LONG-WAVELENGTH WDM VERTICAL-CAVITY SURFACE-EMITTING LASER ARRAYS SPANNING 140 nm

Jon Geske(1), Devin Leonard(2), Michael MacDougal(2), Yae L. Okuno(1), Joachim Piprek(1),
and John E. Bowers(1)
1: University of California, ECE Department, Santa Barbara, CA 93106, USA, geske@ece.ucsb.edu
2: formerly with Gore Photonics, presently with Rockwell Scientific Company

Abstract *We demonstrate record wavelength span from a long-wavelength WDM VCSEL array covering 140 nm from 1460 to 1600 nm. The arrays are fabricated using nonplanar wafer bonding and fully-oxidized distributed Bragg reflectors.*

Introduction

Vertical-cavity surface-emitting lasers (VCSELs) are of great interest due to their advantages in low-cost manufacturing and packaging. These qualities are compatible with the emerging market for wideband coarse wavelength division multiplexing (CWDM) in low-cost, high-performance, optical networks spanning the entire low-loss and low-dispersion fiber transmission window from 1470 nm to 1610 nm. Integrating the CWDM sources in a wafer-scale fabrication process can achieve great cost savings for this application. Uniformity of device performance is particularly important over the array in these applications. Adjusting the cavity mode laterally across the surface of the wafer is sufficient to achieve small wavelength changes across a VCSEL array, however to keep the device properties uniform, controlling the alignment between the gain peak and the cavity mode is necessary in wideband CWDM VCSEL arrays.

In a previous report, we demonstrated a new technique, nonplanar wafer bonding, that is capable of simultaneously achieving lateral thickness and composition control [1]. Using this technique, long-wavelength arrays with a narrow wavelength span have been fabricated using traditional AlGaAs distributed Bragg reflectors (DBRs) [2]. In this paper we demonstrate record wavelength span from a long-wavelength WDM VCSEL array covering 140 nm from 1460 to 1600 nm. This result is made possible by the simultaneous use of a new, simplified nonplanar wafer bonding procedure and through the use of broadband fully oxidized GaAs/AlOx DBRs [3].

Array Fabrication

The fabrication of this device closely follows the procedure previously reported in Reference [1]. Two strained periodic-gain multi-quantum-well long-wavelength VCSEL active regions are grown vertically on an InP wafer and separated by an etch-stop layer. The active regions have an optical-cavity length of 2.5 wavelengths at 1520 and 1600 nm and have photoluminescence peaks at 1480 and 1560 nm, respectively. In addition, the active regions have a three-period superlattice on one side and a single period superlattice on the other side. The single period superlattice can be used to compensate for growth rate error and for additional wavelength control in the second axis of the final two-dimensional array [4].

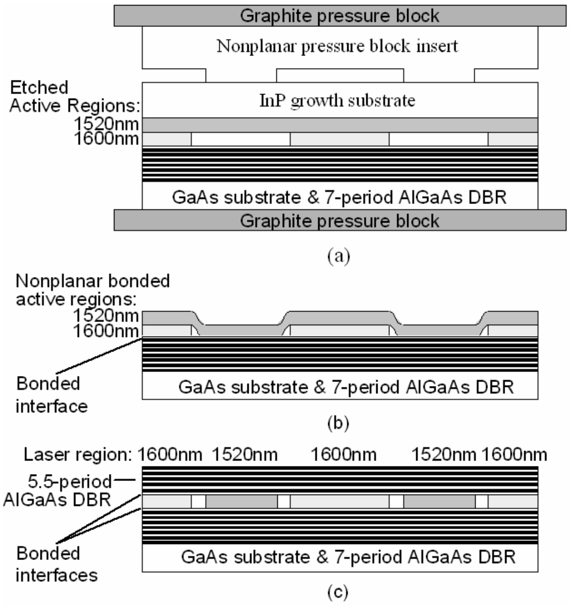

Fig. 1: Process-flow cross-section schematic depicting: (a) the nonplanar pressure block insert against the back of the step-etched InP active region wafer in the graphite wafer-bonding fixture, (b) the VCSEL active regions bonded to the AlGaAs DBR with the InP growth substrate removed, (c) the complete VCSEL array structure after bonding the second AlGaAs DBR and removing the GaAs substrate.

Nonplanar wafer bonding is used to wafer bond the active regions to the bottom DBR of the VCSEL structure. First, the active-region wafer surface is etched with a step-shaped profile to reveal a different active region on each step level. The wafer surface is then placed in contact with a seven-period AlGaAs DBR mirror grown on a GaAs wafer. The active-region epitaxial layers are wafer bonded to the AlGaAs layers by applying pressure and heat in a graphite fixture. A reusable nonplanar pressure block insert is used adjacent to the InP substrate in the bonding fixture. Fig. 1(a) depicts the nonplanar pressure block against the backside of the InP active region wafer before pressure is applied. The nonplanar pressure block is fabricated from InP and designed to have step heights exactly equal to those on the front of the active-region wafer thus causing the wafer to collapse against the AlGaAs DBR wafer surface. In this way, both active regions exposed on the surface of the InP wafer are transferred to the surface of the AlGaAs DBR wafer. After applying 1.7 MPa pressure for 30 min at 600 °C, the original InP growth substrate is removed, leaving the active regions attached to the AlGaAs DBR as depicted in Fig. 1(b). The excess active-region material is removed, revealing a different active region at each lateral position along the first dimension of the AlGaAs mirror. At this point, the original superlattice that was grown on each active region is etched with a step-shaped profile to trim the cavity resonance of each of the two separate active regions in the second dimension of the wafer surface. A second, five-period, AlGaAs DBR is bonded by traditional semiconductor-direct bonding [5] to create the final wafer structure shown in cross-section view in Fig. 1(c).

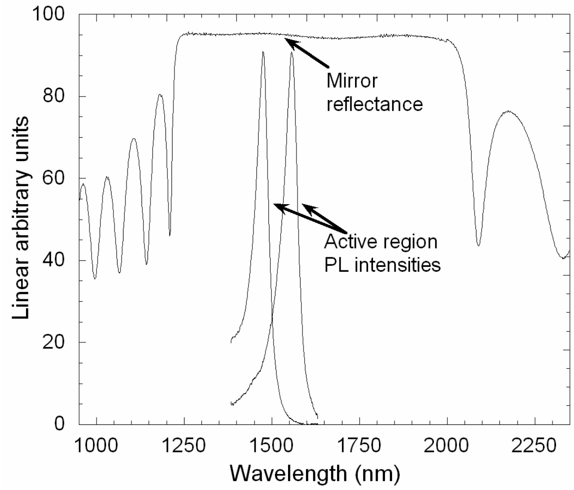

Fig. 2: Reflectivity spectrum of the 7-period fully-oxidized back mirror superimposed with PL spectra from the two integrated active regions.

In order to generate the wide reflectivity bandwidth required for a 140-nm wide WDM VCSEL array we use fully-oxidized DBRs in this VCSEL structure. The mirrors are designed to have peak reflectivity at 1540 nm after the conversion of the AlAs to AlOx by wet thermal oxidation [3]. Oxidation occurs laterally from etched trenches in a steam environment at 430 °C for 16 min. Fig. 2 shows the broad area reflectivity of the 7-period mirror after oxidation. The rippled appearance of the stop-band is believed to be due to the averaging of the trench reflectivity with the mirror reflectivity during the measurement. The PL measurements from the two active regions after the first nonplanar bond are superimposed for comparison.

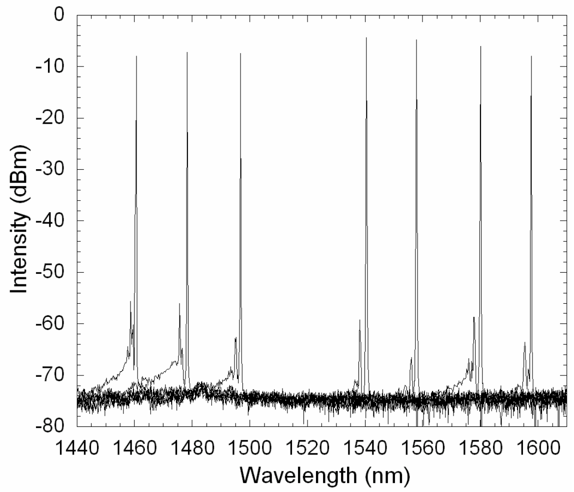

Fig. 3: Superimposed VCSEL emission spectra from the WDM VCSEL array measured at a constant absorbed pump power of 8.4 mW at 0 °C.

Device Results

The final structure is an eight-channel, two-dimensional, WDM VCSEL array. Channel 4, located at 1520 nm, does not have sufficient power for an accurate spectra to be measured. The array is optically pumped with a 980-nm pump laser. Fig. 3 shows the superimposed lasing spectra at a constant absorbed pump power of 8.4 mW for each device. There is a 3.7-dB variation in the output power at this constant pump power. The devices all operate single-mode with side-mode suppression ratios greater than 40-dB. The spectra were measured at 0 °C because the 1520 nm active region was erroneously designed with wells too shallow for room-temperature performance across the entire wavelength span required. Some devices, however, operate as high as 45 °C.

Conclusions

We have demonstrated record wavelength span from a long-wavelength WDM VCSEL array covering 140 nm. These devices exhibit high-quality single-mode emission from 1460 to 1600 nm and show promise for use in CWDM optical-network applications.

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