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Tunable Laser Diode Using Partially Intermixed InGaAsP Multiple Quantum Well

Thamer Tabbakh*[1, 2], Patrick LiKamWa[1]
[1] CREOL, The College of Optics and Photonics,
and Dept. of Electrical and Computer Engineering,
University of Central Florida, Orlando, Florida 32816, USA
[2]King Abdulaziz City for Science and Technology, Riyadh 11442, Saudi Arabia

ABSTRACT

In this work, a two-section wavelength tunable laser diode is demonstrated using an InGaAsP multiple quantum well heterostructure. The laser diode consists of two sections with different bandgap energies achieved using selective area intermixing of the MQW. Using plasma enhanced chemical vapor deposition (PECVD), half of the sample is coated with a 30nm silicon nitride (SiN_x) film followed by a 200nm thick overlay of silicon oxynitride (SiO_xN_y) film over the entire sample. The whole sample is then thermally annealed at 750°C for 30s, and that results in the SiO_xN_y covered section experiencing a narrowing of the bandgap energy, while leaving the SiN_x covered section practically unchanged. A laser stripe is fabricated that passes through both MQW sections. The wavelength of laser operation can then be tuned by varying the injected current levels applied separately to the two sections. The obtained tuning range was 40 nm spanning from 1538 nm to 1578 nm.

Keywords: Tunable laser, laser diode, multiple quantum well intermixing, fabrication

1. INTRODUCTION

The tunable laser has played a crucial role in many applications that demand simple tunable sources with broad wavelength ranges such as photochemistry, optical communications, and many other spectroscopic and sensing applications. Sorokin and Lankard, and Schäfer were first to demonstrated a tunable laser using the organic dye laser in 1966 [1, 2]. Presently, distributed Bragg reflector (DBR) and distributed feedback (DFB) tunable lasers are already being used in many network applications. In those lasers, DBR and DBF geometries along with, phase-controlling sections, form the wavelength-selective mirrors for the optical cavity, [3–4]. There are spectroscopic applications that do not require the narrow spectral bandwidth of DFB lasers. In such applications, simple wavelength tunable semiconductor Fabry-Perot laser diodes can be fabricated more easily and the wavelength control circuitry is much simplified. The first tunable laser that we have successfully fabricated had a 30 nm tuning range with varying output power [5]. In this work, we demonstrate an InGaAsP multiple quantum well tunable laser diode that amalgamate two gain sections with different bandgap energies. This is achieved using selective area intermixing of the multiple quantum wells using impurity-free vacancy induced disordering. This technique is usually performed by selectively capping the MQW sample with SiN_x or SiO_xN_y dielectric layers and thermally annealing it to expand or shrink the bandgap energy [5, 6].. The bandgap energy of the MQW section capped by a SiN_x layer (Section A) remains unchanged at a corresponding wavelength of 1560 nm. Meanwhile, the bandgap wavelength of the section capped

*T.Tabbakh@knights.ucf.edu

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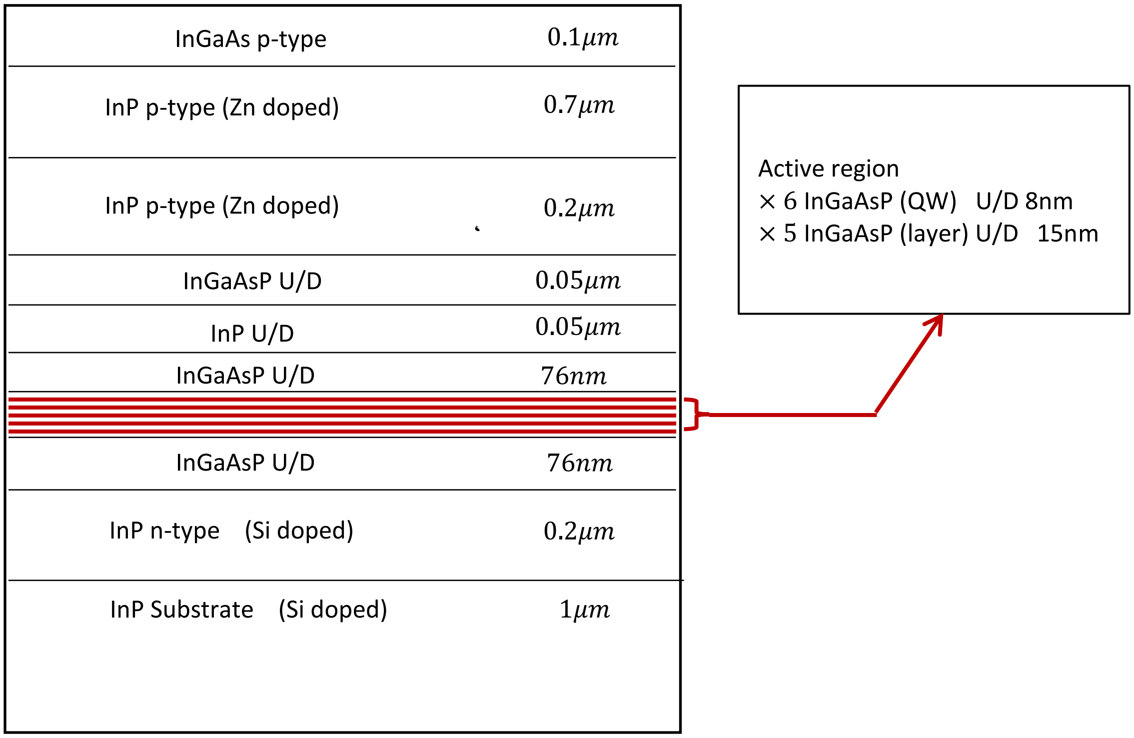
by SiO_xN_y layer is blue shifted to 1530 nm. Different current combination was injected to each section. Wavelength tuning is achieved by varying the two currents ratio. The laser wavelength can be fine-tuned from 1538 nm to 1587 nm with relatively constant output power.

2. DEVICE STRUCTURE

The epitaxial wafer structure used as the platform in this work is shown in figure1. The wafer was grown by metal organic chemical vapor deposition (MOCVD) on a Si-doped InP substrate. The undoped active layer consists of six InGaAsP quantum wells sandwiching five InGaAsP barriers with a larger bandgap energy. This together with two undoped spacers of InGaAsP forms the core of the waveguide. A thin etch-stop layer of InGaAsP is incorporated in the upper InP cladding layer to act as a deterministic ridge height during wet chemical etching processes to fabricate the waveguide devices. The top contact layer consists of a heavily doped p-type InGaAs. .



InGaAs p-type	0.1μm
InP p-type (Zn doped)	0.7μm
InP p-type (Zn doped)	0.2μm
InGaAsP U/D	0.05μm
InP U/D	0.05μm
InGaAsP U/D	76nm
InGaAsP U/D	76nm
InP n-type (Si doped)	0.2μm
InP Substrate (Si doped)	1μm

Active region
× 6 InGaAsP (QW) U/D 8nm
× 5 InGaAsP (layer) U/D 15nm

Figure 1. InGaAsP multiple quantum well laser structure design grown by MOCVD.

3. FABRICATION

Device fabrication is started by coating the entire surface of the sample with a 30 nm thick film of SiN_x using PECVD. Photolithography and reactive ion etching is used to remove the film over half of the sample. Then a 200nm thick layer of SiO_xN_y is deposited by PECVD on the entire sample. After a rapid thermal annealing at 750°C for 30s, the SiN_x coated section (A) is effectively protected from the intermixing and the MQW bandgap wavelength remains at 1560 nm while the MQWs in section (B), whose surface was in contact with SiO_xN_y during the annealing, experiences a widening of the bandgap energy and the bandgap wavelength is shifted to 1530 nm. A ridge waveguide stripe is then delineated by photolithography and wet chemical etching such that it passes through both sections. The device is then planarized using BCB resin and segmented gold contacts are deposited on top of the two sections of the waveguide top p-layer [7, 8]. After depositing the n-contacts on the back of the substrate that has been thinned and polished to a thickness of 100 µm, the sample is cleaved into three separate devices. The first device is cleaved to an overall length of 800 µm with half of the waveguide length crossing each section of the MQWs as shown in figure2. The second device contains an array of 500 µm long laser diodes in the un-intermixed MQWs section A (λ_{PL} = 1560 nm). The third device contains an array of 500 µm long laser diodes in the intermixed MQWs section B (λ_{PL} = 1530 nm). More details on the intermixing and fabrication processes have been reported in our previous work [9, 10].

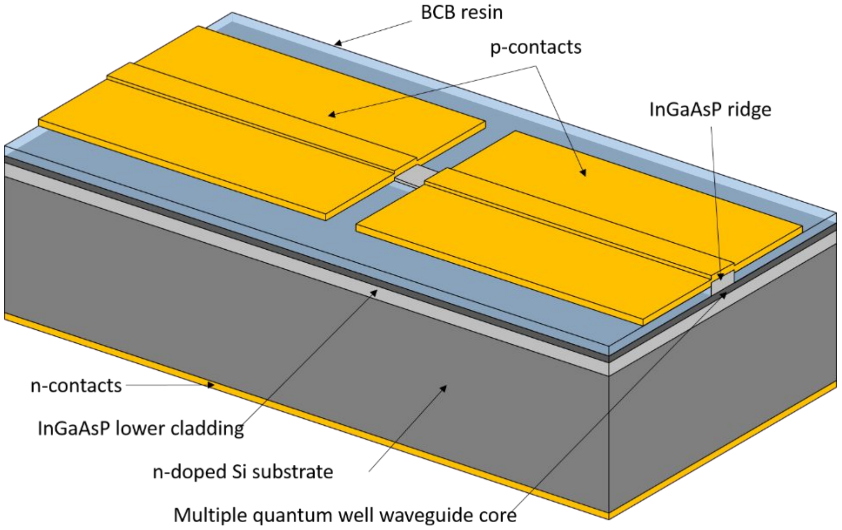


Figure 2. Schematic of the tunable laser diode device after cleaved.

4. RESULTS

The devices are mounted p-side up on a copper header and their operation characteristics were measured using a waveguide alignment setup. The laser light emitted through one of the cleaved facets, was collected by a 40X microscope objective lens and focused into the open end of an optical fiber that is connected to a to an optical spectrum analyzer (OSA) to monitor the emission spectrum. A beam-splitter is inserted between the objective lens and the end of the fiber to project the output light onto a power meter to monitor laser output power as a function of the injected current. Figures 3a shows the emission spectrum of the light output from the laser diodes that contained the un-intermixed MQWs section A. Figure 3b shows the output power as a function of injection current that exhibits a slope efficiency of 0.28 W/A with a laser threshold current of 42 mA. It was also observed that the laser wavelength increased by 1nm when the input current was increased from 100mA to 200mA and this is attributed to thermal effects due to insufficient heat-sinking.

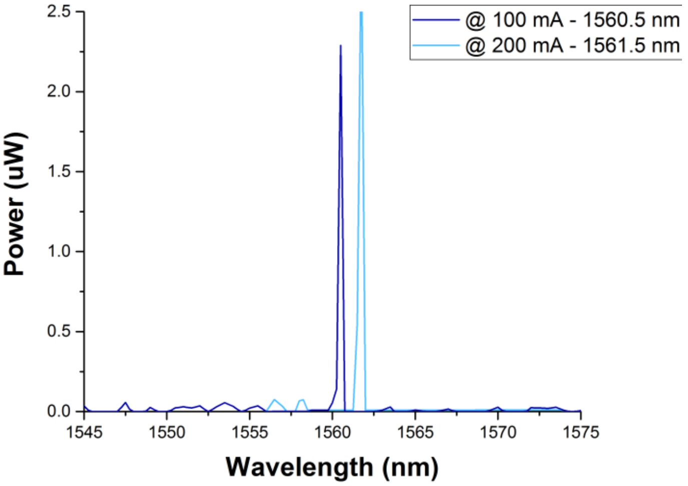


Figure 3a. The laser spectrum for the intermixed SiN$_x$ (Section A) at 1560 nm with 100 mA and at 1561 with 200 mA.

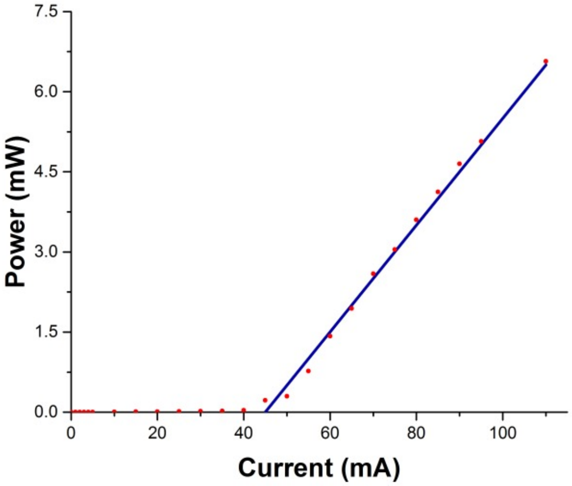


Figure 3b. The L-I curve as a function of injected current into section A

The results for the laser diodes fabricated with the intermixed MQWs are shown in figures 4a and 4b. Here the laser diodes operated with a threshold current of 45 mA and the slope efficiency was 2.16 W/A. Again, it was observed that when the current was increased from 100 mA to 200 mA, the lasing wavelength increased by 1nm, this time from 1560 nm to 1561 nm.

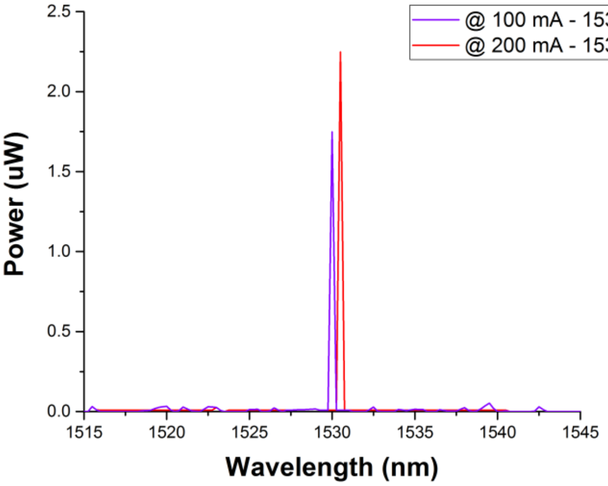


Figure 4a. The laser spectrum for the intermixed SiO$_x$N$_y$ (Section B) at 1530 nm with 100 mA and at 1531 with 200 mA.

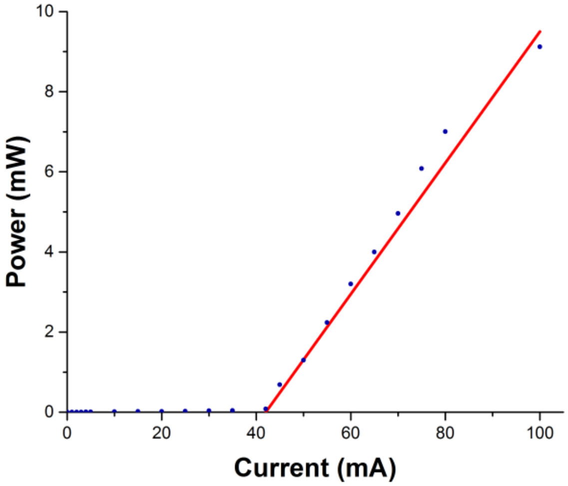


Figure 4b. The L-I curve as a function of injected current into section B

Finally, the two-section laser diode device that contained both un-intermixed section A (λ_{PL} = 1560 nm) and intermixed section B (λ_{PL} = 1530 nm), was tested. Wavelength tuning is achieved by injecting current separately in the two gain sections. When the currents injected in the two sections are varied, the combination of the gain spectra leads to a lasing wavelength whose position depend on the relative magnitudes of the two injected current. The laser wavelength tuning that is obtained by changing the currents combinations is shown in table 1. The tuning range was 40 nm from 1538 nm to 1578 nm as shown in figure 5.

Section A (mA)	Section B (mA)	Total injected current (mA)	Power (mW)	Wavelength (nm)	Section A (mA)	Section B (mA)	Total injected current (mA)	Power (mW)	Wavelength (nm)
12	55	67	0.08	1550	65	30	95	0.79	1539
12	65	77	0.33	1553	65	35	100	1.09	1542
12	75	87	0.726	1553.5	65	45	110	1.16	1545
12	85	97	0.924	1557	65	55	120	1.19	1547
12	95	107	0.957	1560	65	65	130	1.20	1549
12	105	117	1.108	1561.5	65	75	140	1.21	1551.3
12	115	127	1.04	1563	65	85	150	1.21	1552.8
12	125	137	0.726	1566	65	95	160	1.21	1555
25	42	67	0.211	1544	65	105	170	1.15	1558
25	50	75	0.851	1548	75	25	100	0.34	1540
25	65	90	1.122	1550.2	75	35	110	1.08	1544
25	75	100	1.157	1553.5	75	45	120	1.14	1546.5
25	85	110	1.193	1556.3	75	55	130	1.17	1548
25	95	120	1.20	1557.3	75	65	140	1.19	1551
25	105	130	1.20	1560	75	75	150	1.20	1554.2
25	135	160	1.20	1565.7	75	85	160	1.21	1557.4
35	35	70	0.211	1542	75	95	170	1.21	1562
35	45	80	0.99	1545	75	105	180	1.22	1566.8
35	55	90	1.13	1547.8	85	20	105	0.21	1537
35	65	100	1.16	1550	85	35	120	1.15	1545
35	75	110	1.18	1551.8	85	45	130	1.20	1549
35	85	120	1.18	1554.8	85	55	140	1.21	1553
35	95	130	1.19	1555.9	85	65	150	1.22	1556
35	105	140	1.19	1557.3	85	75	160	1.27	1560
35	115	150	1.20	1559.3	85	85	170	1.29	1565.8
45	30	75	0.198	1540	85	95	180	1.36	1568.9
45	45	90	1.12	1545	85	105	190	1.43	1573
45	55	100	1.16	1547.7	100	100	200	1	1578
45	65	110	1.18	1549.3	95	98	192	1.08	1575
45	75	120	1.19	1550.8	55	45	100	1.14	1544.7
45	85	130	1.20	1553.3	55	55	110	1.17	1546.7
45	95	140	1.20	1555	55	65	120	1.19	1549.4
45	105	150	1.21	1557.6	55	75	130	1.20	1551.2
55	25	80	0.34	1538	55	85	140	1.21	1553.4

Table 1. The laser wavelength tuning range as function of the injected currents I_A and I_B in the sections A & B.

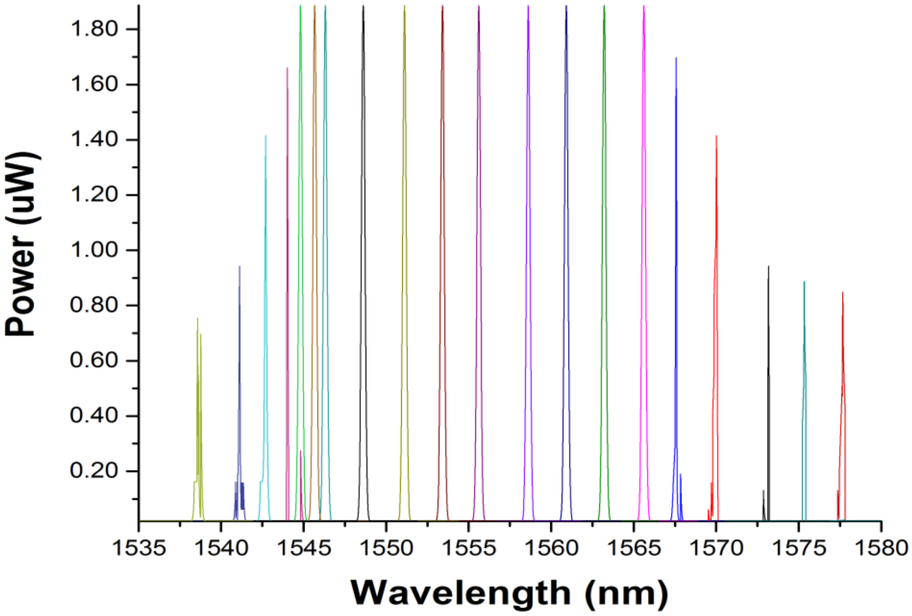


Figure 5. The laser spectra obtained from the two-section laser diode with different currents applied to the two sections.

5. CONCLUSION

Using a controlled technique for selective area intermixing of InGaAsP MQWs, a two-section laser diode whose wavelength of operation can be tuned by varying the injected current applied to the two sections has been demonstrated. The fabricated device was capable of producing laser emission that was tunable from 1538 nm to 1578 nm depending on the currents injected into the two sections. The L-I measurements for individual devices fabricated in either sections show only a small degradation from the characteristics of a reference device fabricated in the as-grown MQW sample.

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