Optically driven current turnstile based on self-assembled semiconductor quantum dots

G. Cerulo [1], V. Liverini [1], P. Friedli [2], H. Sigg [2] and J. Faist[1]

[1] *Institute of Quantum Electronics, ETH-Honggerberg, CH-8093, Zurich, Switzerland*

[2] *Paul Scherrer Institute, Laboratory for Micro- and Nanotechnology 5232 Villigen PSI, Switzerland*

We studied two structures based on a plane of *InAs/GaAs* self-assembled quantum dots (QDs) coupled through a *GaAs/AlGaAs/GaAs* multi-barrier structure to an *InGaAs* quantum well (QW). The latter, filled with the electrons from the *n+* doped *GaAs* top contact layer, works as a reservoir of electrons. The QDs, filled up to the *s* level, are ionized by mid-infrared optical radiation and refilled by the electrons from the QW, which tunnel through the *GaAs/AlGaAs/GaAs* multi-barrier [1]. The electrons, optically excited from the s-level to the continuum, are swept away by the built-in potential, toward the bottom contact, giving rise to a current [2]. Two devices have been characterized with two different QD densities $n_D=2\cdot10^{10}cm^{-2}$ and $n_D=3\cdot10^{9}cm^{-2}$, respectively. The density was estimated by SEM on two reference samples grown in similar conditions (see Fig. 1a). To prove the turnstile operation, the devices were excited by pulsed radiation (100ps) @ $\lambda=6.8\mu m$ (*s→continuum*) (see Fig. 1b), with a pulse rate *f=1kHz*. To remove the contribution coming from the spectral overlapping between *s and p* levels of the QDs, the current measured @ $\lambda=10\mu m$ (*p→continuum*) was subtracted from the current @ $\lambda=6.8\mu m$ [3]. In saturation conditions, when all the QDs get ionized by the incident radiation, the contribution of the electrons from the *s* level is $I=2\cdot N_D\cdot f\cdot e$; where N_D is the number of QDs and *e* the charge of the electron. The current density obtained after the subtraction operation is shown in Fig 1c, as a function of the applied bias. In correspondence of the plateau, because of the proportionality relationship, we could estimate the QD density for the two devices: $n_D=1.60\times10^{10}cm^{-2}$ and $n_D=1.85\times10^{9}cm^{-2}$, respectively. These values are in a good agreement with those obtained from the preliminary SEM characterization, proving the turnstile working principle of the two devices.

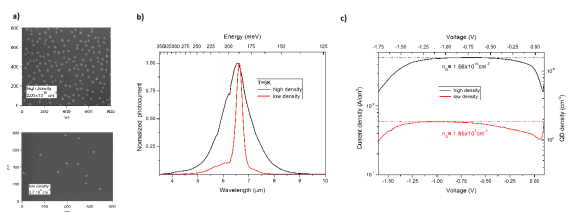

Fig. 6 (a) SEM pictures of the two reference samples; (b) Photocurrent spectra of the two devices based on high density (black), and the low density (red) QDs; (b) Photocurrent density measured exciting @ *6.8μm* at a pulse rate of 1 *KHz* (T=5K) for the electron pump based on high density (black) and low density (red) self-assembled QDs.

[1] G.Cerulo, L. Nevou, V. Liverini, F. Castellano and J. Faist, *J. Appl. Phys.* **112**, p. 043702 (2012)
[2] L. Nevou, V. Liverini, F. Castellano, A. Bismuto and J. Faist, *Applied Physics Letters* **97**(2) p.023505 (2010).
[3] L. Nevou, V. Liverini, P. Friedli, F. Castellano, A. Bismuto, H. Sigg, F. Gramm, E. Muller and J. Faist, *Nature Physics* **7**(5) p.423 (2011).