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Thermal Effect on Mirror Reflectivity Based on DBR for Optoelectronics Devices

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Abstract

In this work, the thermal effect on the mirror reflectivity based on distributed Bragg reflector (DBR) in terms of the center wavelength shifting and reflectivity ratio is theoretically investigated and experimentally validated. The temperature of the proposed device is changing over the range 300 K –to– 400 K steps of 20 K. According to the results, the achievement shifting in the center wavelength is about 25 nm from (1580 nm –to– 1605 nm) and 26.9 nm from (1580 to 1606.9nm) for the theoretical and experimental work, respectively. In addition, about 99.99% within the theoretical and for the experimental work is about 97.3 % of reflectivity ratio were achieved within the proposed device. Finally, the experimental results show a good agreement with the simulation design.

Keywords: *distributed Bragg reflector, thermal effect, center wavelength shifting*

Introduction

Distributed Mirrors based on Bragg reflectors have been proposed in enormous published works due to their applications in different optoelectronic devices [1–7], such as microcavity light emitting diodes [8], Novalux extended cavity surface emitting lasers and vertical cavity surface emitting lasers (VCSELs) [9]. The distributed Bragg reflectors must fulfill certain conditions for operating successfully and contribute in the lasing process. The first condition is high reflectivity exceeding 99% to supply the feedback gain and overcome the losses of the active region. Since the DBR mirrors sandwich the active medium, it also must have high thermal conductivity to deplete the accumulated heat inside the active region and prevent thermal damage.

Finally, the mirror must be made of good conducting materials because they are the main elections supplier for the laser active medium. There are three different kinds of reflectors that can be used in DBR. These mirrors are: Semiconductor, dielectric, and wafer bonded. Semiconductor mirrors fabrication depend on semiconductor materials like AlGaAs/GaAs [10] and InP/InGaAsP [11]. These devices are epitaxial grown (one atomic layer per time) by metal organic chemical vapor deposition or molecular beam epitaxy (MBE). These fabrication methods allow doping of the mirrors during the building process which introduces the current injection to the device.

However, the lattice matched materials for these mirrors are low. In other words, a high number of dielectric layers are required for high reflectivity. The other type of mirror is dielectric mirror. This type of mirror is fabricated be deposition process. The process includes sputtering or evaporating Si/SiO2 and Si/MgO [12]. Both of these materials have high refractive index contrast ratio. Which means it requires a small number of periodic layers to fulfill high reflectivity condition. Though, this type of mirrors has limited usage because of its properties related to limited thermal conductivity, electrical insulation properties, and high absorptivity of materials. The last type of mirrors is wafer bonded mirrors. In this type, mirrors are fabricated separately using semiconductor mirrors and then attached to a laser active medium that has a different lattice constant. However, the thermal and electrical properties of the final device depends on the bonding process. On the other hand, it overcomes the lattice mismatch problem [13].

In this paper, the thermal effect on the mirror reflectivity based on DBR is theoretically investigated and experimentally demonstrated in L-band communication window (1580 nm). In addition, the experimental results show a good agreement with the simulation design. According to the results, the increasing in the temperature from (300 to 400) K caused shifting in the center wavelength about 25 nm and 26.9 nm for the theoretical and experimental work, respectively.

Simulation Model

The scheme of the proposed DBR with epitaxially grown and the simulation parameters which adopted in this work are illustrated in Figure 1 and

Table I, respectively. Alternating periodic quarter-wavelength stacks of low and high refractive index semiconductors, which are used to provide high mirror reflectivity in numerous optoelectronic and photonic devices such as VCSEL. The reflectivity of DBR (R) given by:

$$R = \frac{n_o(n_2)^{2N} - n_s(n_1)^{2N}}{n_o(n_2)^{2N} + n_s(n_1)^{2N}} \qquad (1)$$

Where $n_o, n_1, n_2\ and\ n_s$ are the respective the originating medium refractive indices, the two alternating materials and substrate material, and N is the pair number of low or high refractive index material [14]. The refractive index of compound semiconductor material such as $Al_xGa_{1-x}As$ by using the following equation [15].

$$n(x) = 3.59 - 0.71x + 0.091x^2 \qquad (2)$$

High reflectivity DBR mirror for 1.58µm optoelectronics devices has been obtained by composition of x = 0.47 for the $Al_xGa_{1-x}As$ [16]. The influences of temperature on the reflectivity and the mode splitting can be included in the model by taking into account the temperature dependence of refractive indexes, as follows [17]:

$$\frac{dn}{dT}_{(GaAs)} = 2.67 * 10^{-4}\ K^{-1}$$

$$\frac{dn}{dT}_{(AlAs)} = 1.43 * 10^{-4}\ K^{-1}$$

$$\frac{dn}{dT}_{(Al_xGa_{1-x}As)} = x\frac{dn}{dT}_{(AlAs)} + (1-x)\frac{dn}{dT}_{(GaAs)} \quad (3)$$

$$n(T) = n(T_o) + \frac{dn}{dT}(T - T_o) \quad (4)$$

The average refractive index $\bar{n}$ and the reflectivity r, are defined as:

$$A\bar{n} = d_H n_H + d_L n_L \quad (5)$$

$$\delta = \beta - \pi/A \quad (6)$$

$$\Gamma = \sqrt{k^2 - \delta^2} \quad (7)$$

$$r = \frac{(\beta_1 - \beta_2 - ik)(\Gamma - i\delta) - (\beta_1 - \beta_1 + ik)k}{(\beta_1 + \beta_2 + ik)(\Gamma - i\delta) + (\beta_1 - \beta_2 + ik)k} \quad (8)$$

Where: δ is the detuning parameter, Γ is the propagation constant in Bragg, $k = \frac{2\Delta n}{\lambda}$ is the vacuum wave number and $\beta = \bar{n}k$ propagation constant.

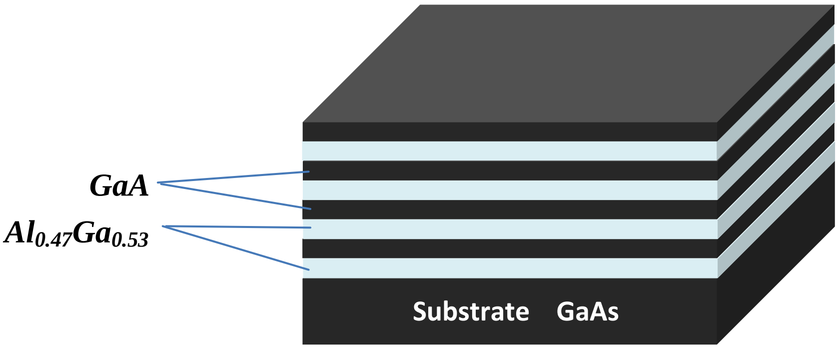

Figure 1: DBR Architecture.

Table I: Simulation parameters of proposed DBR

Layer type	Material	Thickness d (nm)	Doping Concentrations N_d (×10^{17}cm^{-3})	Refractive Index (n)	Repetition
Isolate	GaAs	5	5	3.37	
DBR	GaAs	131.5	5	3.37	25
	$Al_{0.47}Ga_{0.53}As$	152.6	5	3.18	
	GaAs	131.5	5	3.37	
Buffer	GaAs	200	20	3.37	

Fabrication Details

The fabrication process is started by growing 200 nm of GaAs as a buffer layer at 775 K, then, 25 periodic layers of GaAs/Al GaAs are grown for DBR reflection. The GaAs layer is grown at 925 K and the AlGaAs is grown at 980 K. The thickness of GaAs layer is 131.5 nm and the thickness of AlGaAs is 152.6 nm Finally, a 5nm layer of GaAs is grown to isolate and protect the surface. The Figure 2 shows the cross section of the fabricated device.

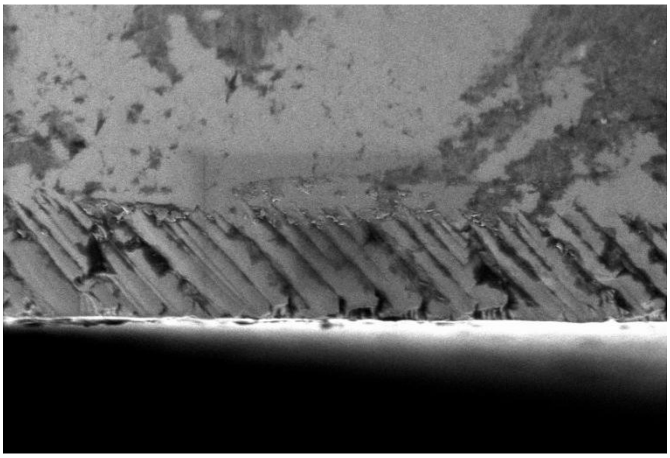

Figure 2: SEM cross section of the fabricated device.

Experimental Setup

The experimental setup for thermal effect investigation of the proposed DBR is illustrated in Figure 3. An infrared laser source within spectral range from (0.9 µm to 2.6 µm) is used as a wide range input signal. The temperature of the proposed DBR is varied via thermal unit from (300 K to 400 K) steps of 20 K, and the reflected signal is collimated to the spectrometer utilizing an optical collimated.

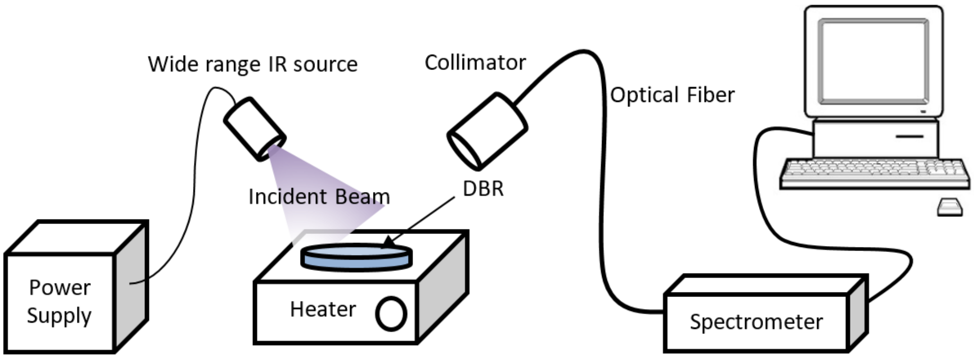

Figure 3: Experimental setup for tunable DBR utilizing thermal effect.

Results and discussion

The effect of temperature increment from 300K –to– 400K on the spectrum reflectivity of the proposed DBR mirror for both of the theoretical and experimental work are depicted in Figure 4 and Figure 5, respectively. The center wavelength of the proposed mirror is about 1580 nm, and the spectra are symmetric around the center wavelength. The most important parameter in the design of the DBR mirror is the reflectivity ratio, about 99.99% within the theoretical and for the experimental work is about 97.3 % were achieved within the proposed design. The analyzed data from Figures 3 and 4 show the thermal effect on the center wavelength for both of the theoretical and experimental work is depicted in Figure 6. According to the results, the center wavelength is shifted about 25 nm from (1580 nm–to–1605) nm and about 26.9 nm from (1580 nm–to–1606.9 nm) for the theoretical and experimental work, respectively.

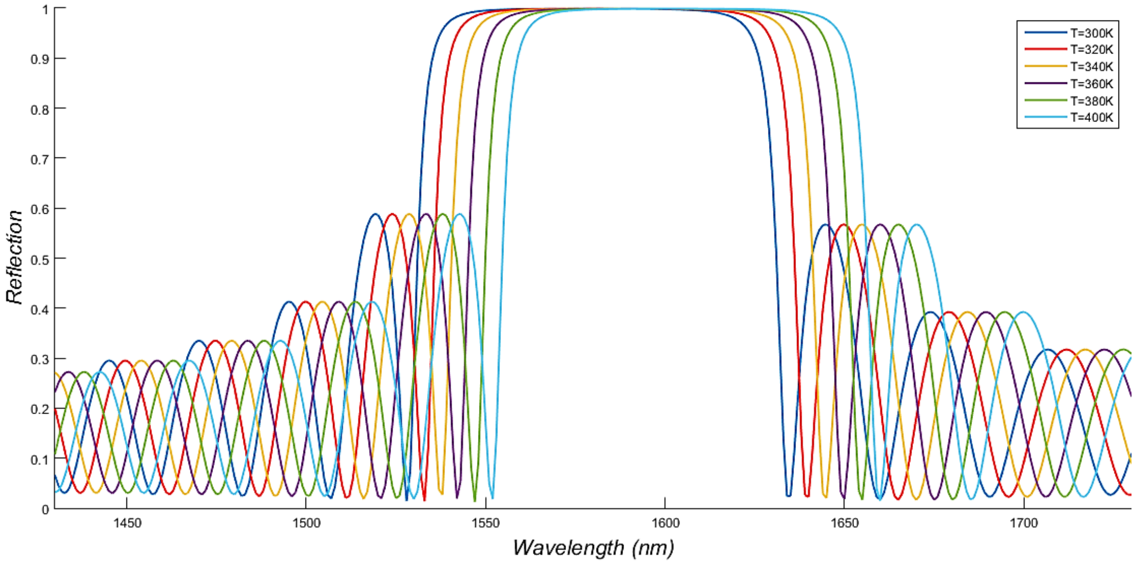

Figure 4: Theoretical spectra versus temperature increment from 300K to 400K steps of 20K for the GaAs/AlGaAs quarter-wave mirrors.

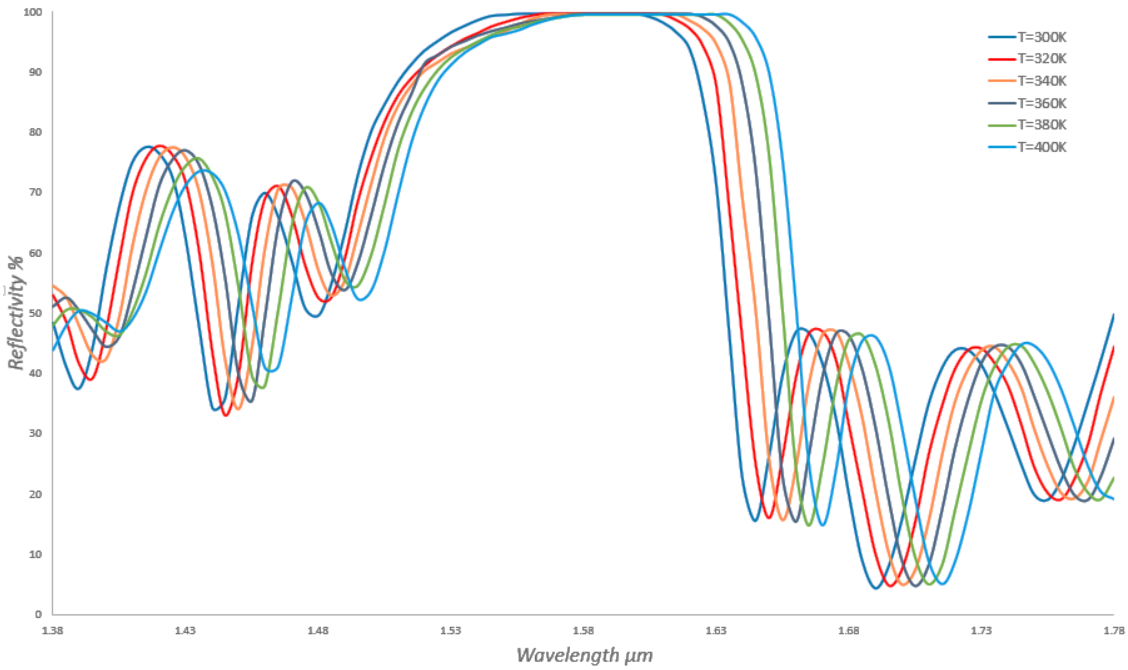

Figure 5: Experimental spectra versus temperature increment from 300K to 400K steps of 20K for the GaAs/AlGaAs quarter-wave mirrors.

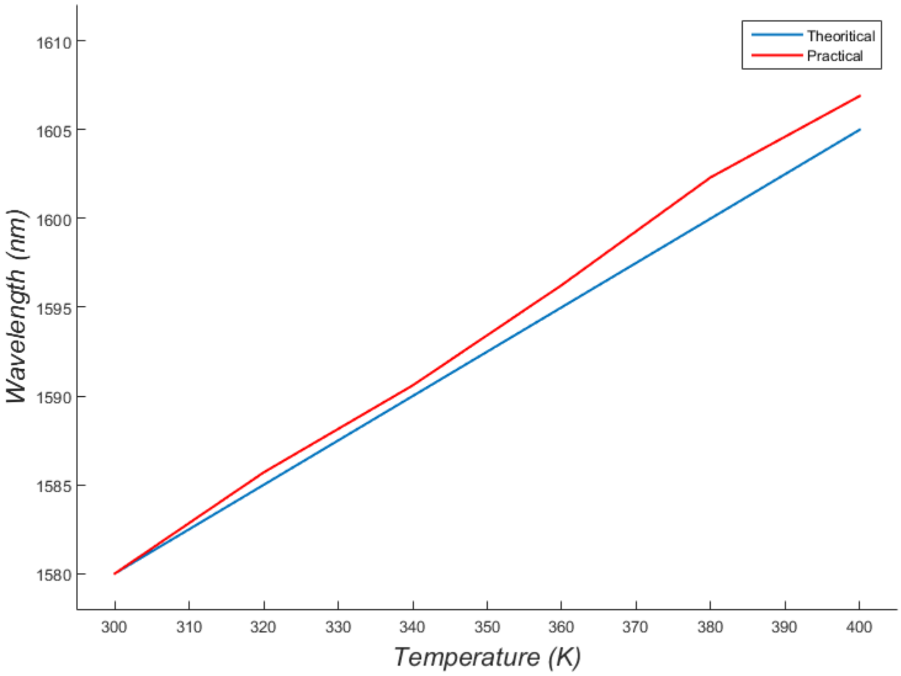

Figure 6: Center wavelengths shifting versus temperature increment for theoretical and experimental results.

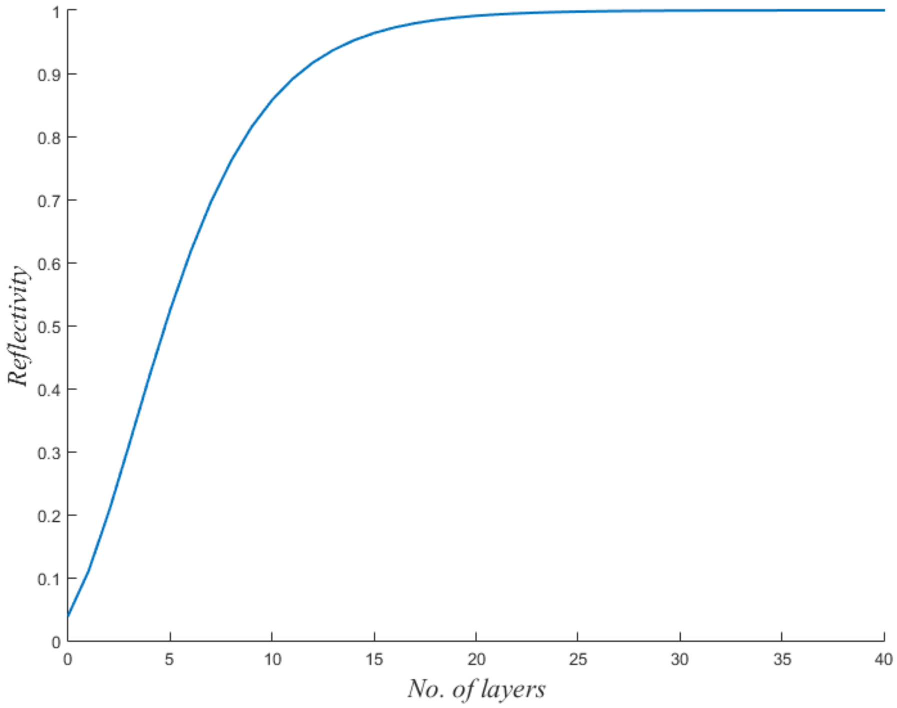

Figure 7: DBR reflectivity vs. Number of alternating pairs layers.

Conclusion

The thermal effect on the mirror reflectivity based on DBR is theoretically investigated and experimentally validated in terms of the center wavelength shifting and reflectivity ratio. The achievement shifting in the center wavelength is about 25 nm from (1580 nm to 1605 nm) and 26.9 nm from (1580 nm to 1606.9 nm) for the theoretical and experimental work, respectively. About 99.99% within the theoretical and for the experimental work is about 97.3 % of reflectivity ratio were achieved within the proposed device, the absorption coefficient is 24.2 cm^{-1}.

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