Role of Surface and Interface States on the Performance of GaAs Based Photodetectors

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Abstract. The effect of surface and interface states of various GaAs based structures such as n^+GaAs, n-n^+GaAs and p-i-n GaAs are investigated for understanding the detector performance. These structures are grown by metal organic vapor phase epitaxy (MOVPE). Surface photovoltage spectroscopy is performed in these structures to investigate the role of surface and interface states on the absorption spectra. Decrease in surface photovoltage signal with increased chopping frequency indicate the presence of slow temporal response states. These states get passivated by growing homo epitaxial layer of GaAs on n^+GaAs substrate. Subsequently, for the isolation of surface and interface states on the p-i-n detector structure, n-n^+GaAs and p-i-n GaAs structures are investigated separately. Further, the detectors of these structures are developed and their spectral response are recorded at room temperature. The responsivity values are evaluated by varying the incident power of 690 nm laser. Ten times increase in responsivity is observed in p-i-n GaAs photodetector compared to n-n^+GaAs photodetector. A low dark current (~ 0.5 nA) is also obtained in p-i-n GaAs photodetector which qualifies its better device performance.

INTRODUCTION

GaAs based photodetectors are important compared to other conventional Si and Ge photodetectors particularly in radiation zone.[1] This is due to its high band gap which results in low dark current, and direct band gap leading to high absorption coefficient. Further, the high electron mobility, with low non-radiative recombination results in a faster device performance. Also for a same photon flux, GaAs possesses a greater photon detection efficiency as compared to Si and Ge, which enables its room temperature operation without any need of cryogenics.[2,3] However, the integration of GaAs on Si or Ge can extend the detection range from 300 to 1700 nm wavelength range. Recently, the GaAs array detectors on Si is investigated for its optical and transport properties.[3] However, the defect free hetero-epitaxial growth of GaAs on Si or Ge is still a challenge because of the lattice mismatch and polar on non-polar issues.[4]Additionally, the presence of interface and surface states can also deteriorate the photodetector device performance. Thus, in this work, the effect of these states on GaAs based structures are investigated via surface photovoltage spectroscopy (SPS) for the detector development. SPS is a simple contactless and non-destructive technique to probe the absorption spectra associated with the sample.[5]

EXPERIMENTAL DETAILS

The structures used in this work are, heavily doped n^+GaAs substrate (S1), lightly doped n type GaAs layer grown on n^+GaAs substrate (S2) and p-i-n based GaAs structure (S3). The n^+GaAs substrate (S1) grown by vertical gradient freeze (VGF) method is procured commercially, while sample S2 and S3 are grown by MOVPE. In MOVPE, the growth is performed at temperature of 670 °C and pressure of 50 mbar. V/III ratios are maintained at ~ 100 and the precursors used for IIIrd and Vth group elements are tri-methylgallium and arsine respectively. Silane and dimethylzinc are used for n and p type doping respectively. SPS measurements are performed in these samples using quartz tungsten halogen lamp as an incident excitation sourceand lock-in amplifier at different chopping frequencies. Subsequently, these structures are fabricated for detector device development using several processing steps, including pattering by mask, contact formation (Ohmic or Schottky) by vacuum coating unit, wire and die bonding etc. The spectral photoresponse of the fabricated detectors are measured under photoconductive mode at room temperature. The current-voltage experiments are performed to measure the output current under dark and illumination conditions. Further, the responsivity of the developed detector devices is evaluated from by varying the incident excitation power of 690 nm laser.

RESULTS & DISCUSSIONS

Figure 1 (a) shows the surface photovoltage (SPV) spectra of n^+GaAs substrate (S1) as a function of incident light wavelength at different chopping frequencies. In all three SPV spectra, the signal drops down at a wavelength of ~ 870 nm, which is referred to the band edge of GaAs. However, the sub-band gap features at higher wavelength (particularly at ~ 914 and 941 nm) show the strong contribution of surface and bulk defect states. The response time of these states are generally slow which therefore decreases the SPV signal with an increase in chopping frequency. The detector performance is highly affected by these processes. Therefore, the impact of surface and interface states on GaAs are further investigated for n-n^+GaAs(S2) and p-i-n GaAs (S3).

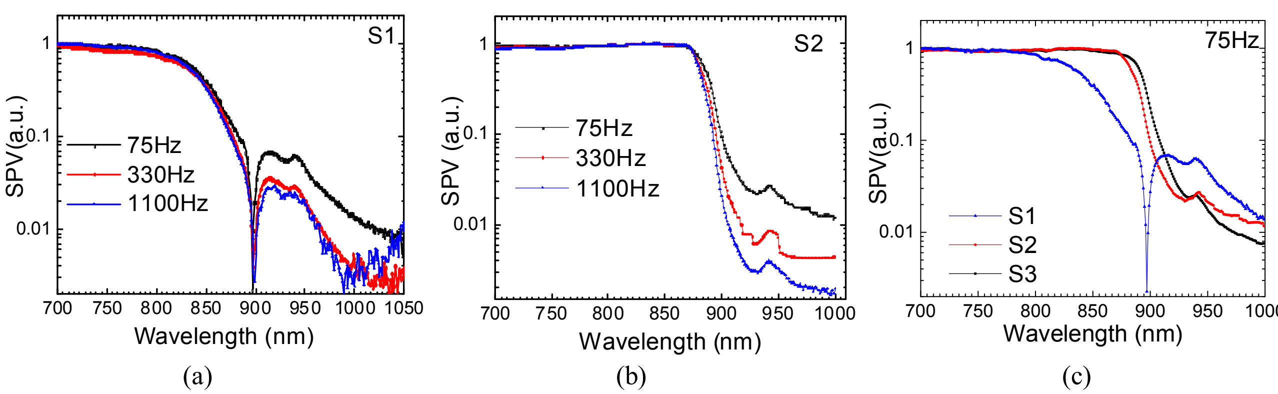


FIGURE 1. *SPV spectra as a function of incident wavelength of (a) n^+GaAs (b) n-n^+GaAs at different chopping frequencies and (c) SPV spectra of n^+GaAs, n-n^+GaAs and p-i-n GaAs at 75 Hz.*

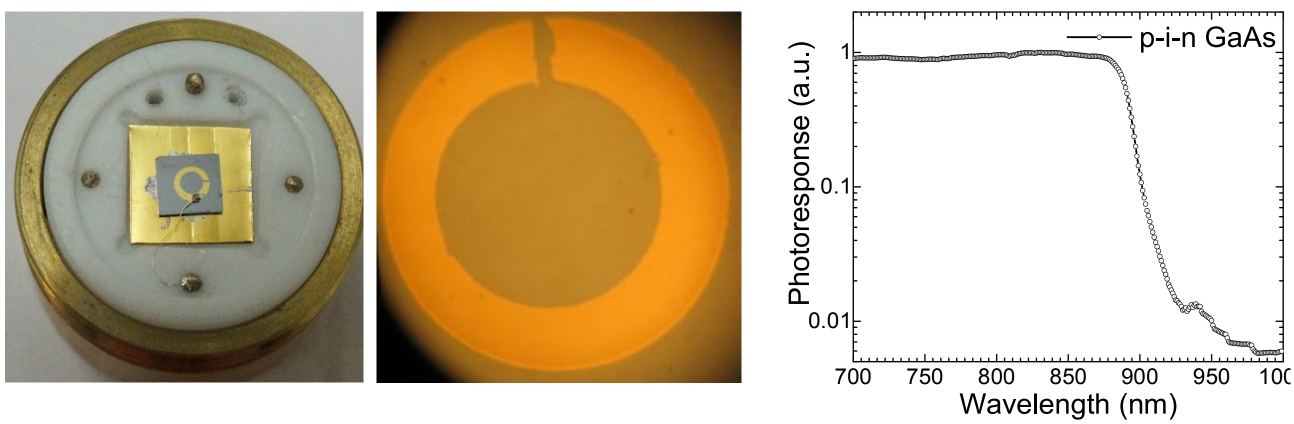
Figure 1 (b) shows the SPV spectra of n-n^+GaAs(S2) with varying chopping frequency. Here also, the SPV features related to the sub band gap are reduced with the increase in chopping frequency as previously observed in Fig. 1 (a). However, the magnitude of the sub band gap signal relative to the above band gap is significantly decreased in S2 as compared to S1. SPV peak at ~ 914 nm, which generally attributed to the bulk defect state of impurity in GaAs substrate, is substantially diminished in S2.[6-8] In addition to this, the SPV peak at ~ 941 nm which may be related to the dopant and surface states of GaAs is also reduced. It infers that thelightly doped n type GaAs layer grown on n^+GaAs substrate by MOVPE passivates these states effectively. Thereafter, the SPV measurements are also carried out on p-i-n GaAs (S3) for further investigations.

Figure 1 (c) shows the SPV spectra for all three samples at low frequency of ~ 75 Hz, where the influence of surface and interface states are highly pronounced. The band edge feature in SPV signal for S1 drops down significantly compared to S2 and S3 due to the high contribution of surface and interface states. It clearly evidences the better suitability of n-n^+GaAs and p-i-n GaAs structure for detector application. It is observed that the homo-epitaxial MOVPE growth of GaAs with different dopants improve the inter-band performance via reducing the surface and interface states. It is therefore, n-n^+GaAs (S2) and p-i-n GaAs (S3) are chosen for the fabrication of detector development.

DEVELOPMENT OF PHOTODETECTOR & ITS CHARACTERISTICS

Figure 2 (a) shows the photograph of the fabricated p-i-n photodetector. The device possessing involve various steps such as initially the samples are cleaned with trichloroethylene-acetone-methanol for 1 minute each to remove grease or oil contamination on the top of the surface. Thereafter, the Ohmic contact is formed at the back side of all the samples S1, S2, S3 using multilayer coatings of Au-Ge/Ni/Au. These metals are deposited by thermal evaporation under the vacuum of ~ 5×10^{-6} mbar. TopmostSchottky or Ohmic contacts are formed using metal mask of ring geometry configuration as shown in Fig. 2 (b). Further, the die bonding is performed using a silver paste to the gold coated copper plate. Subsequently, the wire bonding is performed for external connections on the gold coated copper plate and topmost contact using a gold wire (~25 µm).

The spectral response of the developed p-i-n GaAs photodetector is shown in fig. 2 (c). It depicts the usability of the developed photodetector effectively in the wide spectral range up to 900 nm. Above which the spectral response is limited due to the inherent band gap of GaAs. Further, the current-voltage (I-V) measurements are also performed on the fabricated p-i-n GaAs photodetector. I-V characteristics in absence of light (referred as dark) and in presence of 690 nm laser with varying incident power is also recorded. A low value of dark current (I_d) ~ 0.5 nA is obtained from the indigenously developed p-i-n GaAs detector. Additionally, the responsivity of the developed p-i-n GaAs photodetector is evaluated as ~ 0.36 A/W,which is higher than that obtained from n-n^+GaAs photodetector (~0.03 A/W) for the same active area of the device. The high responsivity with low dark current of p-i-n GaAs photodetector qualifies its better device performance.



(a) (b) (c)

FIGURE 2.*(a) Photograph of fabricated p-i-n GaAs detector and its (b) optical-microscope image. Spectral photoresponseof the fabricated p-i-n GaAs detector is shown in (c).*

CONCLUSION

Surface photovoltage measurements are performed to observe the role of surface and interface states in GaAs based structures i.e., n^+GaAs, n-n^+GaAs and p-i-n GaAs. The spectral response of the fabricated photodetectors is measured at room temperature, where the responsivity of n-n^+GaAs and p-i-n GaAs photodetector are obtained as 0.03 A/W and 0.36 A/W respectively. Furthermore, a low dark current ~ 0.5 nA is also observed in p-i-n GaAs photodetector. Thus high responsivity with low dark current of p-i-n GaAs photodetector confirms its better suitability for numerous applications. This study is beneficial for the devices based on III-V semiconductors on Si or Ge platforms where the surface and interface states play a significant role in device performance.

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