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A full-duplex working integrated optoelectronic device for optical interconnect

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A B S T R A C T

In this paper, a full-duplex working integrated optoelectronic device is proposed. It is constructed by integrating a vertical cavity surface emitting laser (VCSEL) unit above a resonant cavity enhanced photodetector (RCE-PD) unit. Analysis shows that, the VCSEL unit has a threshold current of 1 mA and a slop efficiency of 0.66 W/A at 849.7 nm, the RCE-PD unit obtains its maximal absorption quantum efficiency of 90.24% at 811 nm with a FWHM of 4 nm. Moreover, the two units of the proposed integrated device can work independently from each other. So that the proposed integrated optoelectronic device can work full-duplex. It can be applied for single fiber bidirectional optical interconnects system.

1. Introduction

Accompanying the rapid developing demands for high speed optoelectronic and electronic devices, which are generated from the applications of ultra-wideband communications in the data center, 5G wireless system, cloud computing and supercomputer fields etc., the interconnect technology tends to utilize the optical links to overcome the drawbacks of the electric interconnects, like high power consumption, channel interference and complicated channel electrical isolation etc. Such optical links use optoelectronic devices like vertical cavity surface emitting laser (VCSEL) [1], light emitting diode (LED) [2], uni-traveling-carrier photodetector (UTC-PD) [3], PIN photodetector [4], modulator [5]. Sometimes, optics structure and semiconductor diode will be integrated with them [6,7]. Among them, VCSEL is the most utilized transmitting device for short distance (less than 300 m) optical interconnects due to its benefits of low power consumption, high modulation speed, and high coupling efficiency to multimode fiber etc. To further increasing integration level at the fiber end, some attempts of integrating light transmitting and receiving functions into only one chip, based on VCSEL structure, have been made [8,9]. They are either integrating a PIN photodetector under a VCSEL to monitor the VCSEL's backlight, or integrating a resonant cavity enhanced photodetector (RCE-PD) with a VCSEL laterally. In this paper, based on our former research results of a multi-cavity wavelength selective photodetector [10], an efficient full-duplex working optoelectronic integrated device is proposed. It is constructed by integrating a VCSEL on top of a RCE-PD. With such an integration scheme, the integrated device's performance will be benefitted from the high speed photo-response advantages of the RCE-PD. Moreover, since for a RCE-PD, certain top reflectance is required for obtaining its maximal quantum efficiency, such an integration scheme can be optimized for compensating for the designing and manufacturing reflectance losses generated from the VCSEL to the PD at some extent and make the integrated device more feasible to be realized. And because the device's two units are integrated vertically and coaxially, it will simplify the chip's future coupling scheme to a multimode fiber while being used for application of bi-directional full-duplex optical interconnects in single fiber and lower the packaging cost at the same time.

2. Device design

The structure of the proposed full-duplex working integrated optoelectronic device is shown in Fig. 1. It is composed of a VCSEL unit at the top and a RCE-PD unit at the bottom. To make such a device working full-duplex, electrical performances isolation and optical functions decoupling between its two composing units must be accomplished. The electrical performances isolation is accomplished by inserting an insulating layer between Mirror M1 and Spacer Cavity. It can be realized by growing a 51 nm thick $Al_{0.98}Ga_{0.02}As$ layer during the device's structure epitaxy and then transferring the $Al_{0.98}Ga_{0.02}As$ layer

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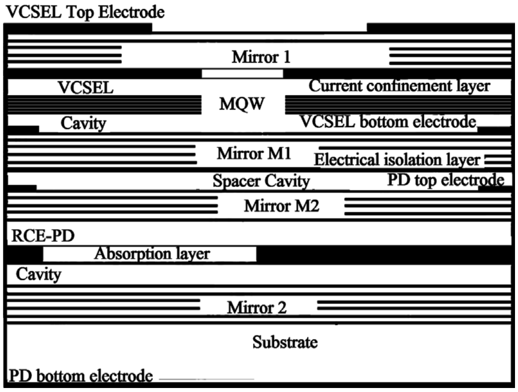

Fig. 1. The device structure.

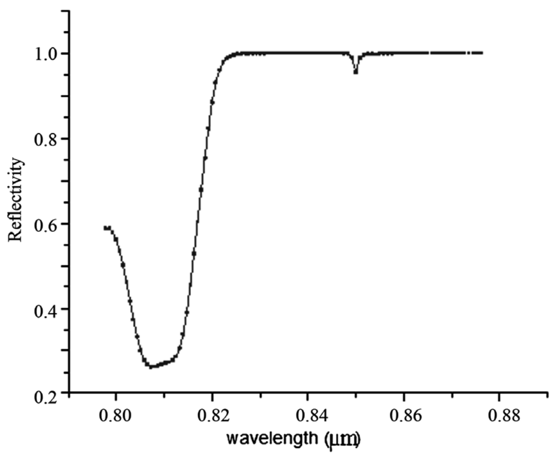

Fig. 2. The reflectance spectrum of VCSEL unit.

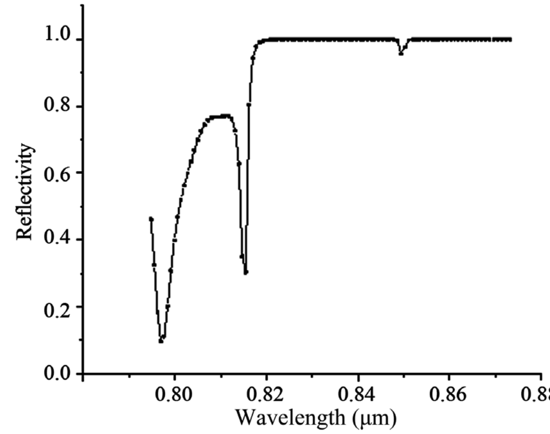

Fig. 3. The reflectance spectrum of RCE-PD unit's equivalent top mirror.

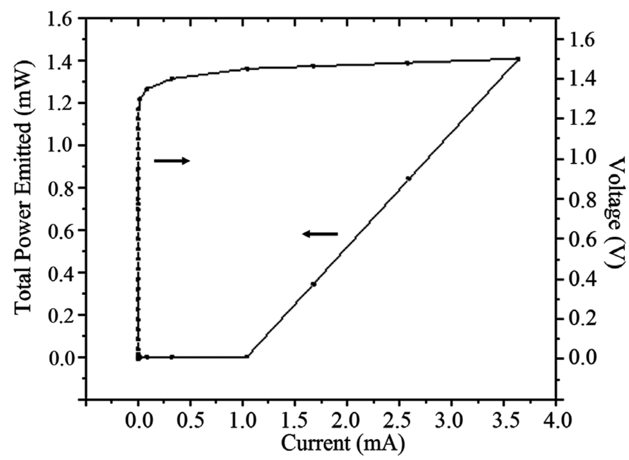

Fig. 4. The performance of VCSEL unit.

to a 30 nm thick Al_2O_3 insulating layer with wet oxidation process. The optical functions decoupling is accomplished by wavelength division multiplexing scheme. Since full-duplex working is required for the proposed integrated optoelectronic device, a particular working optical spectrum of it will be set. The transmitting light wavelength of it is set to be around 850 nm, while the receiving light wavelength of it is set to be around 810 nm.

From the VCSEL unit's point of view, since it is on the top of the integrated optoelectronic device, firstly it should emit lasing light from the top at a wavelength around 850 nm, while at the same time let the receiving light at a wavelength around 810 nm passing through it with low loss. Secondly its backlight should be minimized and have little effect on the RCE-PD unit's performance. Therefore, in the VCSEL unit's structure design, Mirror 1 is composed of 50 layers of *p*-doped $Al_{0.1}Ga_{0.9}As$ and $Al_{0.9}Ga_{0.1}As$ films, which includes 21 pairs of one-quarter wavelength DBR and 8 phase compensation layers. It has an optimized reflectance spectrum, which has reflectivities of higher than 99% at wavelength around 850 nm and lower than 20% at wavelength around 810 nm. Mirror M1 is composed of 60 layers of *n*-doped $Al_{0.1}Ga_{0.9}As$ and $Al_{0.9}Ga_{0.1}As$ films which includes 25 pairs one-quarter wavelength DBR and 10 phase compensation layers. It has an optimized reflectance spectrum, which has reflectivities of higher than 99% at wavelength around 850 nm and lower than 10% at wavelength around 810 nm. Moreover, around the wavelength of 850 nm, the reflectivity of Mirror M1 is designed to be higher than that of Mirror 1 to make sure that most of the output power from the VCSEL unit will be emitted from Mirror 1. So that the influence of the VCSEL unit's output light on the RCE-PD unit's performance will be minimized. At the same time, the extra-loss that will be introduced by the RCE-PD unit's optical absorption to the VCSEL unit will also be minimized. Thereafter, the optimized un-doped VCSEL cavity, which is composed of two $Al_{0.3}Ga_{0.7}As$ spacer layer and 3 pairs of $Al_{0.3}Ga_{0.7}As$/ GaAs (8 nm/ 9 nm) quantum wells, is added between Mirror 1 and Mirror M1. The accomplished VCSEL unit's reflectance spectrum is shown in Fig. 2. It has a resonance wavelength around 850 nm, which allows for the lasing condition of the VCSEL unit, and a low reflectance (reflectivity lower than 30%) range of about 10 nm around wavelength of 810 nm, which permits the receiving signal light passing through it.

From the RCE-PD unit's point of view, its bottom mirror (Mirror 2) is composed of 25 pairs of *p*-doped $Al_{0.1}Ga_{0.9}As$ /$Al_{0.9}Ga_{0.1}As$ DBR, which has a reflectivity of higher than 99% covering the wavelength range from 810 nm to 850 nm. Moreover, according to the RCE-PD's performance optimization theory, since its un-doped GaAs absorption layer's thickness is 300 nm, the optimized reflectivity of the RCE-PD unit's top mirror should be around 75%. For the proposed integrated optoelectronic device, its RCE-PD unit's equivalent top mirror is composed of the VSEL unit, the Spacer Cavity and Mirror M2. Therefore, the structure of the Spacer Cavity and Mirror M2 should be optimized accordingly on the basis of the optimized VCSEL unit's structure. The optimized results are a 400 nm thick *n*-doped $Al_{0.3}Ga_{0.7}As$ spacer cavity and 10 pairs of *n*-doped $Al_{0.1}Ga_{0.9}As$/ $Al_{0.9}Ga_{0.1}As$ aperiodic DBR composed Mirror M2. The optimized reflectance spectrum of the RCE-PD unit's equivalent top mirror is shown in Fig. 3. It has a reflectivity of 77% around wavelength of 810 nm, which assures a high absorption quantum