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Photo-induced Conductivity Transient in n-type β-$(Al_{0.16}Ga_{0.84})_2O_3$ and β-Ga_2O_3

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Abstract

Photo-induced conductivity transient in unintentionally doped (UID) β-Ga_2O_3 and n-type β-$(Al_{0.16}Ga_{0.84})_2O_3$ layers are investigated for sub-bandgap light excitation ranging from 400 nm to 1000 nm (1.24 eV to 3.1 eV). The illumination of the sample with a sub-bandgap light induce an enhancement of the conductance which still prevailed after turning off the light and, then, slowly exhausted. Thus, a persistent photoconductivity is reported for β-Ga_2O_3 materials. The measured photoconductivity well agrees with a theoretical model that allows to estimate the optical cross-sections of the related deep levels. For a light excitation between 480 nm and 640 nm, it has been found that the photoconductivity is originated from two distinct trap levels. Moreover, the spectral dependence of the traps' optical cross-section is reported.

1. Introduction

Beta gallium oxide (β-Ga_2O_3) is one of the most attractive ultra-wide bandgap semiconductors for high-frequency and high-power applications because of its outstanding intrinsic properties such as a high electric breakdown field of about 8 MV/cm and the availability of large size substrates [1]. The recent progress in the growth of Aluminium doped β-Ga_2O_3 (β-$(Al_xGa_{1-x})_2O_3$) allowed the achievement of modulation-doped β-Ga_2O_3 FETs (MODFETs) [2,3] based on the two-dimensional electron gas (2DEG) at β-$(AlGa)_2O_3$/β-Ga_2O_3 (010) heterojunction [2]. This breakthrough opens the way to the implementation of high electron mobility β-Ga_2O_3 transistors. However much remains to be understood such as the effects of deep levels in β-$(AlGa)_2O_3$ and β-Ga_2O_3 on the electrical properties of MODFETs.

In this work, deep levels in β-$(AlGa)_2O_3$ and β-Ga_2O_3 were investigated by photocurrent spectroscopy using sub-bandgap light excitation (1.24 eV to 3.1 eV). The light-induced electrical current transients were measured for β-$(AlGa)_2O_3$/β-Ga_2O_3 stack and β-Ga_2O_3 layers at different photon energy, and the conductivity transients were calculated. Photo-induced conductivity transients were persistent. The origin of this phenomena was discussed.

2. Experiment

<u>Sample description:</u> Sn-doped β-$(AlGa)_2O_3$ and unintentional-doped (UID) β-Ga_2O_3 layers were grown by plasma-assisted molecular beam epitaxy (PAMBE) [5] on the Fe-doped semi-insulating β-Ga_2O_3 (010) commercial substrate. The detailed growth conditions are reported in Ref. [3]. The Al composition x in the β-$(Al_xGa1\text{-}x)_2O_3$ layer was 0.16. The thickness of the UID β-Ga_2O_3 and β-$(Al_{0.16}Ga_{0.84})_2O_3$ layers were 200 nm and 20 nm, respectively. The device structure is shown in Fig. 1. Mesa structures were fabricated by chlorine-based inductively coupled plasma-reactive ion etching (ICP-RIE) using a Nickel mask deposited by electron-beam (EB) evaporation.Titanium, Platinum and Gold (Ti/Pt/Au) metallic stack was deposited by EB evaporation, followed by annealing at 375°C for 20 min in a nitrogen ambient to achieve ohmic contacts.

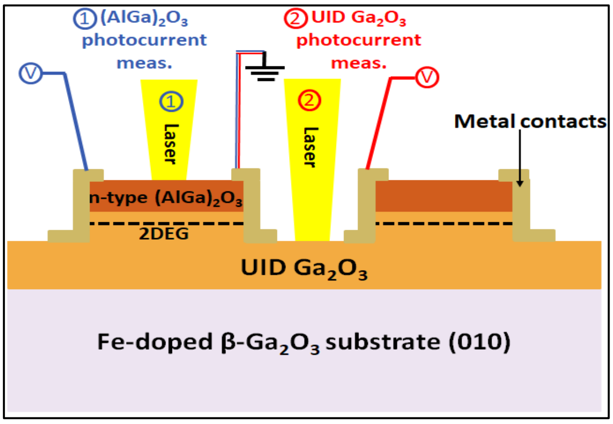

Fig. 1 Schematic cross section of the sample under investigation.

<u>Photocurrent measurement:</u> the photocurrent was measured using a homemade experimental setup based on the Keithley SMU 2635b electrical measurements unit, a supercontinuum laser and a SOLAR TII monochromator (wavelength range: 400 nm to 1000 nm). The photo-induced current transient was measured for the UID Ga_2O_3 and β-$(Al_{0.16}Ga_{0.84})_2O_3$ layers. The effect of the light excitation duration on the current transient was investigated using the wavelength ranging from 400 nm to 1000 nm for excitation. From the measured current, the conductance transient of the device was calculated.

3. Results and discussion

Figure 2 shows the typical photo-induced conductance transient of the UID Ga_2O_3 and β-$(Al_{0.16}Ga_{0.84})_2O_3$ layers (600 nm light excitation). The illumination of the sample with a sub-bandgap light of 2 eV for 6 seconds induced an enhancement of the conductance (laser ON). After turning off the laser, the conductance enhancement still prevailed and slowly exhausted (see decay transient on Fig. 2). Thus, the measured photoconductivity was persistent as high-lighted on Fig. 2 (b).

The build-up of conductance can be approximated by an exponential law [4]:

$$G(t) = G_d + G_l(t) \text{ with } G_l(t) = G_0(1 - e^{-t/\tau_i}), \quad (1)$$

Where G_d is the dark conductance, $G_l(t)$ a time dependent light induced conductance, τ_i the characteristic time constant for the build-up and G_0 a prefactor. Both G_0 and τ_i depend on the photon flux incident on the sample and the carrier recapture rate [6]. The time constant τ_i also exhibits a spectral dependence through the absorption cross-section σ_{opt} since

$$\tau_i \propto 1/(\sigma_{opt}\phi) \quad (2)$$

Where ϕ corresponds to the photon flux.

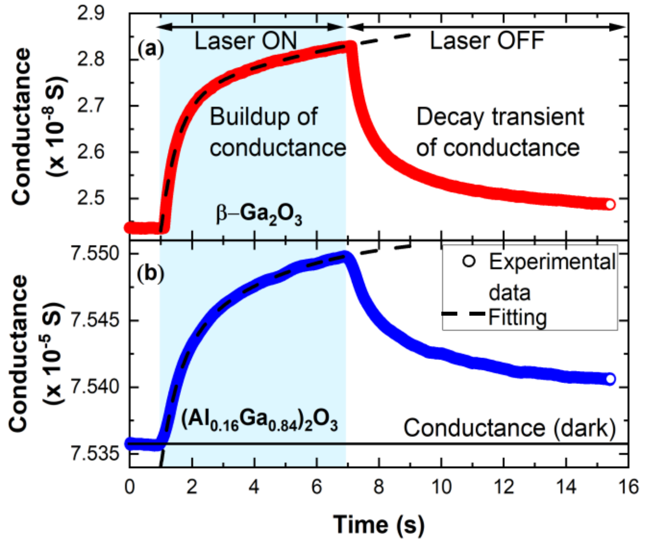

Fig. 2 Build-up and decay transients of conductance under 600 nm light excitation of: (a) the UID Ga_2O_3, (b) β-$(Al_{0.16}Ga_{0.84})_2O_3$.

In this work, the build-up of photoconductance was in a good agreement with the model (equation 1) reported in Ref. [4] (see Fit on Fig. 2). Indeed, the measured photoconductance build-up (for UID Ga_2O_3 and β-$(Al_{0.16}Ga_{0.84})_2O_3$) could be fitted by assuming a $G_l(t)$ defined as followed:

$$G_l(t) = G_1\left(1 - e^{-1/\tau_{i1}}\right) + G_2\left(1 - e^{-1/\tau_{i2}}\right) \quad (3)$$

The time-dependent light-induced conductance included two exponential parts with different time constants. According to the definition of the time constant (see equation 2), τ_{i1} and τ_{i2} were ascribed to two distinct optical cross-sections and, thus, to two distinct trap levels. τ_{i1} and τ_{i2} have been measured for different laser excitations ranging from 480 nm to 640 nm (6 seconds of light excitation). The dependence of the photon flux on wavelength was considered and the relative optical cross-section was calculated. Figure 3 shows the relative optical cross-section σ_{opt} as a function of the photon energy. The σ_{opt}, calculated using the photoconductance build-up measured for the UID Ga_2O_3 and β-$(Al_{0.16}Ga_{0.84})_2O_3$/β-$Ga_2O_3$ stack, were identic (see Fig. 3). That suggests similar origin of the photoconductance. The trap levels related to the calculated σ_{opt} were possibility caused by persistent photoconductivity.

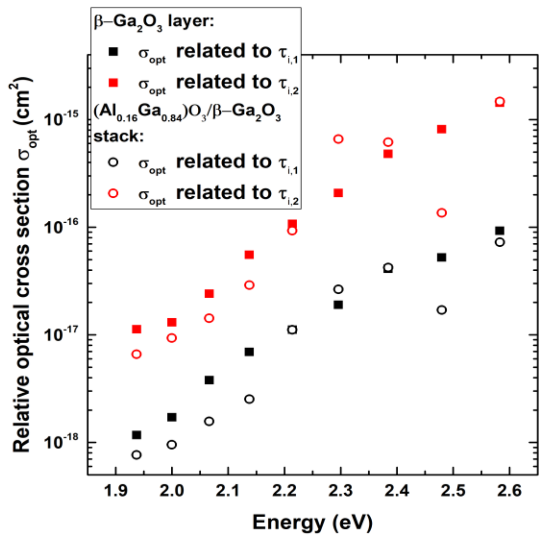

Fig. 3 Relative optical cross section as a function of the photon energy. The relative optical absorption cross section decreases with photon energy.

In this talk, the effect of the light excitation duration on the photo-induced conductivity transient will be examined. An analytical model of the decay transient of the conductance will be introduced and discussed. The origin of the deep levels inducing the persistent photoconductivity will be considered.

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