Reflectivity modulator based on GaSb/GaAs heterostructure

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Abstract. A structure of gallium antimonide (GaSb) and gallium arsenide (GaAs) wafers is built to modulate light reflectivity at CO_2 laser wavelength. A quantum well composed of GaSb/GaAs heterojunction with highly doped GaAs up to 3×10^{18} cm^{-3} is inserted inside a layer structure. A grating of periodic structure of GaAs and gold layer is added just below the substrate. Gsolver software is used to determine the reflectivity of incident light with the existence of free carriers. A voltage is applied to the doped layer to deplete the free electrons and the reflectivity is determined again. The significant difference in reflectivity between the two cases can be used to build a light reflectivity modulator device.

1. Introduction

GaSb/GaAs heterostructure is used in photovoltaic applications, especially, in concentrator solar cells and thermophotovoltaics for space and terrestrial applications [1]. The heterostructure is also used in optoelectronic devices, such as quantum dot lasers [2, 3].

Reflectivity modulation process can be used to build Integrated Mirror Optical Switch (IMOS) and modulating retro-reflectors (MRR) for free space optical communications, which are characterized by security, high bandwidth and non-interference [4].

In this paper, Gsolver is used to optimize a structure of GaAs and GaSb layers to be used as IMOS for Q switch. A similar study was done in [5] and [6] but using only GaAs layers. The impact of using GaSb in the structure is given in the discussion.

2. Device structure

Figure 1 represents the adopted structure built as reflectivity modulator. GaAs substrate is followed by a thick layer of lowly doped n GaAs with doping density of 2×10^{17} cm^{-3}. The aim of this layer is to make the applied electric field perpendicular to the structure which makes equipotential surfaces parallel to layers. A thin n+ GaAs conductive layer with doping concentration of 1×10^{18} cm^{-3} is added to work as an ohmic contact. The following three layers compose a single quantum well of highly doped GaAs wafer sandwiched between two GaSb layers. A dielectric buffer layer of GaAs is followed by a diffraction grating composed of periodic structure of GaAs and gold (Au). The diffraction grating is covered by a thick layer of gold to prevent any transmission of light outside the device. Some applications of grating system are given in [7]. Description of grating structure and its elements is given in [8] and [9].

TM-polarized light is incident on the backside of the substrate. The light propagates through the structure and interacts with the diffraction grating. The incident light corresponds to a CO_2 laser radiation of wavelength λ=10.6 µm, which is in the mid-infrared spectrum. The structural parameters are given in table 1. Refractive index of GaSb is taken from [10] and refractive index of GaAs is taken from [6] and [11].

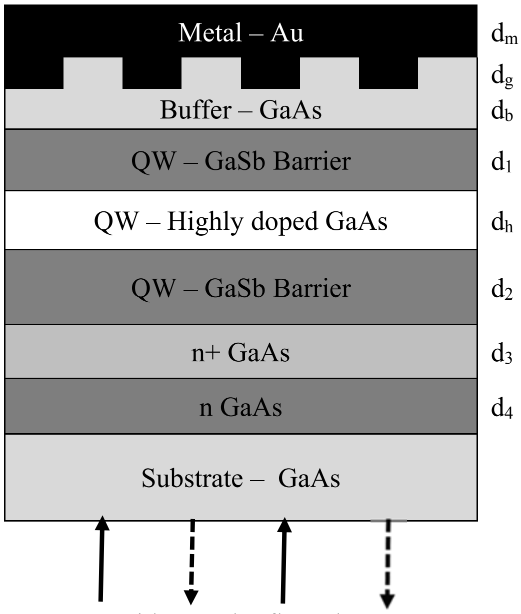

Figure 1. The device structure.

Table 1. The structural parameters.

Layer	Material	Doping density (cm^{-3})	Refractive index n	Refractive index k	Thickness symbol	Thickness µm
Metal	Au		8.521	75.395	d_m	1.5
Grating	GaAs Au	undoped	3.3 8.521	0.0002 75.3946	dg	0.3
Buffer	GaAs	undoped	3.3	0.0002	d_b	0.1
Barrier	GaSb	undoped	3.791	0.000006	d_l	0.04
Highly doped	GaAs	3×10^{18}	2.35	0.59	d_h	0.0088
Barrier	GaSb	undoped	3.791	0.000006	d_2	0.04
Doped layer	n+ GaAs	1×10^{18}	3.072	0.0046	d_3	0.08
Lowly doped	n GaAs	2×10^{17}	3.276	0.00029	d_4	1.5
Substrate	GaAs	undoped	1.000	0		350

3. Results and discussions

The structure is optimized using the software by determination of dependence of light reflectivity on structure parameters in existence of free carriers in the quantum well. This is exhibited in graphs legend as “doped”. The range of low reflectivity R_l, for example when $R_l < 0.3$, is determined. The reflectivity is determined again but with removing charge density from the quantum well. This is exhibited in graphs legend as “undoped”. The range of higher reflectivity R_h, for example when $R_h > 0.6$, is extracted from graphs. Finally, the intersection between the two intervals range shows the optimized parameter of the structure. Quantum well free carriers can be depleted using suitable applied voltage by the means of the ohmic contact represented by the n GaAs layer [6].

IOP Conf. Series: Journal of Physics: Conf. Series **869** (2017) 012038 doi:10.1088/1742-6596/869/1/012038

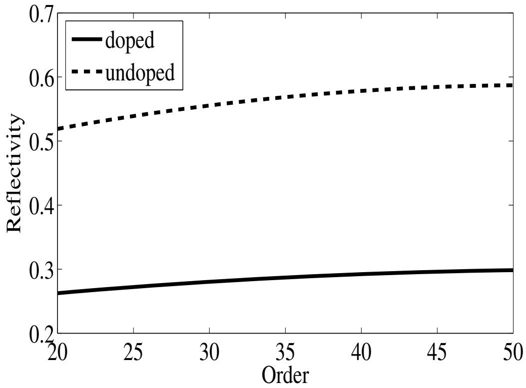

Figure 2. Reflectivity versus number of orders at P=3.15 μm, d_g=0.3 μm and DC=0.30.

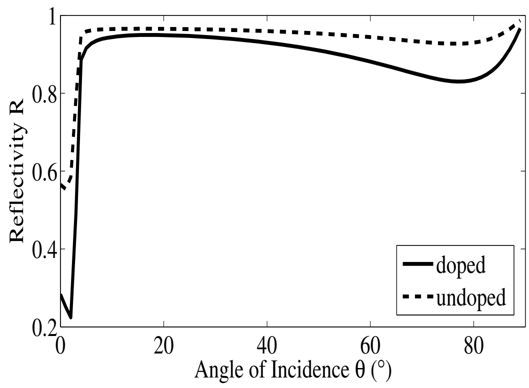

Figure 3. Reflectivity versus incident angle at P=3.15 μm, d_g=0.3 μm and DC=0.30.

Figure 2 represents the dependence of reflectivity R on number of orders adopted in the software. Generally, since we have a grating structure, number of orders should be relatively large. There is no high impact of number of orders on R for the range beginning from 20 orders. In our case, we choose orders of 30. The time of software running is larger if number of orders is increased.

The incident light has TM polarization, which is suitable to interact with grating. The relation between R and the angle of incidence is shown in "figure 3". There is no considerable difference between R of doped and undoped cases when $\theta > 3°$, and so we take normal incident case. There is no significant change in reflectivity when $\theta > 3°$.

The dependence of reflectivity on grating period is shown in "figure 4". The software is used many times to check the reflectivity with diffraction period at different values of duty cycle (DC) and grating height. The most suitable behaviour is taken to be dg=0.3 μm, and DC=0.30. At these parameters, we get $R_l = 0.64$ and $R_h = 0.23$. It is obvious that the figure exhibits a wide region of minimum reflectivity. For example at R = 0.5, the width of the U-shaped graph is $\Delta P = 0.18$ μm. The difference between reflectivity for the doped and undoped cases is maximum at P = 3.1 μm. Therefore, we consider 3.1 μm as the optimal value of period.

Figure 5 shows the relation between reflectivity and grating height d_g at P=3.15 μm and DC=0.30. At these parameters, we get $R_l = 0.61$ and $R_h = 0.28$. We notice that the figure exhibits a wide region of minimum reflectivity. For example at R = 0.5, the width of the U-shaped graph is $\Delta d_g = 0.10$ μm. The difference between reflectivity for the doped and undoped cases is maximum at $d_g = 0.30$ μm. Therefore, we consider 0.30 μm as the optimal value of grating height.

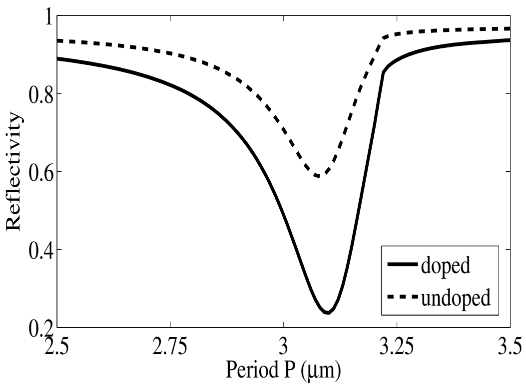

Figure 4. Reflectivity versus period at d_g=0.3 μm and DC=0.30.

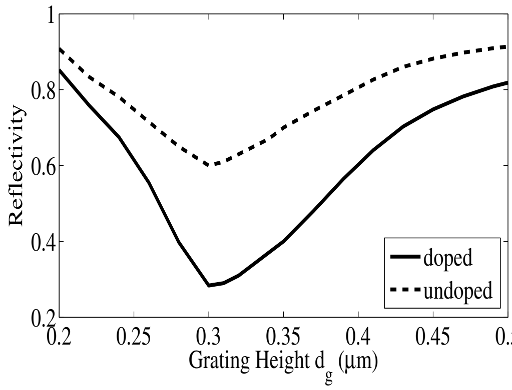

Figure 5. Reflectivity versus grating height at P=3.15 μm and DC=0.30.

Comparison between GaSb/GaAs structure in the present work and GaAs-based structure in [6], it is found that the results of reflectivity against period and grating height are more interesting in the current work. In the present work, minimum reflectivity of the doped and undoped case occurs at the same point of period and grating height (P = 3.1 μm and d_g = 0.3 μm).on the other hand, there is a difference in results of [6] between minimum reflectivity of doped and undoped cases in the graphs of period and grating height. It was found in [6] that reflectivity against period has minimum at P = 3.04 μm and 2.90 μm for doped and undoped case, respectively. In addition, reflectivity against grating height has minimum at d_g = 0.33 μm and 0.26 μm for doped and undoped case, respectively. It is more applicable for a device design if the minimum reflectivity in the case of doped and undoped layer occurs at the same value of structure parameter.

4. Conclusions

We have optimized a grating structure based on GaSb/GaAS quantum well for normal incidence of 10.6 μm. The parameters of the device can be considered as: grating period = 3.1 μm, grating height = 0.3 μm and duty cycle = 0.32. For the structure with theses parameters, we have R_l = 0.64 and R_h = 0.23, which gives a modulation depth of 0.41 and an extinction ratio 2.78. The existence of minimum reflectivity for doped and undoped curves at the same value of parameter (period or grating height) is a point of interest for GaSb / GaAs heterostructure.

Acknowledgment
This work has been funded by Bank of Palestine, the Arab Monetary Fund and Welfare Association through Zamalah fellowship program, and by the Arab American University- Jenin (AAUJ), Palestine.

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