Effect of InGaAs surface states and interfaces on the photo-generated THz pulse shape

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Abstract — **We present some 3D modeling of the physical behavior of a 1.55 µm Photoconductive Switch (PCS). The first one compares PCS with Ohmic contact versus devices with schottky contact. The results are very close. The second study stress on the incidence of the Fermi-level pinning at the surface of the InGaAs layer on the amplitude of the THz pulse. Also, we present the results of an interdigited Photoconductive Switch (IPS) modeling.**

I. Introduction And Background

Recent years have seen a growing interest for the use of terahertz (THz) technology for a number of application domains such as astronomy, medical imaging, spectroscopy and homeland security. For instance, the InGaAs photoconductive switches (PCS) may be controlled at longer wavelengths that coincide with the transmission bands of the telecommunication industry (1.55 µm). This article presents some PCS modelings when considering in one hand the Schottky contact effect versus the ohmic contact on the THz pulse and in the other hand the role played by the Fermi-level pinning at the InGaAs surface. It also describes the shape of the pulse generated from the interdigited design of the PS gap.

The reference modeled device structure consists of 2 µm length gap insert in the center conductor of a coplanar waveguide. The active layer (gap) is a 0.3 µm depth $In_{0.53}Ga_{0.47}As$ layer. The CPW is a 10 µm broad center metallic strip with two infinite ground planes on either side. The 6.6 µm spacings between the central strip and the ground planes result in 50 Ω characteristic impedance at low frequency (1GHz). A 2.5 V bias is applied between the ohmic contacts located on CPW central band. The InP substrate, transparent for telecommunication wavelength (1.55 µm) has a 76 µm thickness with a 12.5 relative dielectric constant (PS figure 1 to insert).

Two other designs of the PCS are modeled. The fist one is the same than the reference structure but with different dimensions (12 µm for the length of the gap and 3 µm between the central strip and the ground planes). In the second PCS, only the simple gap of the previous structure is replaced with an interdigited one. The dimensions are reported in the figure 2.

To simulate all these structures, we use an upgraded version of an IEF-made code described in [1]. This code solves the Maxwell's equations coupled with drift-diffusion equations using the three-dimensional finite difference time domain (FDTD) method with non constant mesh sizes. The PCS simulation starts with initial states for the static field and the carrier distributions.

II. Results

On the one hand, two studies are presented in this section concerning the reference structure of the PCS. The first one concerns the nature of the metal-semiconductor contact. When using the Schottky contacts instead of the ohmic contacts a normal static electric field exist at the metal-InGaAs interfaces. Consequently, the initial distributions of electric field and carrier concentration vary but not so to modify the electric pulse shape. As explained in [1] the THz voltage pulse depends on the value of the static electric field. Concerning the metal-semiconductor contact only the maximum amplitude increases by 0.01 V.

The second study deals with the incidence of the Fermi level pinning at the InGaAs surface. This pinning is due to electronic states within the energy band gap. This phenomenon is included into the modeling by adding a static electric field component (E_{Sz}) normal to the interface to the whole static field at the initial state in the very thin InGaAs layer. E_{Sz} is calculated within bi-dimensional simulations of the InGaAs layer including surface state concentration. Three simulations are done while varying the residual InGaAs layer doping. The Doping levels of interest are 10^{14}, 10^{15} and 10^{16} cm^{-3} leading to 0.5, 2 and 9 kV/cm for E_{Sz} while the $In_{0.53}Ga_{0.47}As$ surface potential barrier is 0.21 eV [2]. Figure 3 shows the THz pulse at 20 µm from the optical excitation for two different values of concentrations. The voltage pulse presented in figure 3 is obtained following the integration path ($\vec{T}$) drawn in figure 1 between the central strip and the ground planes. It is noted that the shape of all the responses are the same as the one without surface state consideration. However, the maximum peak increases by 0.03 V for the maximum concentration. These small dependences with E_{Sz} are, because the electric component following the propagating direction (Ox) controls, in a large extend, the THz pulse shape.

On the other hand, we present the influence of the gap topology over the generated electric pulse shape. Figure 4 shows the THz pulse generated at the edge of the gap by the simple PCS and the interdigited PCS (IPCS). Two main results are noted. The first one is that the electric pulse peak is twice greater for the interdigited structure even if the PCSs are polarized with the same voltage (2.5 V) and illuminated with the same laser. This result can be explained by the fact that the electric field generated by the polarization is bigger for the IPCS because the smallest space between the contacts is equal to 2 µm. The second result is that the FWHM (full width at half maximum) is more broaden for the IPCS. In fact, its value is equal to 0.6 ps for the simple PCS and 1.05 ps for the IPCS. This is due to the carrier generation and recombination. The illuminated volume is not the same over the two gap structures. There is no generation of the carriers in the volume under the fingers of the interdigited gap.

New functionalities of the 3D software are developed such as the capability to include complex permittivity. So, the properties of the electrons in metals are taken into account by using Drude model with the aid of the recursive accumulator [3]. The choice of this model is driven by the fact that is

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considered as an excellent fit to the measured reflectance of large metals in the 3-30 µm wavelength [4]. This model is validated through microstrip line simulations. The metal used is gold. The Drude model parameters are obtained from [4] and the simulation results (not presented in this paper) show a perfect coincidence with the ones obtained by using the conductivity parameter (4.1e7 $Ohm^{-1}m^{-1}$) in time domain.

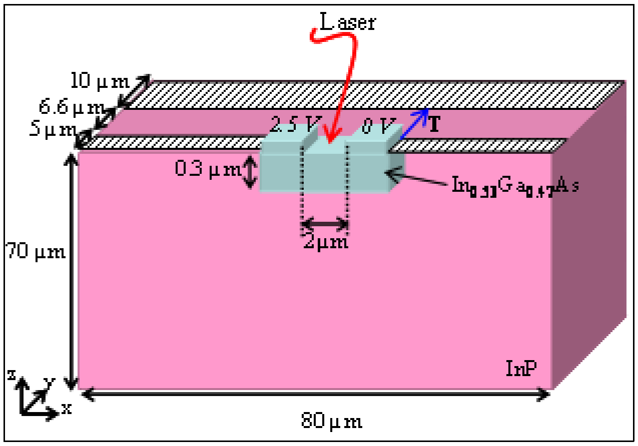

Figure 1: Cross-section of the modeled reference PCS

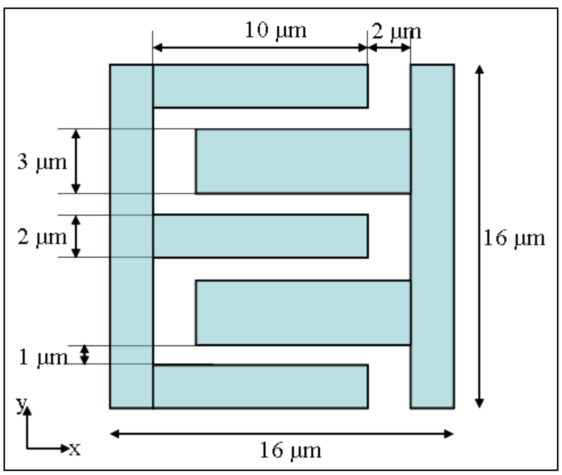

Figure 2: Structure of the modeled Interdigited PCS

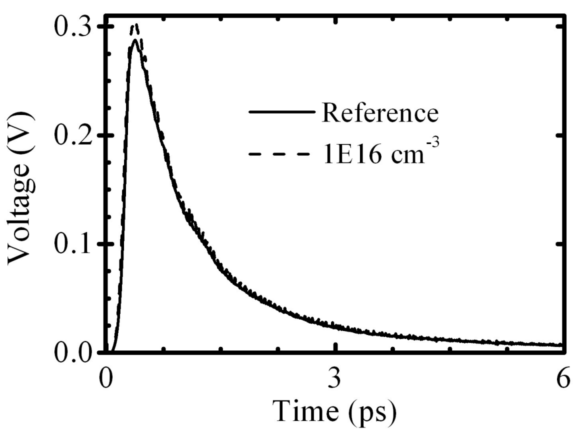

Figure 3: PCS output voltage at 20 µm from the laser excitation for reference case and $10^{16}cm^{-3}$concentration value

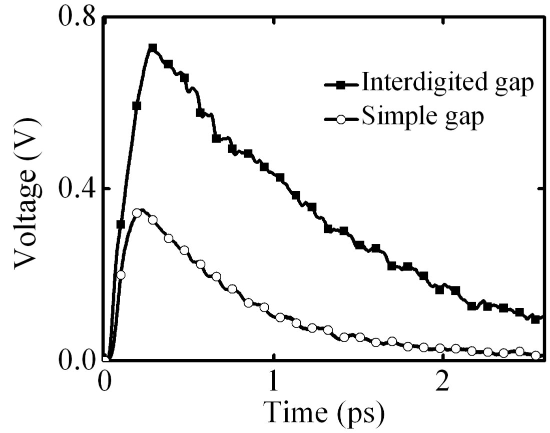

Figure 4: Output voltage at the edge of the gap for the two designs of the PCS: the interdigited PCS and the simple PCS

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