

POLARIZATION PROPERTIES OF VERTICAL-CAVITY SURFACE-EMITTING LASERS SUBJECT TO VARIABLE OPTICAL FEEDBACK POLARIZATION ANGLE

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ABSTRACT: - In this paper, the influence of variable polarization angle (θ_p) of optical feedback (OF) on the polarization properties of a vertical-cavity surface-emitting lasers (VCSELs) is investigated experimentally. Parallel polarization optical feedback (PPOF) and orthogonal polarization optical feedback (OPOF) are employed, where the polarization light is re-injected back into the laser. For the PPOF (OPOF), polarization of the feedback light is parallel (orthogonal) to the polarization light of solitary VCSEL. With respect to PPOF, no polarization switching (PS) occurs over the entire range of θ_p . However, when apply both the PPOF and OPOF PS takes places for a fixed OF level and at certain value of θ_p with increasing bias current (I_b). Furthermore, when increasing θ_p PS occur for a fixed OF level and bias I_b . The results show that a variable polarization optical feedback technique is an effective tool for controlling the polarization instabilities of VCSEL.

Keywords: vertical-cavity surface emitting lasers (VCSELs), polarization switching, optical feedback

1- INTRODUCTION

Vertical-cavity surface-emitting lasers (VCSELs) are relatively recent type of semiconductor lasers and are attractive for a range of applications from sensor to telecommunications. VCSEL is a semiconductor laser, which has a resonant cavity that is vertically formed with the surfaces of the epitaxial layers. Owing to their small active volume, VCSELs have attractive features such as lower manufacturing costs, very low threshold current (μA), circular output beam which offer high coupling efficiency to optical fibers and higher reliability compared to other semiconductor devices. Most VCSELs devices typically emit linearly polarized light. However, VCSEL present a number of problems, including the polarization instability also known as polarization switching (PS). This is because of high reflectivity of the distributed Bragg reflector (DBR) mirror which led to low quantum efficiency [1]. PS can occurred under different conditions such as free running VCSEL operation by either increasing the injection current or changing of the temperature of the laser cavity [2]. In fact, instability is a common features in VCSELs devices owing to weak material and cavity anisotropies [3]. Therefore, polarization instability can happen without external perturbations.

However, under some conditions - such as when the bias current is increased or an external OF is introduced the linearly polarized state switches to the orthogonal linearly polarized state. This usually occurs due to changes in the gain and loss of the orthogonally polarized modes [4], and changes in the operating temperature as well as the magnitude and directionally of the bias current [5]. Based on the relevant studies in the literature,

experimental and theoretical works on VCSELs have shown that increasing the injection current and the OF level can lead to increased polarization inversion and mode competition between the laser polarization modes. Mode competition involves multiple switching, which destabilizes the laser emission and dynamic solutions. Interestingly, variable polarization based OF was recently proposed for external cavity feedback as an effective tool to control the polarization instability of VCSEL [3]. Very recently, we experimentally investigated the PS properties of VCSEL with variable polarization of OF in presence of the modulation signal [6]. We show that a smaller θ_p is required to realize PS with increasing the level of OF. Additionally, for a fixed OF level and increased bias current a smaller θ_p is required to ensure PS.

2-EXPERIMENTAL SETUP

The schematic diagram of the experimental setup as well as the real practical set is shown in Fig. 1 (a) and (b), respectively. The PPOF is achieved with mirror M1, (mirror M2, being closed) and the OPOF is achieved with M2 (M1 being closed) as display in the setup. The system is composed of an 850 nm single mode VCSEL (Avalon photonics UK Components Ltd) with a threshold current (I_{th}) of ~ 3.9 mA at free running operation. The VCSEL is driven by a DC source (7651 YOKOGAWA) and is temperature controlled with a thermoelectric temperature controller (TED 200) to within 0.01 C°.

The VCSEL emits two orthogonally polarization modes X-polarization (XP) and Y-polarization (YP). We refer to the polarizations parallel and orthogonal feedback light to that of the solitary device light. A VCSEL operating at a central wavelength of 850 nm was used in the experiment with a linear light-current (L-I) curve characteristics. A quarter wave plate (QWP) and neutral density filter (NDF) are used to rotate θ_p and control the feedback level, respectively. The collimated laser beam was reflected back to the VCSEL using two mirrors placed at ~ 40 cm away from the VCSEL after passing through a non-polarizer 50/50 beam splitters (BS). The laser output power is decomposed into two orthogonally polarized modes using a cubic polarizer beam splitter (PBS). An optical power meter was used to measure the output power variation using after passing through a linear polarizer (P), which is used to select the polarization direction in which measurements are carried out. The output power is measured using a photo detector (PD) (New Focus Nanosecond photo detector, model No. 1621). The feedback ratio is defined as the ratio of the power fed back into the VCSEL relative to the total output power of the free running operation of the laser.

In this study we defined $\theta_p = 0^\circ$ to a maximum power of the XP feedback and $\theta_p = 90^\circ$ to a maximum power of the YP feedback. For both polarization feedback investigation, PPOF and OPOF, the L-I curve characteristics of the VCSEL was measured under fixed OF level of ~ -6 dB and I_b of 6 mA. The QWP angle is increased linearly from 0° to 180° .

3-RESULTS AND DISCUSSION

Fig. 2 displays the L-I characteristics of solitary VCSELs under study, where in (a) and (b) the total output power and the polarization-resolved output power, respectively. The first lasing mode in Fig. 2(b) with a full black square line refers to the XP mode and the suppressed mode with a full red dot line corresponds to the YP mode. For the XP mode the characteristics is that of a typical laser devices with I_{th} of around 3.9 mA, whereas for the YP mode there is no obvious threshold knee beyond the maximum limited injected current. Thus, the figure shows that the YP mode is being completely suppressed. Therefore, no PS is observed for the solitary VCSEL, which mean that stable polarization emission for the laser.

Fig. 3 shows the output power response of the VCSEL subject to XP feedback (PPOF) with rotating θ_p . In case of rotating the PPOF, the OPOF beam is closed, no PS is observed and the VCSEL lases in the XP mode over the entire range of I_b and over the range of θ_p , see Fig. 3(a - d).

The polarization direction selectivity is high for the VCSEL polarization modes over the whole range of the polarization angle from 0° to 180° especially at low I_b values between I_{th} and ~ 6 mA. This is because the XP mode obtain a maximum feedback light at 0° and 180° with no feedback light for the YP mode [7]. However, when $\theta_p = 90^\circ$ and 180° , which mean the XP mode loss the OF, the YP mode starts increase especially at higher values of I_b , which lead to the polarization selectivity range is deteriorated. Several physical mechanisms can lead to polarization instability such as spatial hole burning [8], thermal effect [5] and modification of the net modal gain and losses due to the injection current [6, 9].

When both the PPOF with the OPOF are applied, the situation is different compared to the PPOF characteristics. When I_b increase from 0 to 9 mA the PS occurs between the XP and YP mode at fixed θ_p and OF level of ~ 6 dB. At $\theta_p = 0^\circ$ and 180° , the VCSEL start lasing with the XP mode for several mA and then switched to the YP mode at ~ 6.8 mA of I_b with mode fluctuation at 180° . After the PS point, the VCSEL starts lasing with the YP mode. However, when θ_p increase to 90° the XP and YP mode behaviors are changed. The laser output power becomes dominant by the YP mode over the entire range of θ_p and the XP mode is suppressed. However, the orthogonally states of the XP and YP modes are degenerated, while they are well separated at $\theta_p = 90^\circ$ and 180° before and after the PS position.

Similar dynamics of the XP and YP modes at 90° is repeated at 120° . For $\theta_p = 0^\circ$ and 180° the gain of the XP mode is dominant before the PS point and therefore the XP become the dominant mode. While for $\theta_p = 90^\circ$ and 120° the YP mode gain is strong enough to let this mode becomes dominant [7, 10]. When θ_p increases to 90° and 120° the XP mode loss the feedback light and becomes suppressed. The results also indicate that the threshold current, I_{th} , of the VCSEL is reduced by several decrements of mA combine with decreasing the slope efficiency of the output power [11].

4- CONCLUSIONS

In this paper, we have experimentally investigated the polarization properties of VSCSELs under varying polarization angle of the optical feedback. These were done using parallel polarization optical feedback (PPOF) as well as orthogonal polarization optical feedback (OPOF). The results obtained indicated that the OPOF forces the laser emits in certain polarization state while the PPOF can enhance the corresponding polarization mode of solitary VCSEL, which in turn led to enhancing the polarization selectivity between the polarization modes of the laser. The results show that OPOF is a suitable candidate for controlling polarization instability of the VSCSEL.

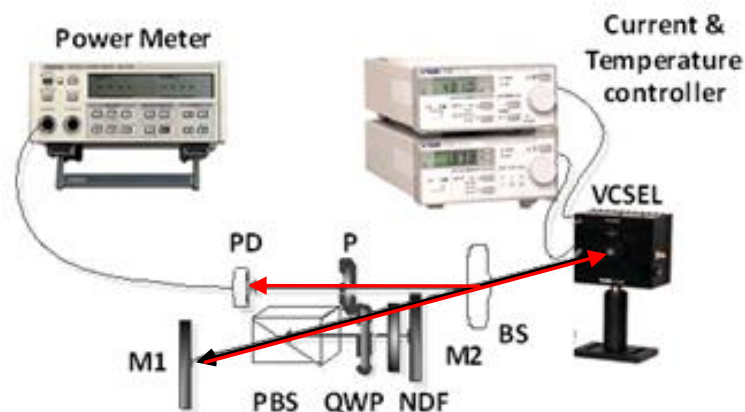
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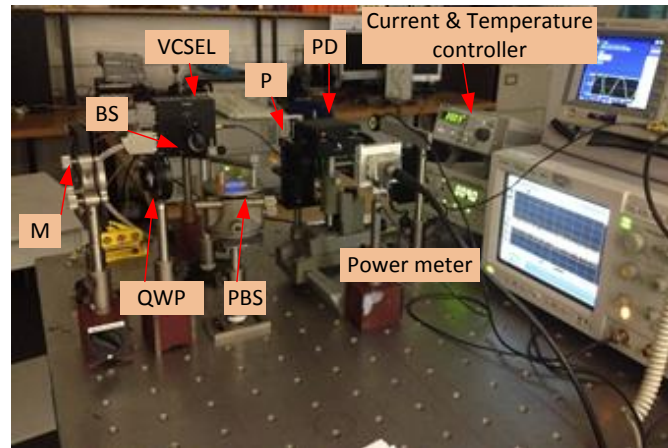
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(a)



(b)

Fig. 1: (a) T-shaped feedback scheme for parallel and orthogonal polarization feedback, non-polarizer beam splitter (BS), polarizer (P), photo detector (PD), mirrors (M1, 2), quarter wave plates (QWP), and neutral density filter (NDF), (b) Real experimental set-up.

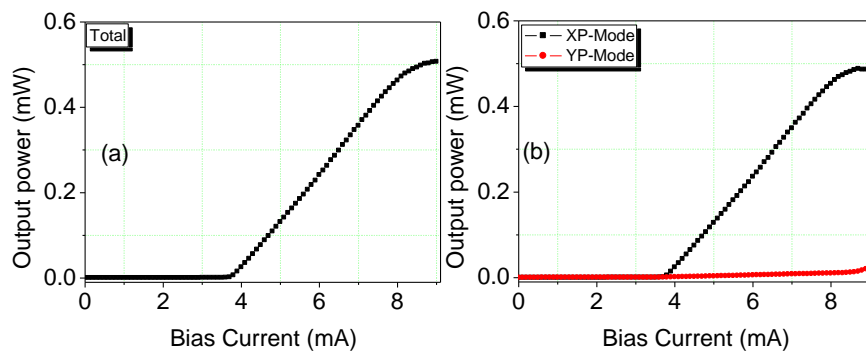


Fig. 2: Light-current (L-I) characteristics of standalone VCSELs under study, (a) the total output power and (b) the polarization-resolved output power for the XP (black squares) and YP modes (red dots).

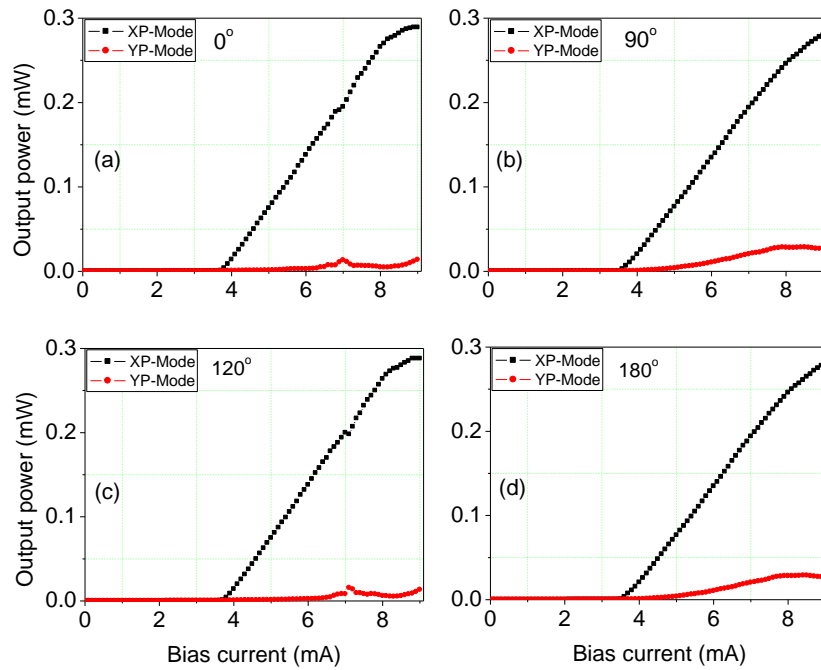


Fig. 3: Measured the output power response of VCSEL with rotated the XP mode of the optical feedback with closed the YP feedback at (a) 0° (b) 90°, (c) 120° and (d) 180°.

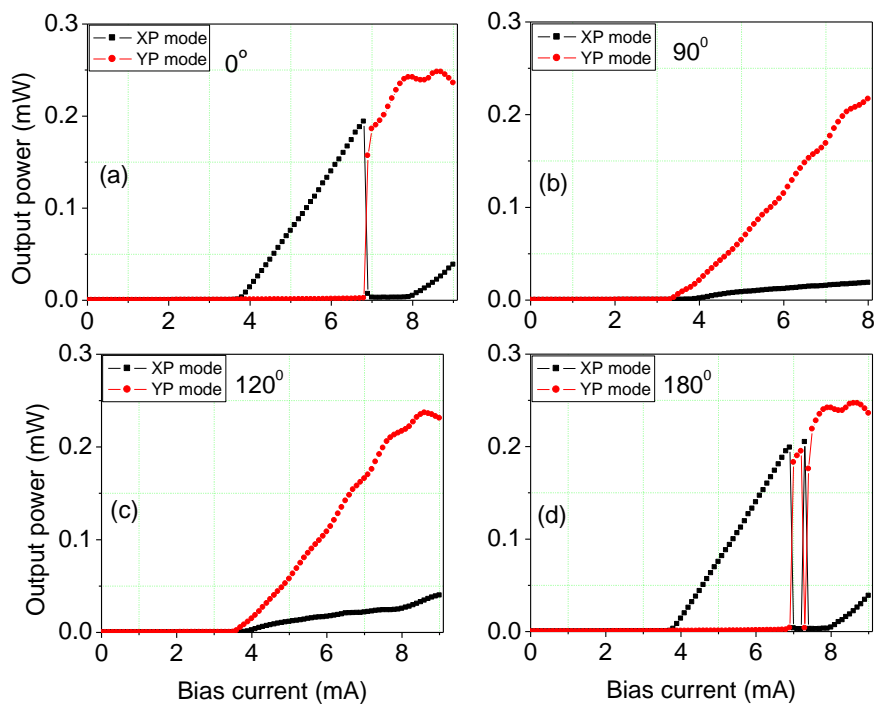


Fig. 4

الخلاصة

في هذا البحث تم عمليا دراسة تأثير تغيير زاوية الاستقطاب لشعاع الضوء المرند عكسيا على خصائص الاستقطاب لليزر الانبعاث المتعامد من السطح (VCSEL), حيث تم حقن الضوء المنعكس المتوازي (PPOF) والمتعامد (OPOF) مع شعاع الليزر الاصلي الى داخل تجويف الليزر. بالنسبة لعميلة حقن الشعاع المتوازي لم يظهر ما يعرف بظاهرة تبديل الاستقطاب (PS) بين شعاع الليزر المستقطب (XP) وشعاع الليزر المستقطب (YP) على مدى زاوية الاستقطاب (θ_p) . إلا ان اعادة حقن كل من الشعاع المتوازي والمتعامد يعطي خصائص مختلفة حيث ان تبديل الاستقطاب يحدث عند زاويا استقطاب معينة في حالة ثبوت مستوى شعاع الضوء المرند مع زيادة تيار الانحياز. فضلا عن ذلك فانه عند زيادة زاوية الاستقطاب فان تبديل الاستقطاب يحدث عند ثبوت مستوى الشعاع المرند وتيار الانحياز. اظهرت النتائج ان تغيير زاوية الاستقطاب لشعاع الضوء المرند هو اداة فعالة للتحكم في ظاهرة عدم الاستقرار المتلازمة لعمل ليزر الانبعاث المتعامد.