relation for J_{th} in a similar manner reported for Qdots [16], as $J_{th} \propto \Gamma_{inh} V_A / \Gamma$, where Γ, Γ_{inh}, and V_A dominates at the two extreme values of stack number (1 and 8, respectively). However, for $N_{lyr} = 2$ and 3 these parameters probably balance each other thus attaining a relatively small value of threshold current density.

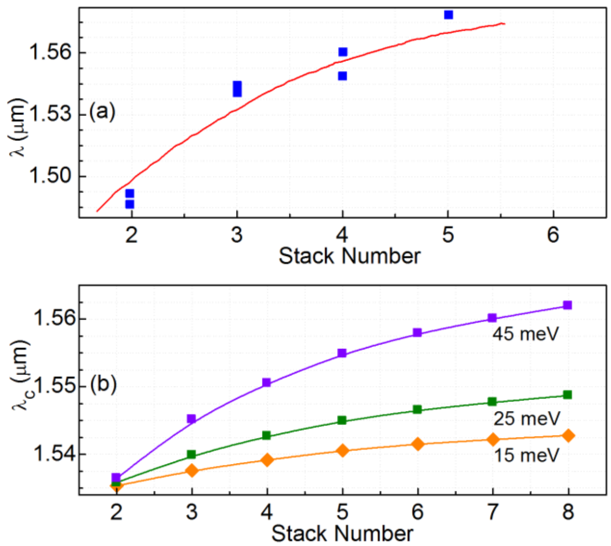

Fig. 2. (a) Experimental [5] and (b) calculated lasing wavelength as a function of the stack number for the Qdash lasers reported in [5] and [15], respectively. The three curves in (b) correspond to various inhomogeneous broadening values calculated at low current injection ($1.1J_{th}$).

The experimental results [5] of lasing spectra as a function of the stack number are shown in Fig. 2(a) and the results obtained from the model in Fig. 2(b). A red shift trend in λ_c is observed experimentally on increasing N_{lyr}, which is well reflected by our calculation, thus showing the effectiveness of our model. The behavior is seen to be consistent with increasing inhomogeneity. A total red shift of $\sim 7.5\ nm$ is observed on increasing the stack number from 2 to 8, corresponding to $\Gamma_{inh} = 15\ meV$. Since, the model does not take into consideration the growth and processing parameters that affect the lasing wavelength, we may attribute this observation to the optical confinement factor (lowers with increase in N_{lyr}) which probably assists in achieving the Γg_{th} rather early. Therefore the lasing condition might be achieved with occupation of carriers in relatively lower energy states, thereby lasing at longer wavelength. Note that the emission at shorter wavelength due to increase in J_{th} with N_{lyr} is suppressed.

Interestingly, our results show that the red shift phenomenon may also be attributed to active medium inhomogeneity. To support this statement we compare the lasing spectra of Qdash lasers at various explicit values of Γ_{inh} in Fig. 2(b). Considering $N_{lyr} = 6$ at $\Gamma_{inh} = 15\ meV$, we observe $\lambda_c = 1541.6\ nm$ and at $\Gamma_{inh} = 45\ meV$, we have $\lambda_c = 1557.9\ nm$. These values correspond to a red shift of $\sim 16.5\ nm$ when Γ_{inh} is increased three times. Moreover, a total red shift of $\sim 26\ nm$ is observed for $\Gamma_{inh} = 45\ meV$ on increasing N_{lyr} from 2 to 8, which is more than three times the value of less inhomogeneous system. This unique observation is a consequence of a quasi zero dimensional DOS of the Qdashes which exploits the increase in the higher energy tail states due to dispersion in dash sizes as a result

#143370 - $15.00 USD Received 1 Mar 2011; revised 12 May 2011; accepted 17 May 2011; published 27 Jun 2011

of increase in Γ_{inh}. In general, dispersive dash sizes result in overlapping DOS which probably increases the states in the high energy tail of the dashes DOS. Therefore, higher energy photons from shorter dashes (smaller height and larger band transition energies) which lase first probably get absorbed in the high energy tails (now incorporating more electronic states due to overlap) of longer dashes (larger height and smaller band transition energies) which lase later and eventually dominate. Therefore, lasing occurs at longer wavelengths due to the small energy photons of the longer dashes. As Γ_{inh} increases, the dashes with least band transition energy subsequently dominate and the lasing shifts to longer wavelengths (red shift of λ_c). In general, we may then deduce the relationship $\lambda_c \propto \Gamma_{inh}\Gamma$.

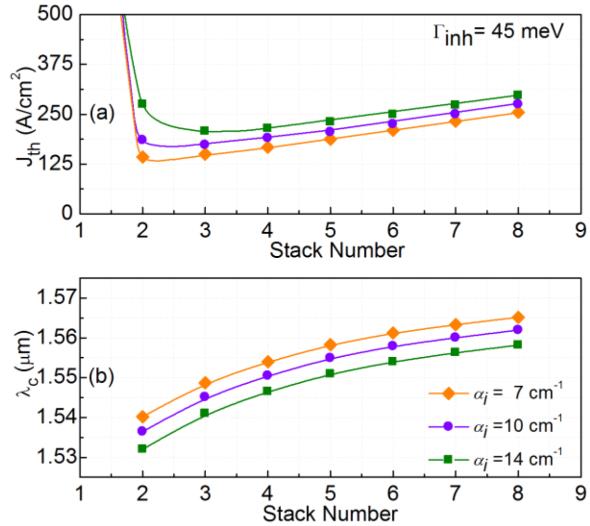

Fig. 3. Calculated (a) threshold current density and (b) central lasing wavelength (at $1.1J_{th}$) for different internal loss values for the Qdash laser reported in [15]. The inhomogeneous broadening is 45 meV.

In our earlier analysis, we have fixed the modal gain Γg_{th} irrespective of increasing N_{lyr}, although experimentally it is shown to increases with N_{lyr} [1,6,16]. Therefore, we now explore the effect of Γg_{th} by varying the internal loss α_i on the threshold current density and the central lasing wavelength as a function of N_{lyr}. The results are shown in Figs. 3(a) and (b), at fixed Γ_{inh}. We observe that lower α_i ($7\ cm^{-1}$) decreases J_{th} and enhances the red shift of λ_c for all values of N_{lyr}. This is typically the practical case for few stacks, where the lasing condition is achieved rather fast due to lower Γg_{th} ($\approx 19\ cm^{-1}$). Hence, further shift to the longer wavelengths is predicted theoretically. However, an increase of J_{th} and a reduction of red shift phenomenon is observed at large α_i ($14\ cm^{-1}$) as illustrated in Fig. 3. This is again consistent with the number of stacking layers. The observation may again be related to the practical case of a large stacking layer structure which improves the modal gain ($\Gamma g_{th} \approx 26\ cm^{-1}$) but with the expense of an increased J_{th} and a shift of λ_c to shorter wavelengths. Besides, Fig. 3(b) show that Γ_{inh} is still the dominant parameter of the red shift phenomenon.

#143370 - $15.00 USD Received 1 Mar 2011; revised 12 May 2011; accepted 17 May 2011; published 27 Jun 2011

4. Conclusion

In conclusion, we have demonstrated theoretically the effect of the number of stacking layers on the characteristics of Qdash lasers. Our model predicts an increase in threshold current density as a result of an increase in the stack number, inhomogeneous broadening and modal gain. We have shown that the red shift phenomenon is a result of the optical confinement factor and, more significantly, of the inhomogeneous broadening. We have qualitatively explained the enhanced red shift phenomenon due to the active medium inhomogeneity by considering the unique DOS of Qdashes.

Acknowledgment

The work was supported by a joint program between KAUST and the University of Michigan, Ann Arbor, under KAUST- Academic Excellence Alliance (AEA) 2010 Grant.

#143370 - $15.00 USD Received 1 Mar 2011; revised 12 May 2011; accepted 17 May 2011; published 27 Jun 2011