Surface and localized Plasmons Polaritons on arrays of doped and undoped semiconductors

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BIOGRAPHY
Thierry Taliercio: was born in Aix en Provence (France) in 1970. Married and three children. He received the HDR (Habilitation à Diriger les Recherches) diploma in solid state physics in 2003 from the University of Montpellier. He is an associate professor in the Institut d’Electronique du Sud since 2008 (NANOMIR group). From 1999 to 2007, he was associate professor in the Groupe d’Etude des Semiconducteurs (GES in Montpellier-France). He is a specialist of the optical properties of nitride semiconductors and particularly of semiconductor nano-structures: small (GaNAs) and wide (InGaN, GaN, AlN) band gap nitride semiconductors. He developed several experimental techniques to measure carriers decay times in semiconductor nano-structures in the infra-red as well as in the UV range within the frame of the ACI project BAND (2003-2006). He developed a micro-photoluminescence experiment in the UV range to study the optical properties of a single GaN/AlN quantum dot, supported by the ACI project BUGATI (2003-2006) and the ANR ZOOM. He developed several simulation tools to model the optical properties of semiconductor based nanostructures. He is now working on photo-voltage spectroscopy to characterize the density of states of mid-infra-red laser and an angular resolved reflectance and transmittance experiment in the IR range (1-20 µm) to study IR photonic and plasmonic nanostructures. Doctor Thierry Taliercio is author/co-author of 76 publications in refereed journals including 42 communications in international conferences and two book chapters. Its articles are quoted 1136 times and its impact factor is of 19.

TECHNICAL ABSTRACT
Surface plasmon polaritons (SPP) are excitations propagating at the interface between a dielectric and a conductor, arising from the coupling of the electromagnetic field and collective excitations of free electrons in the conductor. Many studies are based on metal nanostructures exploiting SPPs resonances from visible to mid-infrared frequencies. We focus our work on doped semiconductors. In contrast to metals, they offer the unique opportunity to adjust the plasma frequency by changing the doping. We recently proposed a theoretical model which describes the optical properties of an InAsSb/GaSb periodical nanostructure in a large range of frequency. The optical properties of these arrays are indeed strongly dependent on the geometry and on the dielectric constant of both materials. In this work, we validate experimentally the existence of SPP resonances in InAsSb and InAsSb/GaSb arrays and study the impact of several parameters.

The samples consist of a 50 nm lattice-matched InAsSb (silicon doped at 10²⁰ cm⁻³) layer grown atop a GaSb substrate by Molecular Beam Epitaxy (MBE). InAsSb arrays are realized by associating holography with positive photore sist and chemical etching with citric acid: hydrogen peroxide (2:1). We obtain with this process an InAsSb grating with a periodicity of 510 nm. Chemical etching has the advantage of changing InAsSb width (or the ratio between InAsSb and GaSb) simply by increasing the etching time. To fabricate the InAsSb/ GaSb grating, we performed an epitaxial regrowth (by MBE) of a 500 nm GaSb layer on InAsSb grating (cf. inset of the figure 1).

Samples were investigated by reflectance measurements in normal incidence in the infrared range. Figure 1 shows reflectance spectra of InAsSb arrays (red lines), of InAsSb/ GaSb arrays (dark lines) and of a layer of InAsSb capped by a GaSb layer (blue line). We performed experiments in both Transverse Electric (TE, dashed lines) and Transverse Magnetic (TM, continuous lines) polarizations to evidence the effect on SPPs resonances. Indeed, the arrays can be seen as a metal in TE polarization whereas it can be seen as an ionic crystal in TM polarization where the oscillator is the SPP resonance. In other words, only the TM polarization (solid lines) exhibits SPP resonances. We can clearly see that the InAsSb arrays exhibit a resonance at 11.5 µm in TM polarization whereas nothing appears in TE polarization. The encapsulation of the InAsSb grating into GaSb leads to a huge red shift of the resonance from 12 µm to 15 µm. The effect
is due to the modification of the refractive index in between the InAsSb lines. It is well explained by previous theoretical work. In the short wavelengths range (between 3 and 6 µm) we can see oscillations due to interferences effect between different layers. If no grating is engraved in the InAsSb layer before the epitaxy of the GaSb, no plasmonic resonance in TM and TE polarization (blue curve) is observed. SPP cannot be excited.

**Figure 1:** Reflectance spectra for uncovered grating of InAsSb (red solid line) and InAsSb/GaSb (black solid line) arrays in TM polarization. Reflectance spectra in TE polarization are in dashed lines. Reflectance of un-etched InAsSb/GaSb is presented in blue solid line. TM and TE polarization are the same. Inset shows the Scanning Electron Microscope (SEM) image with InAsSb grating and GaSb layer regrowth by MBE.

These measurements demonstrate the interest of a nanostructured surface based on semiconductors materials. It is possible to define some key applications include on-chip optoelectronics such as chemical and biological sensing in the IR range, signal processing (filtering), and interconnection. The optical properties of the structure can be adjusted by modifying the geometry, the type of material or by controlling the doping level. The comparison of these experimental results with the analytic model and numerical simulation by finite difference time domain (FDTD) method allow understanding the underlying physics and validating the interest of surface plasmon polariton in doped semiconductor.

REFERENCES
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