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Random telegraph noise in InGaAs self-assembled quantum dots

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Abstract. We have measured random telegraph noise in the photoluminescence of individual quantum dots of InGaAs in GaAs. We have observed not only two-level dots but also dots switching among three level in both systems. The experiments show that the switching InGaAs dots behave very similarly to switching InP dots in GaInP. The switching is attributed to defects and we show that the switching can be used as a monitor of the defect.

Introduction

Random telegraph noise, or blinking, has recently been observed in the photoluminescence from several quantum dot systems, such as colloidal dots of CdSe [1, 2], coherently grown dots of InP in GaInP [3], and strain-induced dots in GaAs [4]. There have also been reports of intermittencies, although not clearly displaying a telegraph signal in coherently grown II–VI dots [5]. The switching rate can be very slow, having typical timescales of seconds or even minutes. In some cases (colloidal [1, 2] and strain-induced dots [4]) the emission changes in energy and in some cases (coherently grown InP-dots [3]) only the intensity is modulated by the switching. For colloidal dots, a model based on photo-ionization has been used to explain the switching [2, 6], whereas for coherently grown dots, a model involving a mobile photo-activated defect has been proposed [3]. This defect was proposed to have two fairly longlived configurations. In one of the configurations the defect captures carriers from the dot causing a low emission intensity whereas in the other configuration the capture of carriers is less efficient and the dot is luminescing in its on-state. The defect model for coherently grown InP dots has received support by experiments in which the defect has been excited independently of the dot, causing a change in the rate of switching [7]. Interestingly, not only switching between two levels have been observed in InP dots, but also switching between three levels [2, 8]. However only one III–V system of coherently grown dots have been observed to exhibit blinking (InP dots in GaInP) and it is important to know if this effect is peculiar to this system. We will here show that GaInAs quantum dots in GaAs also exhibit switching and that the phenomenon could be quite general in III–V semiconductors. In fact the two systems behave in a very similar way, offering the hope for a unifying principle.

1. Experimental

The samples were grown by solid source molecular beam epitaxy. The substrates used were (211) A/B oriented GaAs. They were mounted side by side on the same Mo block with indium to ensure identical growth conditions. After removing the surface oxide at a temperature of 580 °C, a 30 nm GaAs buffer layer was deposited at 600 °C, followed by

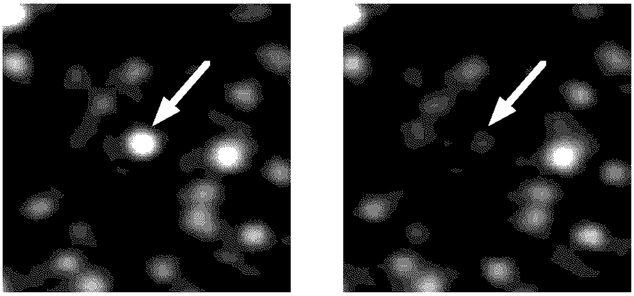

Fig. 1. Images of the sample taken at two different occasions. One dot, marked with an arrow has changed its emission intensity.

a 10 period GaAs/AlAs superlattice, and finally by a 200 nm thick layer of GaAs. The $In_{0.4}Ga_{0.6}As$ quantum dots were then grown at 500 °C via the Stranski–Krastanow growth mode. The InGaAs thickness was 9 monolayers. The quantum dots were covered by 10 nm of GaAs before increasing the temperature back to 600 °C, where a 50 nm GaAs layer was grown followed by a 30 nm of AlGaAs layer and a 40 nm layer of GaAs serving as a cap layer. The samples were not intentionally doped.

The quantum dots were usually excited with the 532 nm line from a frequency doubled YAG-laser with typical excitation power densities of 10–100 W/cm^2. The emission was collected through a microscope and detected with a video-camera, connected to a computer. In order to select a certain wavelength range we used a tunable interference filter having a bandpass of 0 nm. The measurement temperature was typically about 10 K unless temperature dependent measurements were performed. In order to change the excitation power density we used a continuously variable neutral density filter. Unless noted, every experiment has been repeated on several dots in order to find the general behaviour of the switching phenomenon. In fact two samples (with (211)A and (211)B orientation) have been measured showing essentially identical behaviour.

2. Results and discussion

In Figure 1 we show two images of a region of the sample taken at two different times. It can be seen that although the intensities of most dots is constant, there is one dot which has changed its emission intensity between the images, going from an on-state to an off-state. The images were taken through a band-pass filter centered around 1.37 eV, having a bandwidth of 15 meV. We find that for a given experiement only a few (about one in one hundred) dots are blinking. The excitation was in the GaAs barrier in this case. We have also dots directly using an energy of the excitation laser which was below the wetting layer energy, and we find that the dots are still switching. It is thus unlikely that the switching is due to variations in the capture probability.

In Figure 2 we show intensity traces of a two-level quantum dot for different excitation power densities. It can be seen that the frequency of switching increases very rapidly with increasing excitation power density. There is emission from the dot also in the off-state with an intensity of about one third of the intensity in the on-state. We have confirmed for a few dots that the emission energy do not change appreciably between the on-state and the off-state using either visual inspection of video-images after a monochromator, or by using interference filters. Unfortunately the dot density is too high to make detailed investigations.

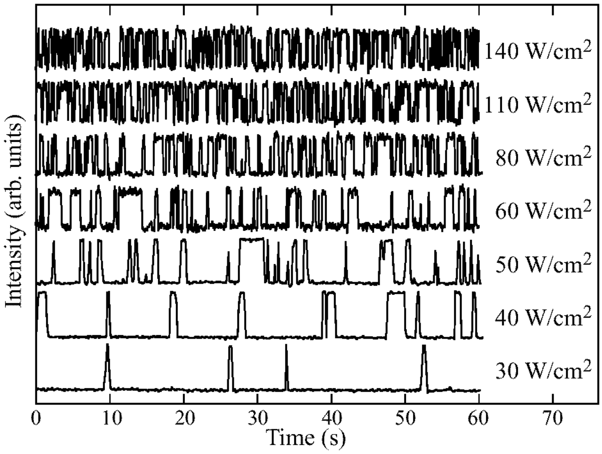

Fig. 2. Traces of the emission intensity for a two-level dot at different excitation power densities.

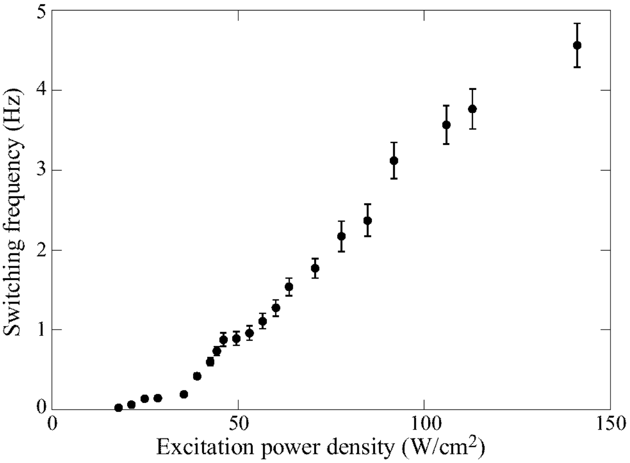

Fig. 3. A plot of the switching frequency as a function of the excitation power density.

It is interesting to notice that for sufficiently low excitation power density the dot is in an off-state which appears to be permanent. All investigated dots have been found to be in an off-state at low excitation power density. This argues against the alternative explanation that the switching frequency is too low to measure, in which case we would expect to see some dots in the on-state (although not appearing to be switching). Figure 3 shows a plot of the switching frequency as a function of excitation power density. In contrast to InP dots, which can irreversibly (and easily) be changed to a permanently on-state by increasing the excitation power density, we find that the GaInAs dots are much more robust. Many GaInAs dots have been exposed to fairly high excitation power densities (5 kW/cm^2) without changing to non-switching dots. At even higher excitation densities (50 W/cm^2) most dots do quench and then always to an on-state, exactly like InP dots. We have also observed dots switching among three levels.

If we compare the behaviour of GaInAs dots and InP dots we mostly find similarities.

Only very few dots are found to exhibit switching and there is emission also in the off-state. The rate of switching increases with excitation power density and with temperature. Dots switching between two levels and dots switching among three levels are present. In both systems about 1 percent of the switching dots are three-level dots and the rest are two-level dots.

There are, however, one significant difference between the two systems. In the InP system it is easy to quench the dots permanently to an on-state by strong illumination. In the GaInAs it is far harder to quench the emission to a permanently on state although this has been done in a few cases. We tentatively propose that this difference could due to the different stiffnesses of the matrix, with GaAs being stiffer than GaInP, leading to a reduced mobility of the defects. However more work is needed to reach a more definite conclusion.

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References

[1] M. Nirmal, B. O. Dabbousi, M. G. Bawendi, J. J. Macklin, J. K. Trautman, T. D. Harris and L. E. Brus, *Nature* **383**, 802 (1996).

[2] S. A. Empedocles, D. J. Norris and M. G. Bawendi, *Phys. Rev. Lett.* **77**, 3873 (1996).

[3] M.-E. Pistol, P. Castrillo, D. Hessman, J. A. Prieto and L. Samuelson, *Phys. Rev. B* **59**, 10 725 (1999).

[4] D. Bertram, M. C. Hanna and A. J. Nozik, *Appl. Phys. Lett.* **74**, 2666 (1999).

[5] B. P. Zhang, Y. Q. Li, T. Yasuda, W. X. Wang, Y. Segawa, K. Edamatsu and T. Itoh, *Appl. Phys. Lett.* **73**, 1266 (1998).

[6] Al. L. Efros and M. Rosen, *Phys. Rev. Lett.* **78**, 1110 (1997).

[7] M. Sugisaki, H.-W. Ren, S. V. Nair, J.-S. Lee, S. Sugou, T. Okuno and Y. Masumoto, *J. Lumin.* **87-89**, 45 (2000).

[8] Mats-Erik Pistol, *Phys. Rev. B* (2001) (accepted).