Two-dimensional electronic beam-steering with implant-defined coherent VCSEL arrays

A.C. Lehman, D.F. Siriani and K.D. Choquette

Evanescently-coupled two-dimensional vertical cavity surface emitting laser arrays may be defined by proton implantation in the top mirror. By controlling injection current to each of the elements in these laser arrays, the main lobe of emission can be steered in different directions up to 5° from normal. This two-dimensional electronic beam-steering with a three-element triangular array is demonstrated.

Introduction: Coherent coupling of vertical cavity surface emitting laser (VCSEL) arrays [1] has been achieved in a variety of device configurations [2–6]. In this work, we demonstrate two-dimensional electronic beam-steering by controlling the current injection to each laser in a three-element VCSEL array defined by proton implantation and emitting at nominally 850 nm. It has been shown that varying the current to each laser in a one-dimensional photonic crystal VCSEL array varies the relative phase between lasers and thus causes electronic beam-steering [7]. Implant-defined coherent VCSEL arrays [8] are preferable for beam-steering because of their tendency to steer around an in-phase condition [9]. The in-phase mode is favoured because the implant provides electrical confinement without adding optical loss between lasers.

Device description: The devices studied have 27 top distributed Bragg reflector (DBR) periods, 35 bottom DBR periods, and GaAs quantum wells that emit at nominally 850 nm. We choose to work with three-element arrays because three is the minimum number of coupled lasers that enables two-dimensional steering. The implant geometry of this device is shown in Fig. 1. A thick resist process is used to define the round, unimplanted regions inside the contact ring of each VCSEL. The energy and dose of the proton-implantation were 340 keV and 4×10^{14} cm^{-2}, respectively. The wafer was tilted at 7° from normal during implantation to prevent channelling. One of the major advantages of these devices is that a standard implantation VCSEL process is followed with minimum fabrication complexity.

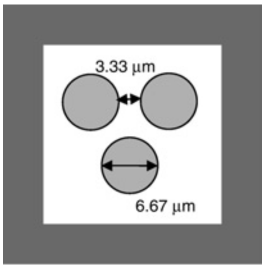

Fig. 1 *Three-element layout within square contact ring with spacing $a = 3.33$ µm and diameter $d = 6.67$ µm*

A focused ion beam etch [10] has been used to segment the top contact to allow for separate current injection [7] to each laser, as apparent in Fig. 2. Figs. 2*a*, *b*, and *c* show that injecting current to only one segment of the top contact causes lasing in only the nearest laser. Fig. 2*d* shows the coupled mode that is emitted when current is injected to the three contacts.

Results: An example of an in-phase far-field pattern generated when current is injected to all three contacts is shown in Fig. 3. There is one dominant lobe in the interference pattern, which is emitted perpendicular to the surface of the VCSEL. For equal current supplied to the three contacts, the total threshold current is approximately 4.5 mA. Other combinations of current values to each of the three lasers were examined as listed in Table 1. The angle of peak emission measured in the far-field for each of these combinations that produce a single dominant lobe is shown in Fig. 4. As can be seen, the angle of peak emission changes in two dimensions as current injection to the three separate contacts is varied. Up to 5° deflection from normal emission is demonstrated. Prior work has shown that the beam deflection arises from phase differences between elements with differing electronic injection [7]. Although arbitrary directions are not selected, clearly steering into two-dimensions is apparent in Fig. 4.

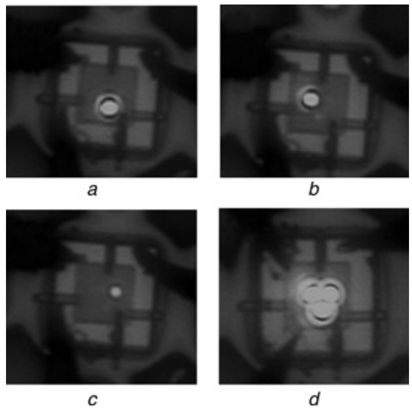

Fig. 2 *Images of VCSEL arrays with (a–c) current to only one element, showing sufficient isolation between elements for individual lasers and (d) current to all three lasers producing a coherent mode*

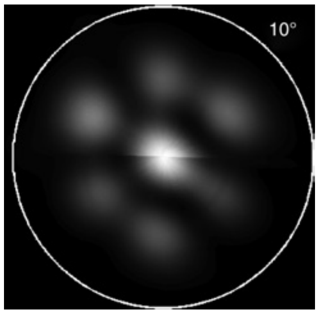

Fig. 3 *Far-field pattern with on-axis maximum generated when all three elements are lasing*

Table 1: Current combinations injected into the three lasers, corresponding to far-field maximum positions in Fig. 4

Label	Top right (mA)	Top left (mA)	Lower left (mA)
1	4.1	2.1	2.1
2	4.1	2.1	3.1
3	4.1	2.1	4.1
4	4.1	2.1	5.1
5	5.1	2.1	3.1
6	3.1	3.1	3.1
7	3.1	3.1	5.1
8	4.1	3.1	3.1
9	5.1	3.1	3.1
10	3.1	4.1	3.1
11	3.1	4.1	5.1
12	3.1	5.1	3.1
13	5.1	2.1	4.1

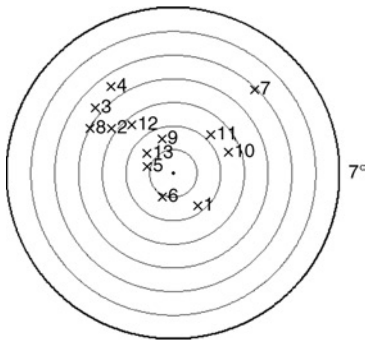

Fig. 4 *Angular location of far-field intensity maxima for injection currents in one device as described in Table 1*

Each circle denotes 1° from normal

Conclusions: We have shown in-phase two-dimensional electronic beam-steering up to 5° from perpendicular to the VCSEL facet with three-element implant-defined VCSEL arrays. By independently varying the current injected into each element, we are able to change the relative phase of the light emitted from each laser and thus controllably rotate the angle of peak emission. Electronic beam-steering may enable reconfigurable optical switching and laser modulation.

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