Optically pumped Silicon laser based on evanescent coupling of Si micro-disk to III-V DBR stack

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Abstract: A Si laser with a Si micro-disk evanescently coupled to a III-V gain medium is proposed. The III-V also functions as a DBR at the gain wavelength to minimize the perturbation of the cavity mode.

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Fabrication of lasers in Silicon has been a long-standing goal in the field of opto-electronics. In the last couple of years Raman amplification has emerged as a leading solution to this problem [1,2]. Another approach is to heterogeneously integrate Si with III-V compounds primarily through wafer bonding. A novel evanescent Si laser based on such integration was recently demonstrated by Park et. al. [3].

Here we propose a similar evanescent laser, where a Si micro-disk is coupled to a III-V structure [Fig 1(a)]. The III-V material, which can be optically or electrically pumped, amplifies only the light in the evanescent tail of the cavity mode [Fig 1(b)]. If the loss in the micro-disk is low enough, this small amount of gain will be enough to offset the losses in the Si cavity and achieve lasing. Since Si micro-disks with quality factors approaching 10^6 can be fabricated [4], the amount of gain needed from the III-V can be reduced to < 1dB/cm. This lowering of required gain serves two purposes: firstly, the lower gain drastically reduces the laser threshold carrier density, thereby significantly reducing the pump powers needed by the laser. Secondly, the III-V stack can be moved farther from the Silicon micro-disk because lasing can be achieved with a smaller overlap between the modal field and the gain medium. The increased distance between the Si and the III-V minimizes the effect of the gain medium on the micro-disk mode and helps maintain its high Q. Therefore the lasing mode is essentially a mode of the Si disk with the III-V appearing only as a perturbation. It must be mentioned that in these respects our design differs significantly from the work presented in ref [3], wherein a linear rib waveguide is used as the cavity and the overall laser mode is a 'supermode' of the III-V and the Si with a considerable fraction of the power being confined in the III-V.

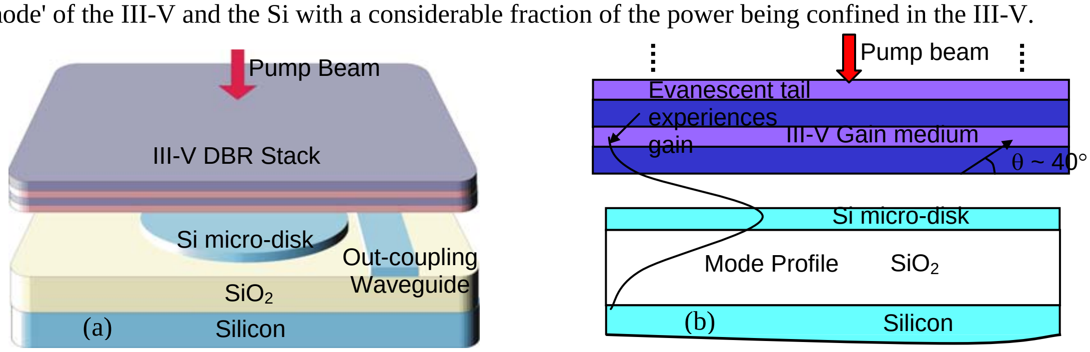

Fig. 1. (a) Schematic of a Si micro-disk coupled to III-V gain medium. The pump beam (@1.31 μm in our experiments) enters from the top of the stack. The laser light is out-coupled through the waveguide, which is also used for Q measurements. (b) Cross-sectional schematic of the device. θ represents the angle at which the evanescent light enters the III-V. The separation between the Si and the III-V stack is of the order of a few 100 nm.

Another crucial feature of our device is the use of a novel DBR structure as the gain medium. While the layers closest to the Si cavity provide gain at a specific wavelength λ_g, the remaining layers of the III-V stack are designed to *reflect* the evanescent portion of the Si mode at λ_g. This further helps limit the overlap between the evanescent tail and the III-V to an amount that is just sufficient to initiate lasing. More importantly it prevents the Si mode from leaking into the bulk InP substrate. In order to construct a Bragg mirror at 1.55 μm, an Antimonide based alloy combination was chosen. Unlike the conventional InGaAsP material system, AlAsSb and GaAsSb have a high enough index contrast (~0.4) to construct an efficient DBR. The exact thicknesses of the layers in the stack are calculated from the vertical component (k_V) of the propagation constant of the evanescent field inside each layer. k_V is simply given by the expression $(k_g^2 - k_{Si}^2)^{1/2}$, where $k_g = 2\pi n_g$ is the total wave-vector of the light in the III-V layer and k_{Si} is the effective propagation constant of the mode in the Si micro-disk (n_g is the refractive index of each layer). For our Si disks, k_V @1.55 μm is ~7.5 and ~10.2 μm^{-1} for the alternating layers, yielding corresponding thicknesses of ~210 nm and ~154 nm [Fig 2]. The gain layers ($Al_{0.01}Ga_{0.99}As_{0.51}Sb_{0.49}$), which have a band-gap of 0.8eV (1.55 μm), are also designed to contribute to the DBR action even though their refractive indices are highly dispersive at the gain wavelength. From the effective masses of the carriers in the gain medium, we estimate that carrier densities of the order of $10^{19}/cm^3$ will yield a gain coefficient in excess of 300dB/cm. All the alloys used are lattice matched to InP and the whole structure shown in Fig 2 has been fabricated using MBE.

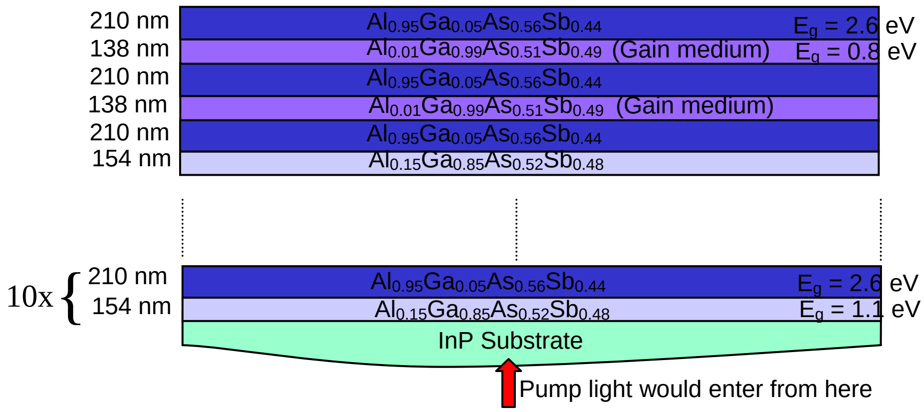

Fig. 2. Structure of the III-V DBR stack. The composition of the gain alloy is chosen so as to have a band-gap of 0.8eV (1.55 μm). The 0.01 Al content in the gain layer improves its stability in air. There are only two layers of the gain medium since the Si modal field is not expected to penetrate very deep into the DBR stack. The topmost layer in the above structure ($Al_{0.95}Ga_{0.05}As_{0.56}Sb_{0.44}$) would be closest to the Si disk in the laser. The gain medium is not grown as the last layer in order to avoid excess surface recombination-induced decrease in carrier lifetime. As indicated, the pump beam for the laser would enter from the bottom InP substrate. A pump at 1310nm (0.95eV) would be absorbed only by the gain layer.

Our initial experiments on this laser structure are being carried out using pulsed optical pumping at 1310nm. The focused pump light enters the DBR from the back [Fig 1(a)] and is absorbed only by the gain medium. 10 μm radius disks, which exhibit Q values of ~10,000 (measured through coupling to an adjacent waveguide), are being used in the setup. Even for these mediocre quality factors, with strong enough pump powers, lasing can be expected from chips in which the separation between the III-V stack and the disk surface is as high as 300nms. SiO_2 spacer layers on the Si maintain the appropriate distance between the DBR and the Si. In our initial experiments the III-V is placed on the spacers without bonding to get preliminary measurements.

In conclusion, a micro-disk based Si evanescent laser has been proposed where the lasing mode is almost entirely in the Si. The device can be expected to exhibit lasing at medium pump powers (~100mW) in spite of mediocre Q factors. The DBR and micro-disks have been fabricated and initial results on light output are expected soon.

References

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