Localized Surface Plasmons Resonances on GaSb-based materials for Infrared applications

Vilianne Ntsame Guilengui, Laurent Cerutti, Jean-Baptiste Rodriguez, Eric Tournié and Thierry Taliercio

Institut d'Electronique du Sud, CNRS-INSIS-UMR 5214, Université Montpellier 2,
34095 MONTPELLIER cedex 05, France
ntsame@ies.univ-montp2.fr

Abstract
We propose to realize and to study an all-semiconductor plasmonic structure based on GaSb materials. Composed of a highly-doped InAsSb sub-wavelength arrays lattice-matched to a GaSb substrate, it supports Localized Surface Plasmons (LSP). The resonance frequencies can be modulated by adjusting the dielectric function of the surrounding material and by adapting the geometry of the array.

The use of Surface Plasmons Polaritons (SPP), electromagnetic excitations at the metal-dielectric interface, offers the ability to control the light mater coupling which is an exciting topic of research. Traditionally, noble metals like gold are employed for plasmonic devices, to obtain wave-guiding [1], biosensing [2] or metamaterials [3]. However, many studies show the benefit of using semiconductors materials instead of metals, especially in the infrared range [4, 5]. Here, we propose an experimentally study demonstrating that for a highly Si-doped InAsSb layer on GaSb substrate, it is possible to design plasmonic structures which exhibits Localized Surface Plasmons Resonances in the mid-infrared.

The InAsSb layer is 100 nm thick and lattice-matched to the GaSb substrate by adjusting the amount of Sb. Moreover, electrons in InAsSb have a small effective mass and the material can then be easily doped at high value (up to few 10^{20} cm^{-3}) to obtain plasmonic resonances in the mid-infrared [6]. The Si concentration varies from 10^{19} cm^{-3} to 10^{20} cm^{-3} which is confirmed by Secondary Ionization Mass Spectroscopy (SIMS) and Hall effects measurements.

To create the InAsSb array on large areas, a holography insolation is realized using an AZMIR 701 diluted positive photoresist. Then, InAsSb material is etched by chlorine-based Reactive Ion Etching (RIE) with Cl_2, N_2 and Ar [7]. This method provides vertical sidewalls and the conservation of the mask shape and precludes parasitic resonances in the reflectivity spectrum. We thus obtain a grating period of 540nm with a constant ribbon width of 240nm. Some samples were overgrown with a 600 nm-thick GaSb layer in a second epitaxy step. This method planarizes the surface on the grating.
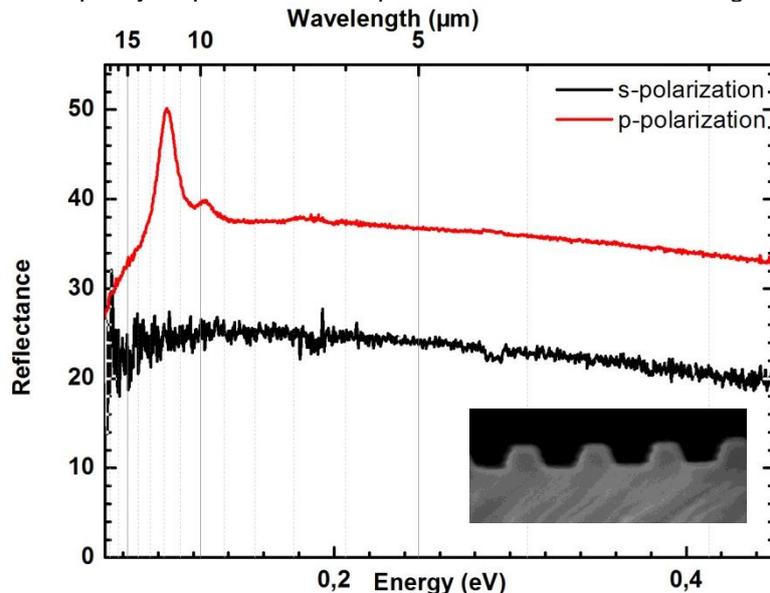

Figure 1: Reflectivity spectra in s (black line) and p (red line) polarizations for a 100nm-thick InAsSb/air grating on Gasb substrate. The inset shows a SEM view of the grating with the following dimensions: p=540 nm and w=240 nm. LPSR are only visible in s polarization.

Reflectance experiments have been performed using a Fourier Transform Infrared (FTIR). Figure 1 present spectra for s and p polarizations (black and red lines respectively) for a 100nm-thck InAsSb array with a period p=540nm and a ribbon width w=240 nm. The inset shows a profile view of the array

obtained by Scanning Electron Microscopy (SEM). As expected, the s-polarized incident light cannot excite surface plasmons, whereas in p-polarization we can see a resonance in the reflectance spectra around 12 µm. The smaller one at 10µm is due to the trapezoidal shape of the array. Both are signatures of the LSP modes at the interface between InAsSb and GaSb material. In fact, these resonances are affected to LSP because of the very small period of the array compared to the wavelength of incident light [8]. This is confirmed by angular resolved reflectance. The wavelengths of the LSP resonances are sensitive to the size and the shape of the grating. They follow a similar behavior than in the case of metallic particles [9].

We also performed reflectivity measurements on an InAsSb array encapsulated by a GaSb layer (black line) and compare it with the spectrum obtained for uncovered InAsSb array. This is reported on figure 2. The main observation is the red-shift of all the resonances observed in InAsSb/air array. It moves from 12 µm for an InAsSb/air system to 14µm for an InAsSb/GaSb system, with an enhancement and a shape modification of the resonance. Since Surface Plasmons are sensitive to changes in their surroundings. Adding GaSb material creates this shift. Interferences at shorter wavelengths are due to the   superposition of layers.
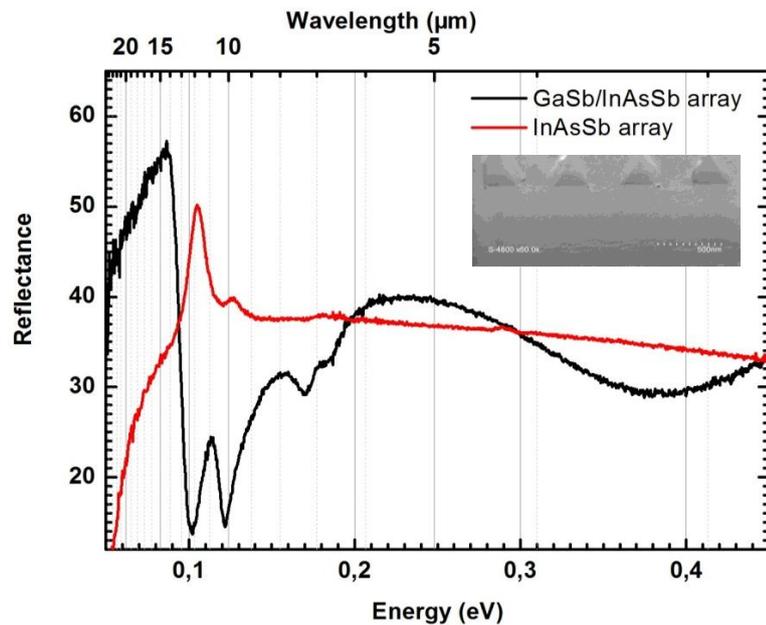

Figure 2: Reflectivity spectra in s polarization for a InAsSb/air grating (red line) and InAsSb/GaSb grating (black line). The SEM image in the inset represents a InAsSb grating with p=540 nm and w= 240 nm. The layer of GaSb is 600 nm-thick. A red shift of LSPR is observed for the encapsulated structure.

This present work is the demonstration of the possibility to elaborate an all-semiconductor plasmonic device operating in the infrared.

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