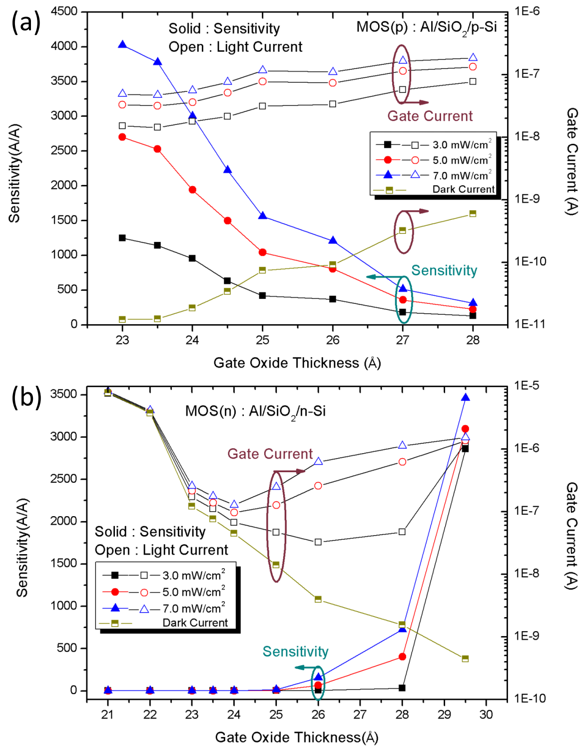

Fig. 2 Sensitivity and gate current versus oxide thickness curves of (a) MOS(p) and (b) MOS(n) at light intensities of 3, 5, and 7 mW/cm^2.

current caused by holes concentration is negligible. Since more electrons accumulating at the edge of depletion region, the voltage turns to drop in oxide edge, which results in great amount of holes injecting into silicon substrate by means of lower Schottky barrier height of holes. This phenomenon is referred as Schottky barrier height modulation . On the other hand, the mechanism of light current of MOS(n) is more complex. When the electron–hole pairs are generated in the quasi-neutral region, the gradient of minority carriers (holes) will rise and lead to lateral diffusion current, which can supply additional holes into inversion layer. The voltage drops more in oxide compared to the dark current condition. Thus, the light current decreases with increasing *dox* when it is not thick enough. However, the device with thicker oxide allows more electrons to tunnel through the oxide due to layer oxide voltage drop modulation mechanism. As a result, the influential energetic electrons in thicker oxide causes the light current to increase when *dox* increases .

4. Conclusions

The *I-V* behavior, especially the light current of MOS photodiodes of p-type (MOS(p)) and MOS photodiodes of n-type (MOS(n)) is studied in this work. For MOS(p) with thick oxide, there are more electrons accumulating in the inversion layer at the edge of device, which cause lower Schottky barrier height and larger light current instead the device with thin oxide has smaller light current and lighter pinned oxide electric field. On the other side, the light current for MOS(n) will have a minimum; as the oxide thickness increases, the light current is approaching to its minimum, the voltage drop in oxide dominates thus the current decreases. As the light current reaches its minimum, the energetic electrons dominate and cause increasing light current. Consequently, the sensitivity of MOS(p) with thin oxide is higher than that with thick oxide due to lower dark current along with the sensitivity of MOS(n) with thin oxide is lower than that with thick oxide.

Acknowledgements

This work was supported by the Ministry of Science and Technology of Taiwan, ROC, under Contract No. NSC 102-2221-E-002-183-MY3 and National Taiwan University under Contract No. NTU-ERP-104R89087.

References

[1] M. du Plessis *et al.*, IEEE J. Sel. Topics Quantum Electron **8** (2002) 1412-1419

[2] C. W. Liu *et al.*, IEEE Electron Device Lett. **21** (2000) 307-309

[3] C.-H. Lin and C. W. Liu, Sensors **10** (2010) 8797-8826

[4] C.-C. Ting, Y.-H. Shih, and J.-G. Hw, IEEE Trans. Electron Devices **49** (2002) 181

[5] B. E. Coss *et al.*, Applied Physics Letters **95** (2009) 222105-1

[6] Y. -K. Lin and J. -G. Hwu, IEEE Trans. Electron Devices, **61** (2014) 3222