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# Homoepitaxial ZnSe MIS Photodetectors Using $SiO_2$ and BST Insulator

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## 1. Introduction

ZnSe is an attractive material for optical applications of short wavelength. ZnSe based photodetectors detecting in the blue/ultraviolet spectral regions can be important for many space, military and medical applications due to its large band gap, high resistivity and low capacitance [1-3]. However, the reported ZnSe photodetectors were all grown on the closely lattice matched GaAs substrates. However, the slight lattice mismatch (0.27% at room temperature) between ZnSe and GaAs will still generate a huge amount of defects when we grow very thick ZnSe epitaxial layers on GaAs substrates. The defects generated at the ZnSe/GaAs interface will significantly reduce the efficiency of the ZnSe-based photodetectors [4]. In order to suppress the high dark current, the thin insulating layer can be inserted into metal/semiconductor interface to form metal-insulator-semiconductor (MIS) structure [5-6]. Interfacial layers always affected the potential barrier height, capacitance and stability of Schottky photodiode structure. In this study, we investigate the performances of homoepitaxial ZnSe metal-insulator-semiconductor (MIS) photodetectors with $SiO_2$ and BST insulating layer.

## 2. Experiments

The ZnSe samples in this study were grown on ZnSe substrate by molecular beam epitaxy (MBE). The source materials used in our MBE system are Zn (6N) and Se (6N) while $ZnCl_2$ was used as the n-type doping source. We then loaded the ZnSe substrates into the growth chamber to grow a 1.5-μm-thick n-type ZnSe epilayer at 300$^o$C. Then, Indium was thermally evaporated onto the backside surfaces of the Iodine doped n-ZnSe substrates to serve as the bottom of ohmic contact electrodes. The insulating layers of $SiO_2$ and $Ba_{0.25}Sr_{0.75}TiO_3$ (BST) were deposited on top of ZnSe epilayer. $SiO_2$ films were deposited by photo-CVD with based pressure of 0.9 torr, $SiH_4/O_2$ flow rate of 18/32 sccm and processing temperature of 200$^o$C. BST films were sputtered with pressure of 10 mTorr, power of 100 W and $Ar/O_2$ flow rate of 10/10 sccm at room temperature. The top contact electrodes of 100 nm ITO were sputtered by RF-sputter through lithography process onto ZnSe epitaxial films with a contact area of $1x10^{-3}$ cm$^2$.

## 3. Results and Discussions

The reverse current-voltage (I-V) characteristics of homoepitaxial ZnSe MIS photodetectors with passivation of $SiO_2$ and BST interlayer in dark are shown in Figure 1. It was found that dark current density of MIS photodetectors with $SiO_2$ and BST passivation was less than about $5x10^{-8}$ A/cm$^2$ at -1V. Moreover, dark current density of $SiO_2$ was smaller than BST insulator indicated that the $SiO_2$ shows better insulating ability. As shown in figure 2, with an incident wavelength of 448 nm, it was found that the maximum responsivity for MIS photodetectors with $SiO_2$, BST interlayer and Schottky photodiode were about 0.106 A/W, 0.064 A/W and 0.14 A/W respectively, which correspond to a quantum efficiency of 29%, 17.5% and 38.5% respectively. The reduction of responsivity was attributed to the photo generated carriers have to tunnel through the thin inserted insulator and carriers could be captured at generation-recombination center and interface traps. On the other hand, in the inset of Figure 2, it shows the transmittance of $SiO_2$ and BST interlayer was about 94% and 89% at wavelength of 400 nm, respectively. Compared to Schottky photodiode, the reduced responsivity of MIS photodetectors was attributed to partial transparency of inserted insulator induced blocking of incoming light. Figure 3 (a)-(c) were shown the measured low frequency noise spectra of ZnSe MIS photodetectors with $SiO_2$ and BST insulator under different bias. From the measured curves, it was found that the noise spectra was estimated to be commonly 1/f noise for Schottky photodiode and $1/f^{\gamma}$ ($\gamma$=1.2) for MIS photodetectors at low frequency. Noise power densities of MIS photodetectors with $SiO_2$ and BST insulator and Schottky photodiode as a function of current density at frequency of 10 Hz were also shown in the Figure 4. We simulated that $\beta$ value was about 2 for Schottky photodiode. This behavior was in agreement with Kleinpenning's formulation of the noise for Schottky diode [7]. Furthermore, $\beta$ value of 1.1 and 1.3 was simulated for MIS photodetectors with passivation of $SiO_2$ and BST, respectively. Further, interface trapping states were investigated as the source of charge fluctuations, using the McWhorter Theory [8]. Effective density of traps ($N_{teff}$) of Schottky photodiode and MIS photodetectors with $SiO_2$

and BST were calculated to be 3.9x10$^{22}$, 2.46x10$^{21}$ and 1x10$^{22}$ cm$^{-3}$eV$^{-1}$ at f of 10 Hz and bias of -1 V, respectively. We suggested that trapping and de-trapping of carriers were reduced by fewer surface trap states, which were attributed to the insertion of insulator and further improved the noise power density. In addition, for a given bandwidth of 100 Hz, NEP of homoepitaxial ZnSe MIS photodetectors with $SiO_2$ and BST and Schottky photodiode at given bias of -1V were calculated to be 1.24x10$^{-13}$ W, 1.9x10$^{-13}$ W and 2.1x10$^{-13}$ W respectively. Further, the corresponding D$^*$ were 2.55x10$^{12}$ cmHz$^{0.5}$W$^{-1}$, 1.67x10$^{12}$ cmHz$^{0.5}$W$^{-1}$ and 1.5x10$^{11}$ cmHz$^{0.5}$W$^{-1}$ respectively. Such a low NEP and high D$^*$ should be attributed to the insertion of good insulating $SiO_2$ and BST insulator, which result in the good performances of ZnSe MIS photodetectors.

## 4. Summary

ZnSe MIS photodetectors were fabricated and investigated by interfacial passivation of $SiO_2$ and $BaSrTiO_3$ (BST) films. Dark current densities of MIS photodetectors were suppressed efficiency and shown less than about 5x10$^{-8}$ A/cm$^2$ at -1V. With an incident wavelength of 448 nm, it was found that the maximum responsivity for MIS photodetectors with $SiO_2$ and BST interlayer were about 0.106 and 0.064 A/W respectively, which correspond to a quantum efficiency of 29 and 17.5 %, respectively. Furthermore, noise equivalent power (NEP) of ZnSe MIS photodetectors with $SiO_2$ and BST were calculated to be 1.24x10$^{-13}$ and 1.9x10$^{-13}$ W, respectively. The corresponding normalized detectivity (D$^*$) were 2.55x10$^{12}$ and 1.67x10$^{12}$ cmHz$^{0.5}$W$^{-1}$, respectively.

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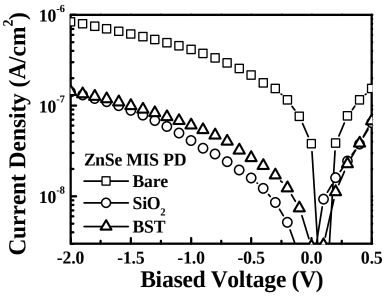


Fig. 1 Dark I-V characteristics of MIS photodetectors with $SiO_2$ and BST insulator and Schottky photodiode.

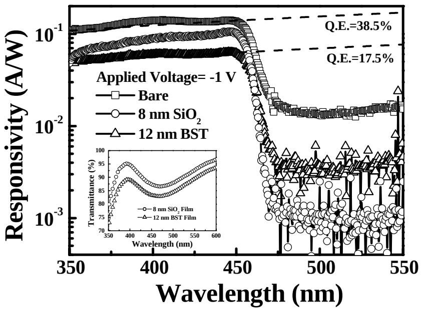


Fig. 2 Responsivity of MIS photodetectors with $SiO_2$ and BST insulator and Schottky photodiode

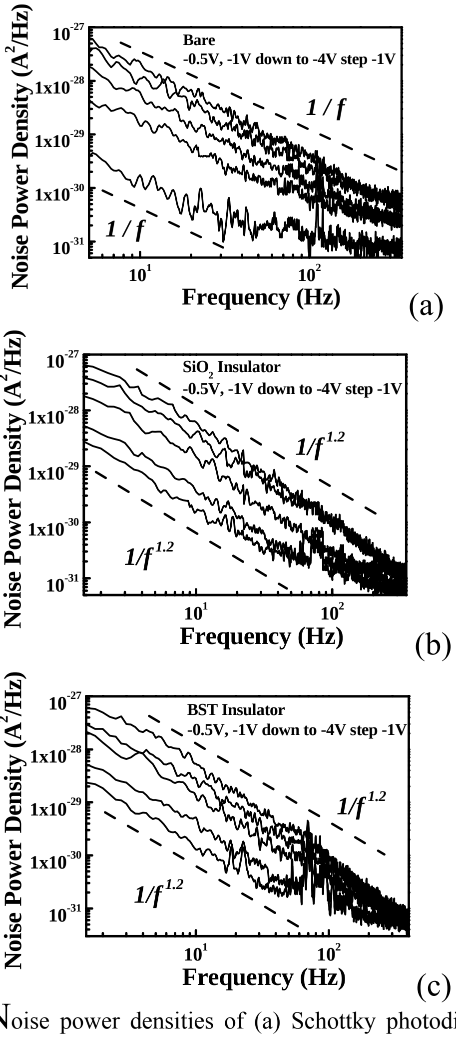


Fig. 3 Noise power densities of (a) Schottky photodiode and MIS photodetectors with (b) $SiO_2$ and (c) BST insulator.

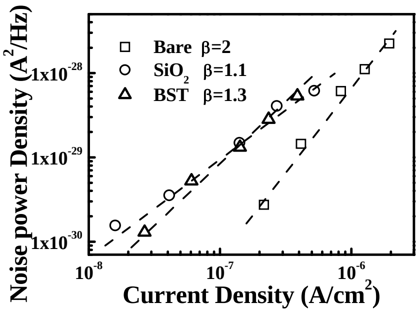


Fig. 4 Noise power density as a function of current density for MIS photodetectors with $SiO_2$ and BST and Schottky photodiode.