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4:30 pm – 4:45 pm

Microfluidic cavity surface emitting laser based biosensor

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Laser based microfluidic devices are very attractive for biomedical diagnostics applications. We report for the first time an electrically pumped vertical cavity surface emitting laser with a microfluidic channel as an integral part of the laser cavity to form a photonic biosensor. The goal of this research is to characterize different biological cells with the help of intracavity spectroscopy following the work of Gourley et al [1-4] in 1997. This paper reports initial results on device fabrication, and modulation of laser threshold and slope efficiency, with the bioanalyte's refractive index. An approximate mathematical model is also proposed to support the experimental results.

The device is constructed by attaching a bottom emitting VCSEL above an external dielectric mirror with an intervening ~10-20 μm thick photoresist spacer which forms the sidewall of the fluidic channel. The VCSEL contains a complete top DBR mirror and gain region, but only a partially reflecting bottom mirror so that the external dielectric mirror completes the resonator cavity. The external dielectric mirror is made on a BK7 polished substrate with a high reflective coating (~99%) at the laser wavelength (980nm). The sensor is assembled by heating the dielectric mirror with patterned photoresist at 125 ºC and attaching the VCSEL die to the softened photoresist. The result is a closed fluidic cavity formed between the dielectric mirror and the VCSEL diode. This closed fluidic channel allows fluids and other biological samples through the reservoirs to the cavity of the laser. Figure 1 shows the schematic of the device structure.

The sensing mechanism of the device depends upon the variation in resonator internal losses with the change in refractive index of the fluid flowing through its cavity. Consequently the threshold gain and slope efficiency are modulated and provide a method for sensing the refractive index of the fluid. Figure 2 shows the output optical power vs. laser current characteristics for two different refractive indices of the 10um thick fluidic cavity. It is observed that the laser's threshold current density decreases and slope efficiency increases with increasing refractive index of the fluidic cavity.

A mathematical model has been constructed that quantitatively relates the refractive index of microfluidic cavity to the laser's threshold current and slope efficiency. The model is based on evaluating the change in beam profile at the gain region and hence calculating the change in transverse confinement factor with increase in fluidic cavity index. Changes in the fluid affect both the laser's internal losses and the transverse confinement factor, but the relative change in confinement factor is much higher than that of internal losses. As a result, increased fluid index increases the confinement factor and thus reduces the threshold material gain represented in equation (1).

$$\Gamma_z \Gamma_{xy}(n_{fluid})\, g_{threshold} = \langle\alpha_{internal}\rangle(n_{fluid}) + \langle\alpha_{mirror}\rangle \qquad (1)$$

Here n_{fluid} is the refractive index of the fluidic cavity, Γ_z and $\Gamma_{xy}(n_{fluid})$ are respectively the longitudinal and transverse confinement factors of the laser; $g_{threshold}$ is the material gain at threshold and $\langle\alpha_{internal}\rangle(n_{fluid})$ and $\langle\alpha_{mirror}\rangle$ are the average internal losses and mirror losses respectively. Due to the approximate linear relationship of the material gain of the laser with the current density, it can be said that laser threshold current density deceases with increase in fluid index. On the other hand, the dependence of internal losses on fluid index can be considered to explain the increase in slope efficiency of the laser. From the formula for slope efficiency of a laser diode (2), it can be said that if the internal losses decrease

$$\eta_{slope}(n_{fluid}) = \frac{\langle \alpha_{mirror} \rangle}{\langle \alpha_{internal} \rangle (n_{fluid}) + \langle \alpha_{mirror} \rangle} \qquad (2)$$

with increase in fluid index, then the slope efficiency should increase, which explains the experimental results. The exact dependence of laser threshold and slope efficiency is affected by the laser construction including any tilt of the external mirror due to fluctuations in photoresist thickness. Continuing work on characterization and modeling of fluidic cavity VCSELs in the presence of non-idealities will be presented.

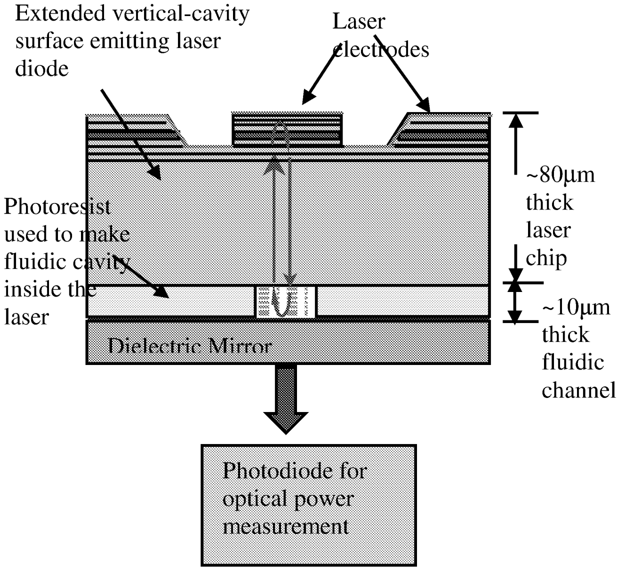

Figure 1. Schematic diagram of the microfluidic cavity surface emitting laser based biosensor.

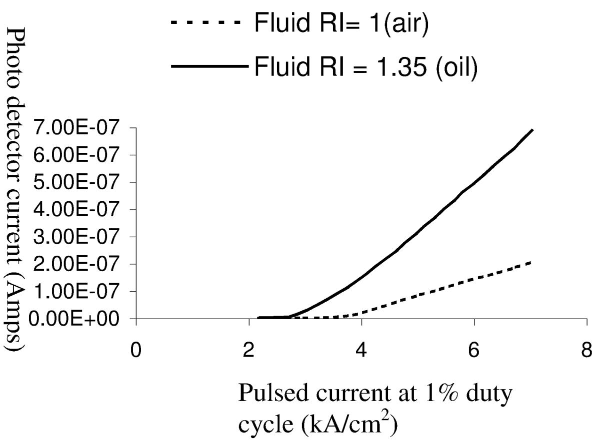

Figure 2. Optical power vs. laser current characteristics of the biosensor device for two different refractive indices of the fluidic cavity. Active region area of the device is approximately 2000 μm^2 and the fluidic cavity thickness is 10μm.

The authors acknowledge the generous donation of VCSELs for the project by Novalux Inc. at Sunnyvale CA.

References:

[1] P.L.Gourley and A.E.McDonald, "Semiconductor microlasers with intracavity microfluidics for biomedical application", Proc. SPIE 2978, pp.186-196, 1997.

[2] P.L. Gourley, T.French, A. E. McDonald, E.A. Shields, and M. F. Gourley, "Ultrasensitive detection of red blood cell lysing in a microfabricated semiconductor laser cavity", Proc. SPIE 2978, pp.195-206 1998.

[3] P. L. Gourley, et al., "Detecting cancer quickly and accurately", Proc. SPIE 3912, pp.2-10, 2000.

[4] P. L. Gourley, et al., "Semiconductor microcavity laser spectroscopy of intracellular protein in human cancer cells", Proc. SPIE 4265, pp.113-124, 2001.