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Two Photon Induced Lasing in 1550 nm Quantum Dash Optical Gain Media

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Abstract: We report on a unique lasing mechanism observed in quantum dash Gain media. While the gain media is electrically pumped below lasing threshold, a strong optical pulse excites carriers by two photon absorption into high energy states of the quantum dashes and wetting layer. Fast inter band carrier relaxation and capture processes into the ground states of the quantum dashes result in increased gain followed by lasing at the gain peak irrespective of the stimulating pulse wavelength. The temporal response of the lasing line is examined on a 40 GHz scope and full characterization of the pulse by the XFROG scheme is performed. We show the lasing mechanism to be governed mainly by the wetting layer dynamics and extract a direct measurement of the carrier-carrier scattering time constant.

OCIS codes: (140.5960) Semiconductor lasers; (250.5980) Semiconductor optical amplifiers; (230.5590) Quantum-well, -wire and -dot devices

A unique phenomenon in which an instantaneous gain response takes place in quantum dash (QDash) optical amplifiers was recently reported [1]. This process is initiated by high energy carriers, induced by two photon absorption (TPA), which relax fast to the ground states of all QDashes via carrier-carrier scattering. The instantaneous gain occurs all across the inhomogeneously broadened gain spectrum and is observable using multi wavelength pump probe measurements.

This paper describes a unique use of the TPA induced gain which can be sufficiently large to cause a QDash amplifier with low, but finite facet reflectivities, to oscillate with a threshold that depends on the optical pulse wavelength. The laser oscillation was characterized in both the spectral and time domains. The gain inducing pulse itself was characterized using X-FROG measurements which yield pulse shape and phase responses on the time scale of the, 150 fs wide, pulse itself.

The QDash amplifier we used was 1.5 mm long. The gain region comprised six InAs QDash layers separated by InGaAlAs barriers placed within a GRINCH structure. The amplifier facet reflectivities were estimated to be 0.03% - 0.05%.

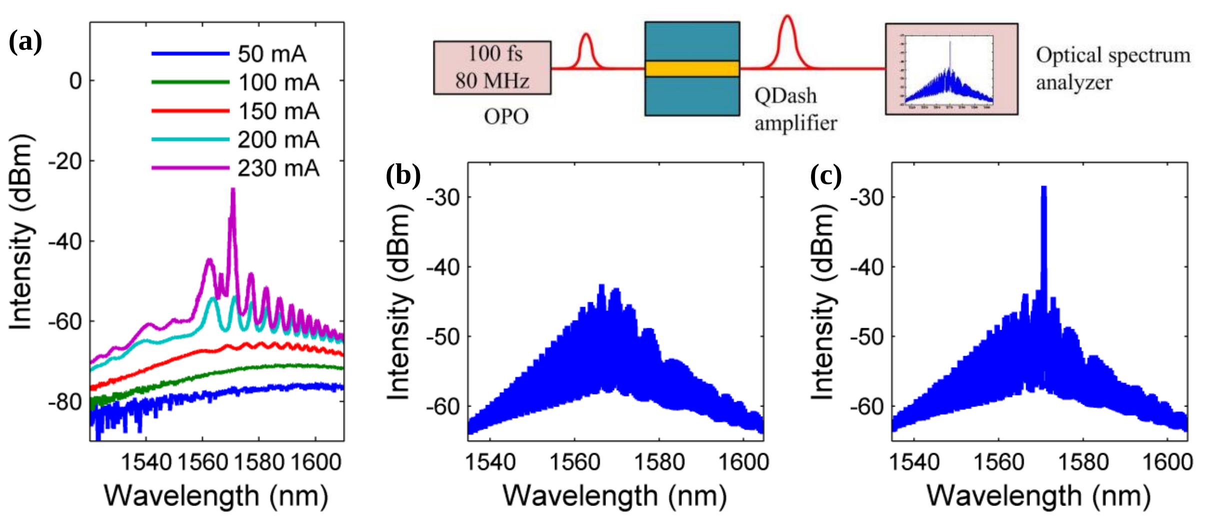

Fig. 1 - Measured spectra. (a) Bias dependent ASE. (b) ASE at a bias of 210 mA. (c) Output spectrum at a bias of 210 mA fed by a 100 fs, 300 pJ optical pump at 1530 nm as shown above the spectra.

The bias dependent amplified spontaneous emission spectra are shown in Fig. 1(a). For bias currents above 220 mA (which is 5.5 times its lasing threshold prior to the facet coating), the amplifier lases. Driving the amplifier at 210 mA yields the ASE spectrum shown in Fig. 1(b). Adding an optical input pulse (as seen in the schematic above Fig. 3(c)) yields a clear lasing spectrum with a narrow line at 1570 nm which is 15 dB larger than the background. The lasing line appears always at the same spectral location independent of the pump wavelength. In order to understand the lasing phenomenon we examined the bias threshold for different pump wavelengths keeping the pump energy constant at 3 pJ. The results are shown in Fig. 2 (a).

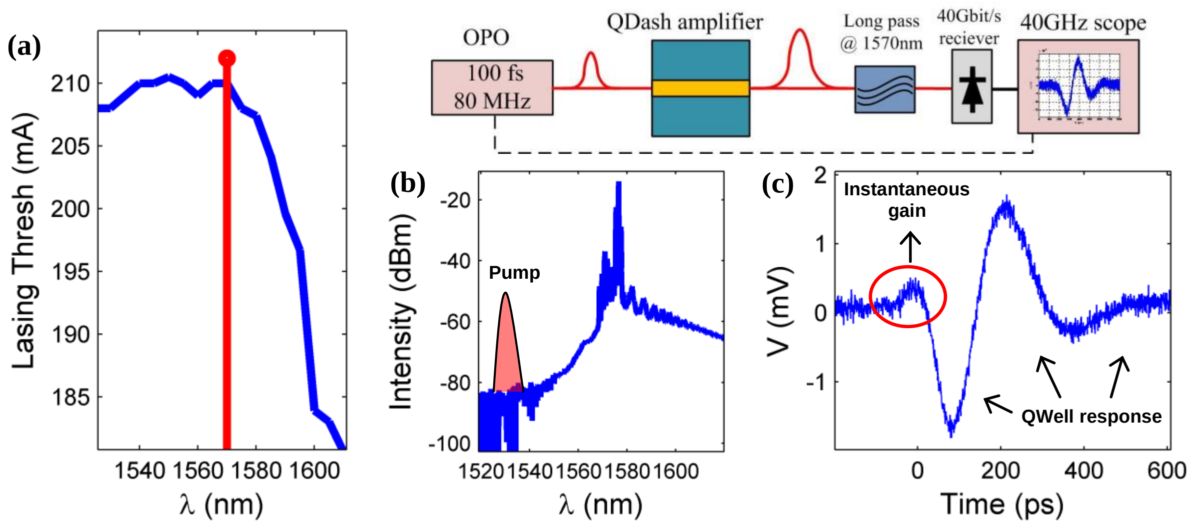

Fig. 2 – (a) Wavelength dependent threshold for a fixed pump power of 3 pJ. (b) Resolved spectrum after long pass filter. The filtered pump is marked for illustration. (c) Temporal response of the laser line. Time response measurement setup is shown above.

The lasing wavelength, 1570 nm is marked by a red line. For pump wavelengths shorter than 1570 nm, the threshold is basically constant at 210 mA. However, for long pump wavelengths, the lasing threshold drops significantly down to 180 mA at 1608 nm.

The optically induced lasing results from a TPA induced gain increase as demonstrated in [1]. This gain increase has an instantaneous response which is irrelevant to the lasing phenomenon but has also a long lived component due to an increase of the barrier state and wetting layer populations. This long lived component manifests itself in the pump probe measurements [1] as an increased transmission, relative to the transmission prior to the pulse perturbation, which lasts for many tens of ps or more. This is long enough for several round trips in the 1.5 mm long amplifier so that lasing oscillation can build up. This means of course that the spectrum in Fig. 1(c) is an average spectrum and the laser is on for only a fraction of the time between the pump pulses (12.5 ns). With this concept in mind, it is possible to explain Fig. 2(a). The longer the pump wavelength, the lower the energy of the TPA induced carriers and therefore the energetic distance to the lasing wavelength (1570 nm, where the cavity losses are minimal) is smaller. This means that the carrier relaxation to the lasing state, mediated by carrier-carrier scattering, is faster [2, 3] so the gain increase is more efficient. Moreover, pumping at long wavelengths causes no depletion of carriers at energies higher than the lasing energy thereby maintaining the efficiency of the carrier-carrier scattering relaxation. The results of these two effects is a reduction of threshold with pump wavelength as seen in Fig. 2(a).

To clarify the effect further, we performed spectrally resolved time response measurements. An example is shown in Fig. 2(b) and 2(c). Fig. 2(b) shows the spectral constellation of the pump (this time at 1530 nm) and the lasing line which is 40 nm longer. The lasing line was filtered using the set up shown above Fig. 2(c) and, detected using a fast detector and measured on a fast sampling oscilloscope. The result is shown in Fig. 2(c) which shows an initial (unresolved) instantaneous gain increase circled in red followed by rather conventional relaxation oscillations of the laser as it turns on.

Several experiments measuring the temporal response of semiconductor lasers biased above lasing threshold and perturbed by an optical pulse were previously performed [4-7]. These were performed in order to study relaxation oscillations and laser line gain switching and yielded a variety of interesting phenomena such as large signal optical modulation [6] and the initiation of dark pulses [7]. however, no previous report showed any evidence of lasing initiation from below threshold due to an optical perturbation.

Finally, we examine the properties of the perturbing pulse itself as it propagates through the QDash amplifier. To this end, we have used a cross – frequency resolved optical gating (X-FROG) system [8,9] shown schematically in Fig. 3(a). The X-FROG scheme requires that the intense sampling pulse be fully characterized by a standard FROG measurement. The input pulse centered at 1585 nm had energy of 926 pJ while the amplifier was biased below threshold at 192 mA. Fig 3(b) shows the perturbing pulse which is a clear Gaussian like pulse with low chirp. Fig. 3(c) shows the pulse after traversing the amplifier and initiated lasing. The original pulse is followed now by a second much stronger pulse which is delayed by approximately 200fs. Based on the knowledge of the instantaneous gain response detailed in [1], we understand the second peak to be an observation of self-induced amplification namely, amplification of the pulse trailing edge by TPA excited carriers originating from the leading edge. The observed effect can be interpreted as a direct measurement of the carrier-carrier scattering time. The delay of about 200 fs is consistent with theoretical predictions [2].

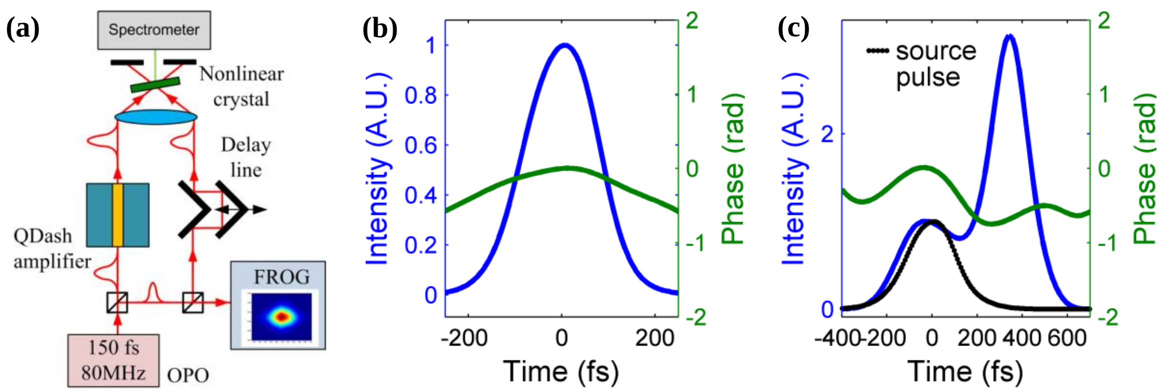

Fig. 3 – (a) The X-FROG scheme. (b) Retrieved source pulse. Intensity is normalized so that the peak reaches unity. (c) Retrieved pulse after propagating through the amplifier. The source pulse is marked for comparison. Intensity is normalized so that the first peak reaches value of unity.

To conclude, we have demonstrated a unique lasing mechanism in quantum dash gain media which relies on TPA, the wire like density of state function of the dashes and the gain inhomogeneity. Lasing at 1570 nm is initiated by short pulses centered at wavelengths which are either longer or shorter than 1570 nm with the laser threshold dropping as the pump wavelength increases. Detailed time domain characterization of the lasing output as well as X-FROG measurements which characterize the perturbation pulse itself have been presented. The latter reveals a direct observation of the nearly instantaneous gain response and a direct measure of carrier-carrier scattering times.

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