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# OPTICAL BISTABILITY DUE TO PHOTO-INDUCED CHARGE TRANSFER IN A TYPE-II GaAs/AlAs QUANTUM WELL

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We present a bistability of low temperature photoluminescence in a *n-i-n* type-II GaAs/AlAs quantum heterostructure. Spectral analysis and electrical measurements indicate that the two states correspond to hole accumulation in different layers. The transition occurs with the alignment of electronic $\Gamma$ and $X$ states due to optical pumping, and no external voltage bias is needed.

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The feasibility of type-II GaAs/AlAs heterostructures involving $X$-point conduction states has motivated several studies since 1986 [1–3]. In an asymmetric structure, the creation of internal electric fields due to spatial separation of charges has been demonstrated [4]. We describe here a type-II quantum well structure which exhibits an intrinsic optical bistability on photoluminescence (PL). The most outstanding point is that, because of photocreated electric fields, it is observable without any external voltage bias, contrary to all other electro-optic bistable devices like self electro-optic effect devices (SEED) [5], double-barrier resonant-tunnelling structures [6] or asymmetric quantum wells [7–9]. However, electrical detection and switchings are also possible.

The structure grown by molecular beam epitaxy consists of a *n-i-n* sequence. The intrinsic region is made of four layers, as described and labelled in Fig. 1. It may be viewed as a type-II quantum well, embedded into a $Ga_{0.65}Al_{0.35}As$ layer acting as a barrier for $\Gamma$- or $X$-electrons. The electron ground level is of $Xxy$ symmetry [10] and located in the AlAs layer, whereas the hole ground state is of $\Gamma$ symmetry and located in the GaAs layer. The $\Gamma$-symmetry conduction level located in the GaAs layer is about 60 meV above the $X$ ground state. For electrical measurements under optical excitation, we have made 300 × 300 $\mu$m mesa-type diodes with a peripheric Au–Ge–Ni ohmic contact by conventional lithography and chemical etching.

The PL spectra, obtained with an Argon-laser excitation, show two main lines (Fig. 2): the one (at about 1.80 eV) is attributed to recombination in the type-II well, the other (at about 2.00 eV) to recombination in the GaAlAs barriers. When the *n-i-n* diode is short-circuited (either by the external contacts in

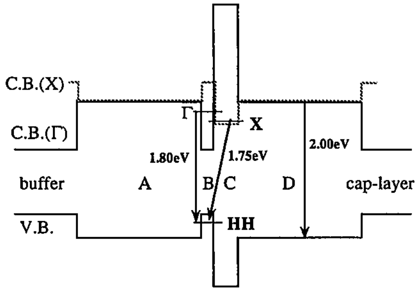

Fig. 1. The *n*-*i*-*n* structure is made of the following sequence: substrate+buffer GaAs *n*+; A, $Ga_{0.65}Al_{0.35}As$, 100 nm; B, GaAs, 2.5 nm; C, AlAs, 10 nm; D, $Ga_{0.65}Al_{0.35}As$, 100 nm; cap-layer GaAs *n*+, 100 nm. The potential profiles for $\Gamma$-electrons and holes (solid line) and $X$-electrons (dashed line) are sketched, as well as calculated energy levels. The resulting transition energies are indicated.

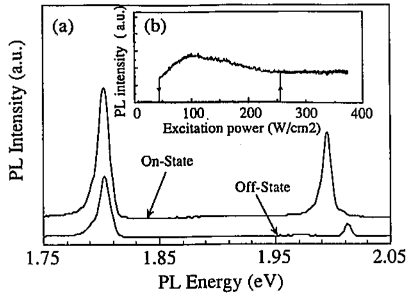

Fig. 2. (a) PL Off- and On-spectra of as-grown sample for $P_{ex} = 100$ W/cm$^2$. (b) Hysteresis loop versus $P_{ex}$ of PL intensity at 2000 meV.

mesa-type sample, or by oval defects or various imperfections in as-grown sample), two different spectra may be obtained in the 40 to 250 W/cm$^2$ $P_{ex}$-range, depending on previous value of $P_{ex}$. The most prominent distinction is found on the high energy line: its intensity is 50 times more intense in the On-state than in the Off-state and it is broadened towards lower energies. The low energy line intensity typically increases twofold in the On-state.

Before the Off/On commutation, we observe with increasing $P_{ex}$ a blue-shift and a broadening of the type-II line, which saturates when $P_{ex}$ is about 100 W/cm$^2$. This is well understood as consequences of the filling of the two-dimensional densities of states associated to $X$-electrons and heavy holes (HH) ground levels in the well. The filling is described by Pseudo Fermi Levels (PFL); the broadening of the line is then equal to the sum of both electron and hole PFL. These charge accumulations in two different layers (B and C) also induce a band bending that leads to the blue-shift of the transition. In such a type-II and indirect well, the lifetimes are long ($> 1\mu s$), then large carrier densities may easily be obtained under relatively low optical excitations. But, because of the filling and the band bending, the $X$ PFL in C-layer is lifted up to the $\Gamma$ level in B-layer, allowing a fast (about 1 ns) $\Gamma$–HH recombination. This mecanism decreases drastically the lifetimes of whole holes and of electrons close to the $X$ PFL, and then leads to a saturation of the filling. We estimate the saturation densities at $7 \times 10^{11}$ cm$^{-2}$.

On mesa-type sample, we measure a strong positive photovoltage on the cap-layer (up to 300 mV), and the PL of open-circuited diodes looks like the On-state (high recombination from the barriers, shifted towards low energies), even for low $P_{\text{ex}}$. Then, no bistability occurs. This behaviour is explained by a hole accumulation in the D-layer that takes place because of the C–AlAs barrier in the valence band which prevents holes photo-created in the D-layer from being collected in the B-layer. In the A-layer, both electrons and holes can move freely, then any electric field in this layer would be screened as far as charges accumulations are possible at its extremities. Figure 3a shows the resulting potential profile in open-circuit conditions.

When the diode is short-circuited, D-holes in excess are allowed to flow towards the cap layer, generating a positive photo-current. It induces a positive charge accumulation at the interface buffer/A-layer and then an electric field in the A-layer. It increases the hole injection in the B well and therefore the B-hole population. The field in A-layer is then screened and we are led to an equilibrium between the negative B–C dipole and the positive C–D dipole (Fig. 3b). Then the D-hole population remains weak; it corresponds to the Off-state.

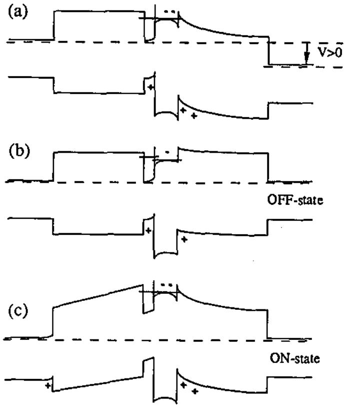

Fig. 3. Potential profile (a) in an open-circuited diode; (b) in a short-circuited diode in the Off-state; (c) in a short-circuited diode in the On-state.

When $P_{\text{ex}}$ increases, both B–C and C–D dipoles will grow, until the alignment between the $X$ PFL and $\Gamma$ electrons level occurs in the well. At this point, the hole lifetime is strongly reduced and the augmentation of hole injection in the B-well will no more result in an augmentation of the B-hole population. The electric field in the A-layer is then no more screened and further lowers the $\Gamma$ electron level with respect to the $X$ PFL. It favours fast $\Gamma$–HH recombination and further reduces B-holes lifetime, thus providing a positive feed-back that leads to a discontinuous change in charge repartition: hole accumulation no more occurs in the B-layer, but at the buffer/A-layer interface. Because of the larger separation between holes and electrons, the left dipole amplitude is higher with the same charge quantity, and allows much higher hole accumulation in the D-layer; it characterizes the On-state (Fig. 3c) and is detected through a huge increase of the D-barrier PL.

To summarize, we have observed in low temperature conditions an optical bistability between two different charge distributions. The time response is about 10 ns for Off/On commutation and about 1 $\mu$s for On/Off commutation; the On/Off contrast ratio is 50:1. The more important point is that it needs no external voltage bias and then no electrical addressing. Moreover, threshold values are at least two orders lower than in current all-optical devices [11].

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