Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 186-187

A-5-4

Analysis of AlGaAs/GaAs Heterojunction Photodetector with a Two-Dimensional Channel Modulated by Gate Voltage

Hongjoo Song and Hoon Kim

NANO scale quantum devices Research Center, Korea Electronics Technology Institute, # 455-6 MaSan-Ri, JinWi-Myon, PyungTaek-Si, KyungGi-Do 451-865, South Korea

Phone: +82-31-610-4383 Fax: +82-31-610-4383 E-mail:shj4011@keti.re.kr

1. Introduction

The high electron mobility transistors (HEMTs) have been utilized in a relatively wide application for high speed digital and microwave circuits due to their high frequency low noise and high power amplification performance[1,2]. With their high abilities for electronic devices, HEMTs have been researched as a photodetector[3,4].

In this paper, we discuss the interesting photodetective mechanism, subsequently report the high-responsive properties and a effect of gate voltage on responsivity of n-AlGaAs/GaAs HEMTs. Here, we present that the responsivity of about 2700A/W is shown at 0.27nW (λ=740nm) low optical power level and a gate is effectively modulated for high sensitive photodetector in illumination. The whole contents are summarized as follows. First, the relationship between photocurrent (I_{ph}) and optical power (P_{opt}) is identified by measuring the dc I-V under relatively low optical powers. This shows that the photocurrent has nonlinear dependence on optical power. Next, we present that the responsivity (I_{ph}/P_{opt}) is very high at low power levels, but is decreased greatly as the optical power increases. Finally, an effect of gate voltage (V_{GS}) on responsivity (I_{ph}/P_{opt}) is focused. A gate voltage controls responsivity as well as a dark current and is optimized for high sensitive photodetector.

2. Experiment

A epi-structure was first grown by molecular beam epitaxy (MBE) by depositing it onto a (001) semi-insulating GaAs substrate, successively a 600-nm-thick undoped GaAs buffer layer, a 30nm-thick undoped $Al_{0.27}Ga_{0.73}As$ spacer layer, a 40nm- thick Si-doped n-$Al_{0.27}Ga_{0.73}As$ layer ($N_{si}=1\times10^{18}$) and a 10nm-thick n-GaAs cap layer. A ohmic metal Ni/Au/Ge/Ni/Au was deposited by e-beam evaporator and annealed by rapid thermal annealing (RTA) at 450℃ for 20 seconds after N_2 purge for 10 minutes. A mesa structure was formed by optical lithography and wet chemical etching using $H_3PO_4 : H_2O_2 : H_2O = 1 : 2 : 20$ solution. A typical etching rate at room temperature was 300nm/min. Before defining the gate, n-doped GaAs cap layer was removed by wet etchant including the citric acid monohydrate. A citric acid solution was prepared by 10g $C_6H_8O_7$: 10mL H_2O. A etching solution was consisted of citric acid solution: H_2O_2: H_2O =3:1:40. A typical etching rate at 20℃ was 100Å/min. The length and width of active channel, as detector area, is 100um and 100um, respectively. The Ti/Pt/Au gate was defined with length 5um between ohmic electrodes. The schematic cross-section is shown in Fig.1(a).

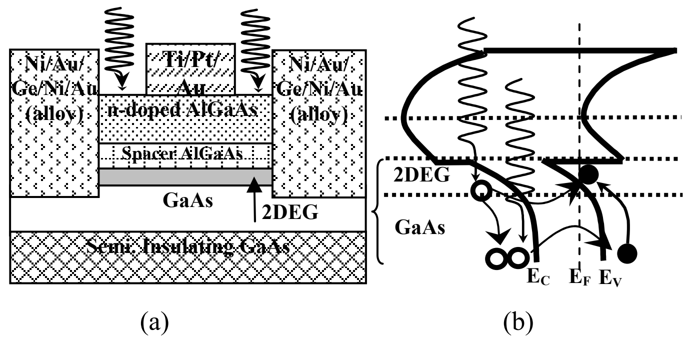

Fig.1 (a) The schematic cross-section of HEMT Photodetector
(b) Vertical energy band diagram

3. Results and Discussion

The dc I-V characteristics were measured under the various optical powers and gate voltages. Since the wavelength of light source is 740nm, light is transmitted into the $Al_{0.27}Ga_{0.73}As$ layer (λ_c ~ 680nm) and mostly absorbed in the GaAs layer (λ_c ~ 870nm). Fig.1(b) shows the vertical band diagram of device. Due to the built-in electric field in the vicinity of AlGaAs/GaAs interface, the photogenerated electrons sweep toward two dimensional electron gas (2DEG) while holes move into the GaAs buffer. The separated holes have a long lifetime and are accumulated in GaAs neutral region. The accumulated holes deduce the electron injection from the external circuit through the electrodes in order to satisfy the neutral conditions. This process gives rise to the high responsivity (I_{ph}/P_{opt}) as well as photovoltage (V_{ph}); that is, the photocurrent is expressed by the following equations.

$$I_{ph}= \Delta I_{DS}= I_{ill} - I_{dark} = g_m V_{ph} =(g_m/q)\Delta E_f \quad (1)$$

$$\partial I_{DS}/\partial N_s = (g_m/q)(\partial E_f/\partial N_s) \quad (2)$$

The drain current as the function of optical power is depicted in Fig.2. First, there is a large dark current due to the ohmic contacts and doping. As be expected, the negative gate voltages restrict the photocurrent as well as the dark current. It is noted that the variation of photocurrent is large at low power levels, and decreases as optical powers increase. The variation of photocurrent for light power (or photon flux) results from the dependence of

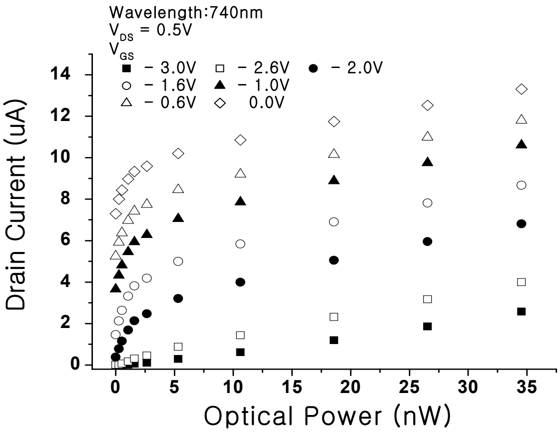

Fig.2 Drain current vs. Optical power at drain voltage (V_{DS}) 0.5V under the various gate voltages.

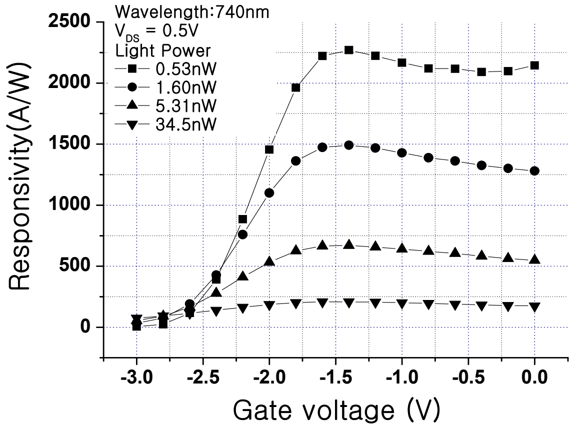

Fig.4 Responsivity vs. Gate voltage at drain voltage (V_{DS}) 0.5V under the various optical powers

the Fermi-energy shift (ΔE_f) on the carrier concentration (N_s) in 2DEG layer as estimated from eq. (2).

The responsivity (I_{ph}/P_{opt}) as a function of the optical power (P_{opt}) is shown in Fig.3. The data indicate that the responsivity, when gate voltage is 0V, decreases exponentially as optical power increases. As shortly mentioned above, it results from that the $\partial E_f / \partial N_s$ is reduced greatly as an optical power increases. The data, also, show that the photodetector has a high responsivity, about 2700A/W at 0.27nW, at low optical power levels. The high responsivity means that the photocurrent is dominantly contributed by photovoltage, not the number of directly photogenerated electrons. However, it is shown that the responsivity is greatly decreased at high negative gate voltages. At high negative gate voltages, the photocurrent is suppressed because the photogenerated electrons are depleted from the 2DEG, but holes are transferred into the 2DEG.

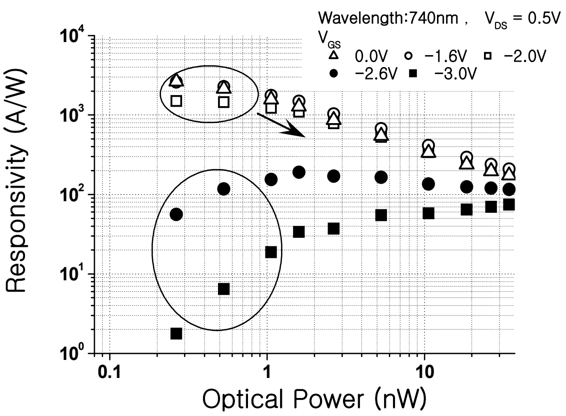

Fig.3 Responsivity vs. Optical power at drain voltage (V_{DS}) 0.5V under the various gate voltgage

To identify the effect of gate voltage on responsivity in detail, the responsivity as a function of gate voltage is shown in Fig.4. As a gate voltage becomes more negative, the responsiivity drops remarkably due to the depletion of 2DEG. However, it is emphasized that the responsivity increases greatly as the gate voltage is going from 3V to 0V and it reaches the maximum value at a specific gate voltage. These results present that under illumination the gate voltage is optimized for a maximum transconductance (g_m) as well as an optical responsivity.

4. Conclusions

We showed that the characteristics from HEMT under illumination were interpreted by a photodetection mechanism. The nonlinear dependence of responsivity on the optical power was shown and the high responsivity was obtained for low power levels. The dependence of responsivity on a gate voltage presented that a gate could reduces the dark current as well as modulates optical responsivity.

Acknowledgment

This work is mostly supported by an Electro-0580 from the Ministry of Commerce, Industry and Energy, Information and Communication, Korea.

Reference

[1] L.Johnstn, et al., IEDM Techn.Digest, (1986), p.252

[2] B.J. Van Zeghbrock, et al., IEDM Techn. Digest, (1986), p.832

[3] Nabet, B.; Romero, M.A.; Cola, A.; Quaranta, F.; Cesarco, M: Microwave and Optoelectronics Conference, 2001. IMOC 2001. Proceedings of the 2001 SBMO/IEEE MTT-S International, 1, 57, (2001)

[4] Nabet, B.; Quaranta, F.; Cola, A.;, IEEE Microwave Magazine , 2 , 40, (2001)