Semiconductor nanostructures for spectral filtering

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Abstract: We present theoretical and experimental study of nanostructured guided-mode resonant filter, made of a highly doped InAsSb grating and a GaSb waveguide.

In the context of infrared spectral filtering, nanostructured components offer simple filter architectures such as GMR (Guided mode resonance). This architecture consists of a planar waveguide and a grating that couples the incident wave to the guided mode. These structures are generally composed entirely of dielectric materials where quality factors are high and losses are low [1]. In Ref. [2], authors proposed the use of a metallic grating in order to increase the spectral bandwidth, but this leads to losses.

The current trend is to integrate these filters directly at the level of the detection pixel [3] but at the cost of many manufacturing steps and potential incompatibility with the detector materials. We thus propose a GMR filter made of semiconductors in order to guarantee a monolithic integration. We present the numerical and experimental study of component made of InAsSb and GaSb, which are the materials used in particular for superlattice photodetectors epitaxy [4] or in lattice parameter matching. The grating of the GMR filter is made of heavily doped InAsSb, while the waveguide is made of undoped GaSb. In order to demonstrate the filter function, we consider that the GMR is deposited on a GaAs substrate (Figure 1). We define a component geometry operating in the far infrared spectral range (8 µm -14 µm, LWIR), where the highly doped InAsSb behaves as a metal (doping level is $N = 5.5e19\ cm^{-3}$). The GaSb is transparent in the LWIR and we have taken a GaAs substrate because it has a refractive index of 3.27, lower than that of GaSb (3.7), which is essential to guide the wave.

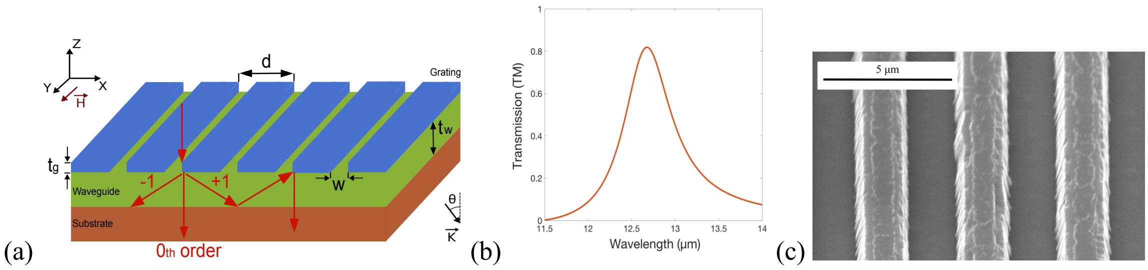

Fig. 1 (a) Guided-mode resonance filter composed of a GaAs (n=3,27) substrate, a waveguide in GaSb (n=3,7) and a grating in InAsSb doped at $5.5e19\ cm^{-3}$. d = 3.9 µm; w = 1.2 µm; t_g = 1.1 µm and t_g = 2.2 µm. (b) Transmission spectra calculated in TM polarization and normal incidence. (c) Scanning electron microscope image of a sample (d=4 µm, w=1.9 µm, t_g =1.26 µm and t_W =2.8 µm).

In the legend of Figure 1(a), we give the opto-geometric parameters of the component. With Figure 1(b), we show a normal incidence transmission spectrum calculation, in transverse magnetic polarization. This theoretical result is obtained using a calculation method RCWA (Rigorous coupled-wave analysis) [5]. We observe a resonant transmission at $\lambda = 12.67$ µm, with a maximum transmission $T_{max} = 81.85\%$. The permittivity of the InAsSb was modeled with a Drude function, where we took into account an effective mass of $0.1273\ m_o$. The high carrier density is at the origin of this high effective mass. We have evaluated it thanks to reflection measurements, performed on an unstructured GaAs - GaSb - n^{++}-InAsSb stack [6].

We developed a fabrication process in IES facilities to realize a sample. It consists of a GaAs substrate where are grown by solid source molecular beam epitaxy a thick layer of totally relaxed GaSb (the waveguide) and a thick layer of n^{++}-$InAs_{0.91}Sb_{0.09}$ lattice matched to GaSb. On n^{++}-InAsSb layer, the grating geometry is defined with contact photolithography and it is then etched with reactive ion etching (RIE) process. Figure 1(c) shows a top view scanning electron microscope image of the component, where we can evaluate the anisotropy of the etching and measure the lateral geometries of the grating: d = 4 µm and w = 1.9 µm. Transmission measurements of the sample is in progress in our laboratory.

References

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