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Monolithically-integrated long vertical cavity surface emitting laser incorporating a concave micromirror on a glass substrate

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Abstract – **We present a fully monolithically integrated vertical laser using an InGaAs/GaAs/AlGaAs gain medium directly bonded to a glass substrate with a concave micromirror. The lasing wavelength is 980nm with maximum output power of 39mW.**

I. INTRODUCTION

Vertical extended cavity surface-emitting lasers (VECSELs) are of general interest because they have most of the advantages of their short cavity counterpart such as wafer level testing, high quality circular beam, and 2D array scalability. But beyond these advantages, the long stable cavity of a VECSEL allows for better transverse mode discrimination, reduced diffraction losses, and high-power high-quality single mode operation. VECSELs may find applications in optical interconnects and amplifiers due to their ability to provide high output powers in a high quality circular beam appropriate for free-space optics and for efficiently coupling into fibers. Such devices have been demonstrated in the past with external mirrors actively aligned to the gain medium [1,2], achieving hundreds of milliwatts of output power while maintaining single transverse mode operation [1]. However, a fully monolithically integrated structure is advantageous to reduce cost and ease mass production.

Vertical long cavity devices are also of interest for mode-locking. These devices are promising sources for wavelength division multiplexing (WDM), optical time division multiplexing (OTDM), optical interconnects, and optical clock distribution [3,4]. Typically, optical filters in the form of partial intracavity mirrors [1,2] are incorporated in the design of VECSELs to obtain single axial mode operation. However, in the case of mode locking, minimal optical filtering is desired in the cavity to allow the largest possible lasing bandwidth and produce very short high peak power pulses at high repetition rates.

In this work we demonstrate a fully monolithically integrated vertical long cavity surface emitting laser using a glass substrate as the cavity. Fig. 1 shows the general schematic of the device. A stable laser cavity is formed between an AlGaAs/GaAs Distributed Bragg Reflector (DBR) and a concave mirror on the glass substrate serving as the output coupler. The gain medium is located in between the DBR and the glass substrate and is electrically pumped through an intracavity contact and the semiconductor DBR. The laser sits on a heatsink for electrical contact and proper heat dissipation. The cavity is designed to have minimal optical filtering in order to obtain broad gain bandwidth.

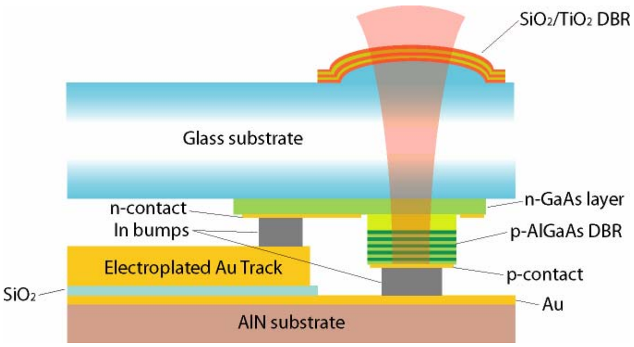

Fig. 1. Schematic of a monolithically integrated vertical long cavity surface emitting laser.

II. FABRICATION

Microlens arrays were fabricated on a 500μm thick fused quartz wafer by photoresist reflow and dry-etching shape transfer techniques [5]. The 99% reflecting concave micromirrors were formed by depositing a SiO_2/TiO_2 DBR on the microlenses. After dicing, each array was bonded at room temperature [6] to a similar size piece of active epitaxial material. The epitaxial structure consisted of a p-doped highly reflective 32-pair AlGaAs DBR followed by 3 sets of 3 $In_{0.14}Ga_{0.86}As$ MQWs surrounded by GaAsP strain compensating barriers and a n-doped contacting layer. The structure was grown up-side down with an $Al_{0.95}Ga_{0.05}As$ release layer in between the GaAs substrate and the AlGaAs DBR.

After bonding the n-GaAs layer to the glass substrate, the GaAs substrate and release layer were selectively etched away leaving a very thin layer of semiconductor material on the glass substrate. Photoresist mesas were lithographically defined on the semiconductor layer and aligned to the micromirror array on the backside of the glass substrate. The mesas were etched down to the n-contact layer by reactive ion etching (RIE). A second mesa was also etched to isolate the n-contact layer of each device. Next, n- and p-type metal contacts were deposited and annealed. Finally, the structure

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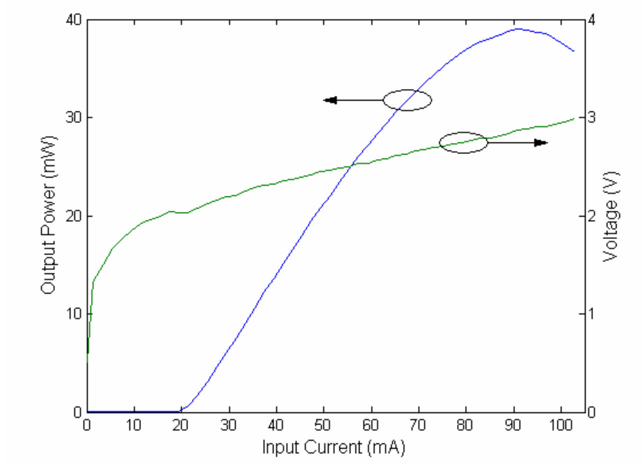
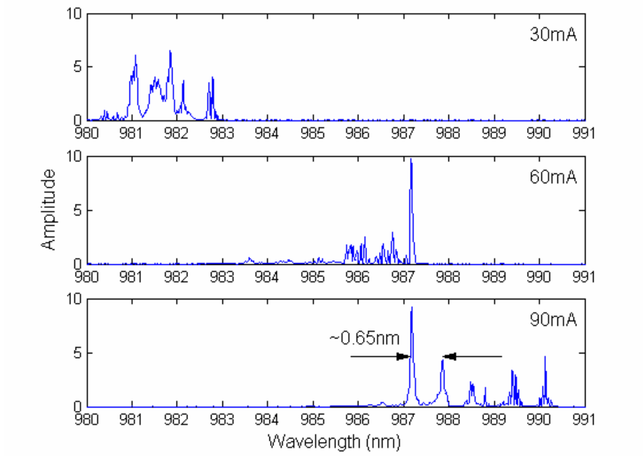
was indium bump-bonded to the gold contact structures on the AlN heatsink as shown. This fabrication process is also valid for integrating other semiconductor gain materials at different wavelengths.

III. DEVICE RESULTS

A silicon heatsink with an array of devices was placed on a cooled copper chuck for testing. The devices were tested CW at a chuck temperature of 15°C, corresponding to a device temperature at the indium bond of approximately 36°C at 90mA pump current [7]. Fig. 2a shows the output power and voltage drop vs. input current for a 52µm mesa device with a radius of curvature of 600µm for the micromirror. The threshold current was 20mA with a differential quantum efficiency of 58%. The maximum power obtained out of this device was 39mW before rolling-over.



(a)



(b)

Fig. 2. a) Output power and voltage drop vs. input current for a device with a 52µm mesa and a 600µm radius of curvature micromirror. b) Lasing spectrum of the same device for three input currents.

The output transverse mode remained stable during operation, however the shape resembled that of a higher order mode. It is believed single transverse mode operation could be achieved by further confining the current injection to obtain a more uniform gain profile.

The spectrum of the laser for three injected currents is shown in Fig. 2b. The broad lasing bandwidth is approximately 3nm wide and red-shifts as the current injection increases. The main peaks of the spectrum at 90mA are spaced by approximately 0.65nm or 200GHz, which corresponds to the axial mode spacing expected from a 500µm thick glass cavity. The sidebands surrounding each main peak indicate the presence of higher order transverse modes.

IV. CONCLUSIONS

We have presented a fully monolithically integrated long vertical cavity surface emitting laser using a glass substrate as the cavity and incorporating a concave micromirror. We have demonstrated CW operation at 980nm with threshold currents of 20mA for a 52µm mesa with 58% differential quantum efficiency and 39mW maximum output power. The device showed the broad gain bandwidth necessary for producing high-power short-pulses when mode-locked.

ACKNOLEGMENTS

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