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AUGER Effect provoked Luminescence Line Shift of highly compensated GaAIAs Samples at elevated Excitation Levels

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Abstract

Electron-beam excited luminescence measurements at low temperature bring about a new bonding state in highly Silicon doped and almost compensated Ga_{1-x}Al_xAs. It has been identified as a {donor-acceptor 1-acceptor2}-molecule showing in the luminescence spectra AUGER effect behavior. Carrier transitions via two recombination channels involve the donor-acceptor pair transition at 1.8 eV, and a free-to-bound transition at 2.1 eV. At high excitation level the main peak position and luminescence intensity of the donor-acceptor recombination channel turns out to be affected in a characteristic manner by the existence of AUGER molecules. Recent fabrication techniques [1] may now allow constructing in a controlled fashion such AUGER-type molecules in semiconductors with predefined spacing of the participating donor and acceptor atoms. Own experimental results are analyzed by use of a set of rate equations, incorporating a particular bonding state together with an AUGER process.

Introduction

Excess charge carriers in semiconductors, after having experienced an external excitation to higher energetic levels, regain their equilibrium state by several ways, one of which being the radiative recombination. Between many others is the donor-acceptor radiative pair transition frequently found in the luminescence of doped semiconductors [2,3]. The involvement of AUGER transitions is discussed, when emission bands are quenched or even missing, which otherwise should be present. A particular situation is created, when a highly doped and almost compensated semiconductor is excited to an extent, that almost all existing donor-acceptor (da) pairs are involved in the recombination process. As a consequence, a new type of bound state can be supposed, which is formed of a close da -pair and a neighboring second donor or acceptor. The de-excitation behavior of such a bound state resembles characteristics known from AUGER transitions, which suggests this constellation to be called an AUGER molecule. The da -pair recombination, on the other hand, provides a means to dismantle the existence of AUGER molecules by virtue of the common intensity saturation and peak energy behavior of the main emission band. As an interesting result one should even expect a red-to-green color shift of the integral luminescence radiation at higher excitation levels.

1. AUGER molecule

We consider an AUGER molecule in the here discussed context as a bound state between three interacting impurity atoms (d_1 , a_1 , a_2) within a crystalline semiconductor host, as shown in the following Figure 1(a).

In the present case the acceptor of a close impurity pair, formed of donor d_1 and acceptor a_1 , separated by a distance R_1 from each other, is situated near the acceptor of a distant pair (R_2), formed of donor d_2 and acceptor a_2 . The separation distance R_3 between the two acceptors is an important measure for the formation of the AUGER molecule. It is clear, that only highly doped (n-type in the discussed case) and almost compensated semiconductors provide for such a situation. The expected relaxation processes after an external excitation are shown in Figure 1(b). Given a relative closeness of a_1 and a_2 , the otherwise radiative transition P_{DAP} between d_1 and a_1 is quenched due to a non-radiative AUGER transition $d_1a_1a_2$. As a consequence, an energetic hole is pushed into the valence band, which after thermalization allows a transition P_{Fb} between the AUGER-liberated donor d_2 of the second pair d_2a_2 , and the AUGER-freed hole from a_2 .

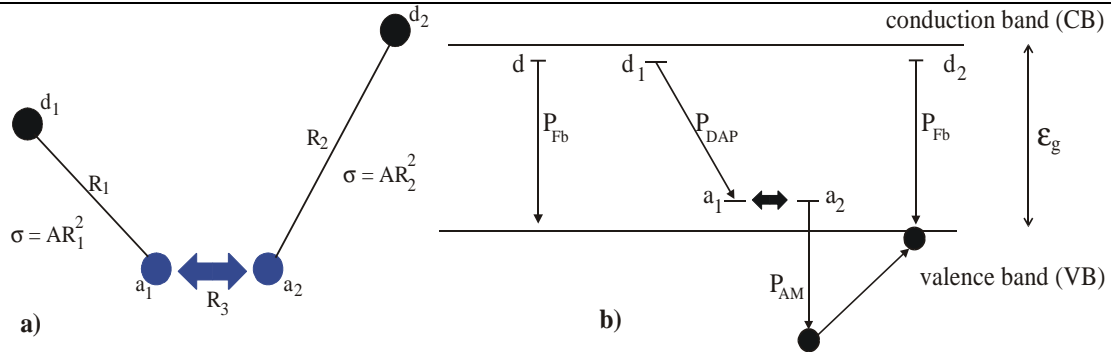


Fig. 1. (a): The donor-acceptor pairs (DAP's) d_1a_1 and d_2a_2 are separated by a distance R_3 ; (b): Radiative recombination transitions P_{DAP} and P_{Fb} , and non-radiative AUGER transition P_{AM} .

Due to their large capture cross section $\sigma \sim R^2$, donor-acceptor pairs (DAP's) with large pair separation R are occupied first at external excitation, so that at a low external excitation rate only common DAP spectra are observed. There exist particular conditions of the pair distribution, and a situation can be build, where a distant and a close pair are situated at a separation R_3 such, that once occupied, both pairs interact with each other. Indeed, at high excitation intensities, ever closer pairs are occupied, providing for the formation of a molecule consisting of three components as shown in Figure 1. Such a *daa*-excitation represents an AUGER molecule with a strongly increased probability of a three-body collision, involving one electron and two holes. No net photon emission occurs, as the energy released by the recombination of the short living donor-acceptor molecule of close separation is immediately absorbed by the hole of the longer living distant pair, which is excited deep into the valence band and then dissipates this energy by emitting phonons and partly heating up the hole population. This effect would be difficult to be proven by its own, though. Nevertheless leaves the *daa*-process an occupied donor of the distant pair behind, as well as an additional hole in the valence band. An additional donor-to-valence band transition is likely to happen, with the consequence of a competing intensity between this now three recombination channels, that is the common donor-acceptor pair (DAP), the AUGER molecule (AM), and the donor-to-valence band (Fb) transition. The recombination intensities are evaluated by the following rate equations:

$$R_{DAP} = B_{DAP} a_0 d_0, \quad a_0 d_0 \text{ concentration of occupied DAP's} \quad (1)$$

$$R_{Fb} = B_{Fb} \cdot d_0 \cdot p, \quad d_0 \text{ concentration of occupied donors} \quad (2)$$

$$R_{AM} = X \cdot a_0^2 \cdot d_0, \quad (3)$$

X stands for the collision probability between charge carriers on d_i , a_i , and a_2 , which is a function of the separation distance R_3 in the AUGER molecule, and thus also a function of the external excitation density due to the occupation probability of the DA pairs. In order to determine a_0 and d_0 the following time independent balance equations are considered:

$$\frac{d(a_0)}{dt} = 0 = pT_A(A - a_0) - Xa_0^2d_0 - B_{DAP}a_0d_0 - I_Aa_0 \quad (4)$$

$$\frac{d(d_0)}{dt} = 0 = nT_d(D - d_0) - B_{DAP}a_0d_0 - B_{Fb}d_0p - I_Dd_0 \quad (5)$$

with $T_A = v_h \cdot \sigma_A$ - acceptor-capture coefficient, $T_D = v_e \cdot \sigma_D$ - donor capture coefficient, v - thermal carrier velocity, σ - capture cross section, n - excess electron concentration in the CB, p - excess hole concentration in the VB, D - concentration of donors in the host, A - concentration of acceptors in the host, I_D - thermal re-emission probability of neutral donors, I_A - thermal re-emission probability of neutral acceptors. The formation and participation of AUGER-molecules in the recombination process is clearly visible in the down-swing of the net radiative recombination intensity in figure 2. This defines the existence region of AUGER molecules.

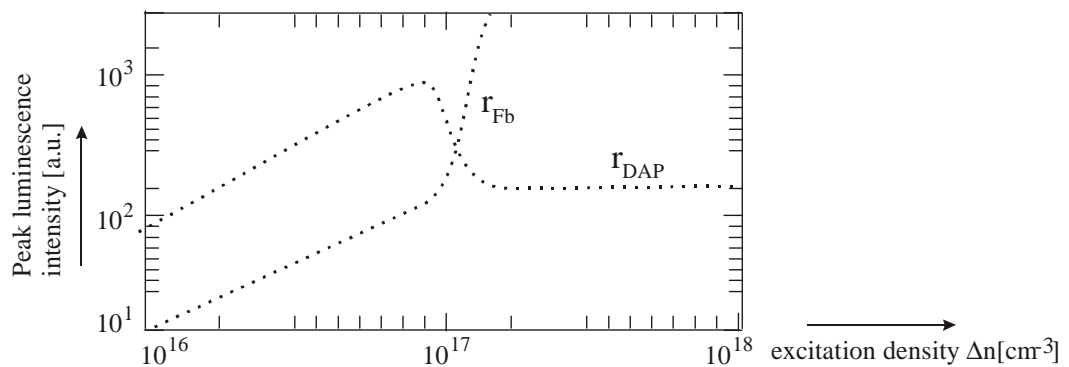


Fig.2: Calculated peak luminescence intensity under consideration of an AUGER annihilation process at high external excitation levels ($A = 10^{18} \text{ cm}^{-3}$, $D = 2 \cdot 10^{18} \text{ cm}^{-3}$, $X_0 = 4 \cdot 10^{-29} \text{ cm}^6 \cdot \text{s}^{-1}$, $\Delta n_t = 10^{16} \text{ cm}^{-3}$, $B_{Fb} = 10^{-9} \text{ cm}^3 \cdot \text{s}^{-1}$, $T_D = 10^{-8} \text{ cm}^{-3} \cdot \text{s}^{-1}$, $T_A = 10^{-6} \text{ cm}^3 \cdot \text{s}^{-1}$, $B_{DAP} = 10^{11} \text{ cm}^3 \cdot \text{s}^{-1}$).

2. Precision atomic layer doping

Scappucci et al. [1] reported recently the successful fabrication of precise dopant layers stacked in a crystal host of Germanium with high Phosphorous concentrations and sharp profiles. Their process is shown in the following figure, taken from [1].

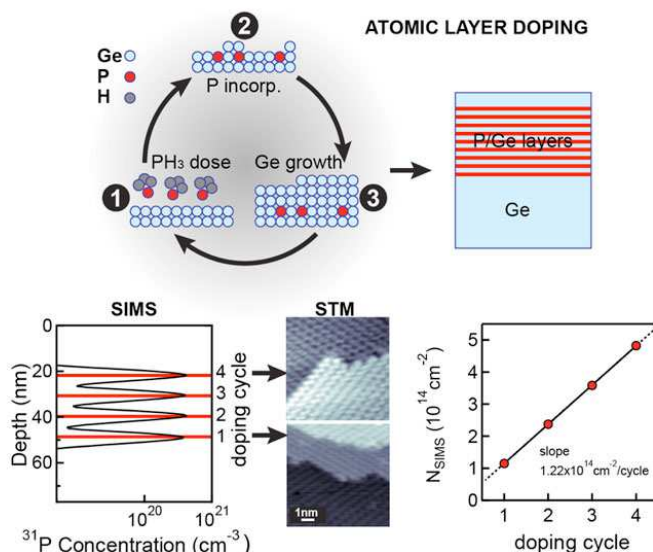


Fig. 3 Doping process after [1] based on the repetition of atomically controlled doping cycles. As seen in the first image, each doping cycle comprises three steps: i) the adsorption of phosphine molecules in ultra-high vacuum onto a near defect-free and atomically flat Ge(001) surface; ii) a thermal anneal to drive the incorporation of P atoms into the crystal matrix; and iii) a Ge overgrowth by molecular beam epitaxy to embed the incorporated P dopants in a high quality crystal without altering their atomically sharp vertical distribution.

In order to prove the process to be reproducible, Scappucci et al. used STM (scanning tunnelling microscopy), SIMS (secondary ion mass spectroscopy) and electrical measurements.

Sequential donor doped and acceptor doped layers with defined layer distances will provide for exactly defined values R_1 , R_2 and R_3 (see Fig. 1a).

3. Conclusions

Once activated the *daa*-AUGER molecule, for any two donor-acceptor pairs, bound into the AUGER molecule and taken out of the radiative DAP-transition channel, one additional excess hole appears in the valence band, and one additional neutral donor (see Figure 1b) participates in the Fb-recombination channel instead of the DAM-channel. This explains the intensity shift between the two involved luminescence bands, which at the same time translates into a red-to-green color change of the integral emission corresponding to the peak photon energies of the DAP- and Fb-transitions, separated by more than 200 meV.

References

- [1] G. Scappucci, G Capellini, W. M. Klesse and M. Y. Simmons: Nanotechnology (2011) Vol. 22, n° 37, 375203 doi:10.1088/0957-4484/22/37/375203
- [2] P.J. Dean, Progress in Solid-State Chemistry, Vol.8, Pergamon, Oxford 1973.
- [3] S. Shigetomi, T. Ikari, H. Nishimura: J. Luminescence, 78, 117 (1998)