Calculation of Auger recombination thresholds in narrow gap HgCdTe based QW heterostructures

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Abstract

Auger recombination is a three-particle threshold process. It can be considered that as a result of the recombination of two particles, the third one acquires high energy and momentum. This effect reduces the population inversion and heats up charge carriers, which leads to its competition with the process of radiative recombination. An obvious way to reduce the rate of such a process is to increase the Auger threshold energy [2], [1]. It can be defined as the total kinetic energy of the initial particles.

Analityc relations

A problem can be defined mathematically. It is proposed to consider two different options: CCHC & HHCH processes. Also we can minimize the final state energy, it linearly depends on ε_{th}.

$$\varepsilon_{th} = \min_{\vec{k}_1,\vec{k}_2,\vec{k}_3} K(\vec{k}_1,\vec{k}_2,\vec{k}_3);$$
$$\begin{cases} K = \varepsilon_f(\vec{k}_1+\vec{k}_2-\vec{k}_3) - \beta\cdot\varepsilon_g; \\ \beta = \begin{cases} 1 & \text{CCHC} \\ 2 & \text{HHCH} \end{cases}; \\ \varepsilon_1(\vec{k}_1)+\varepsilon_2(\vec{k}_2)-\varepsilon_3(\vec{k}_3) = \varepsilon_f(\vec{k}_1+\vec{k}_2+\vec{k}_h); \end{cases} \quad (1)$$

A necessary condition for the minimum is the coincidence of the group velocities of the particles:

$$\nabla\varepsilon_1(\vec{k}_1) = \nabla\varepsilon_2(\vec{k}_2) = \nabla\varepsilon_h(\vec{k}_h); \quad (2)$$

In most cases, this leads to the fact that the CCHC process is dominant. Despite this, it can be observed resonance phenomena involving several valence subbands.

Algorithm description

In HgCdTe the bands are not parabolic thus the calculations of Auger recombination rates for classical semiconductors are not applicable. The energy-momentum law can be calculated for HgCdTe heterostructures in the Kane 8x8 model [3]. It can be interpolated with the Akima cubic splines. This trick provides enough smoothness and also helps to avoid parasitic oscillations.
Starting points for (1) optimization can be selected on sites with the same derivative & second derivative sign. This fact ensures finding the required points.
The maximum threshold energy is considered limited by temperature [2]:

$$\varepsilon_{th,max} = 2T; \quad (3)$$

References

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Auger threshold energy vs. barriers

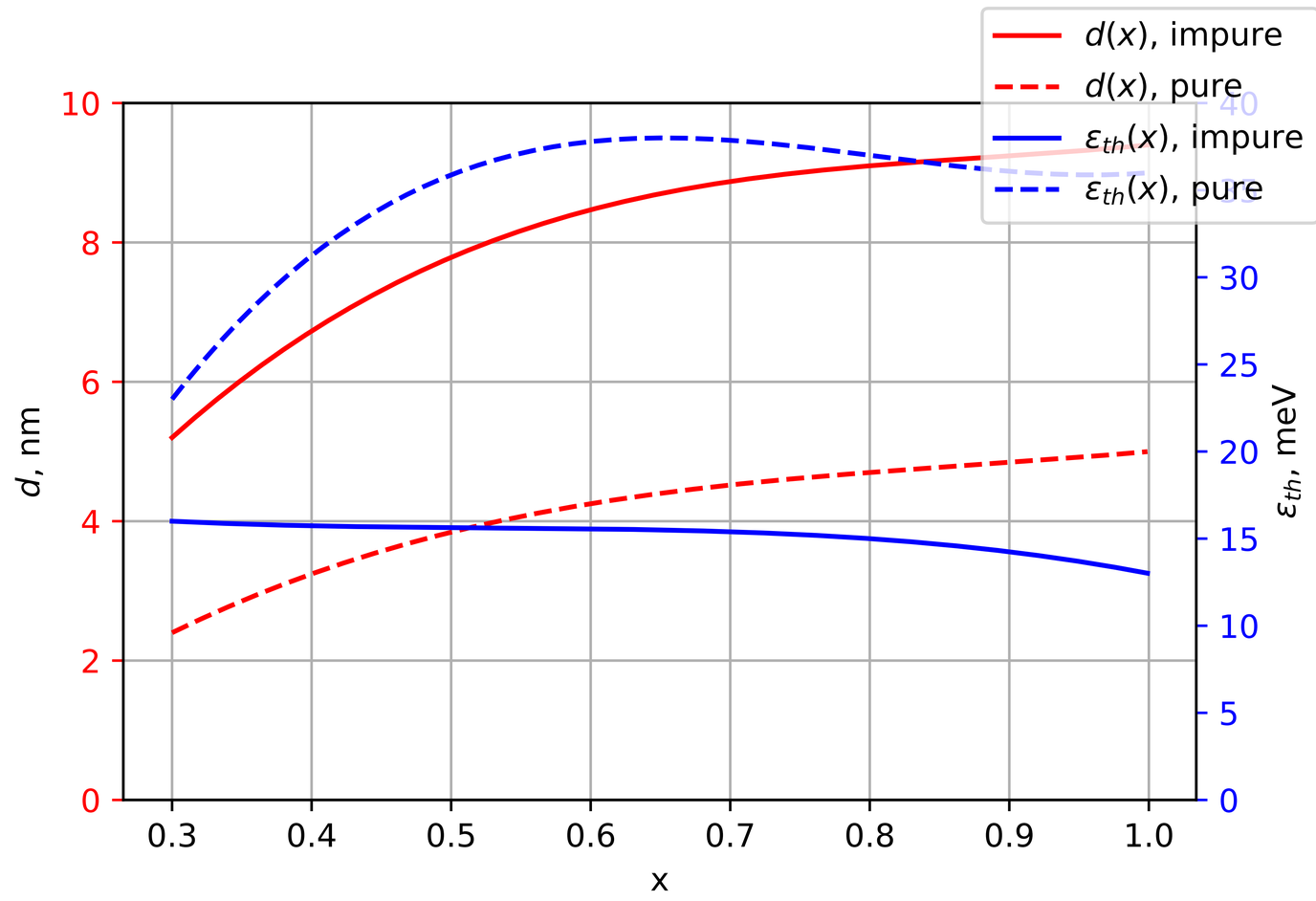

Figure 1: The dependence of Auger-threshold energy and required QW thickness on the concentration of Cd in barriers with fixed temperature and ε_g.

Comparison at various Cd%

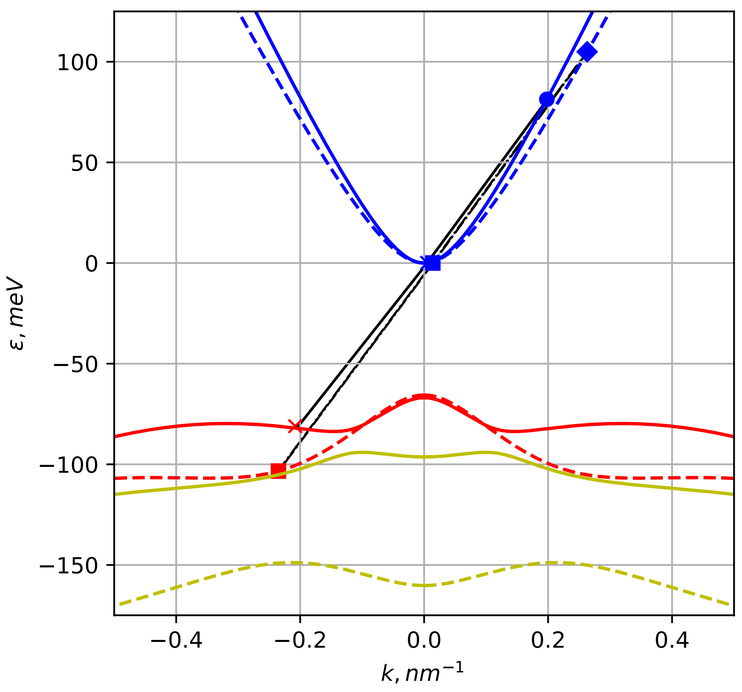

Figure 2: Threshold Auger processes in $Hg_{1-x}Cd_xTe$ QWs for $x = 0.1,\ x = 0$.

Discussion

We consider the structure of the composition $Hg_{0.9}Cd_{0.1}Te/Cd_{0.65}Hg_{0.35}Te$ with 10 unrelated quantum wells 8.7 nm thick. It allows to observe stimulated radiation with $\lambda \approx 18\ \mu m$ close to 40 K (Fig. 3).
On Fig. 2 continuous lines are responsible for the structure described above, shaded lines are responsible for the structure without cadmium in the QWs.
We can investigate the effect of cadmium content in quantum wells on threshold energy. As it can be shown, lower concentration of Cd reduces side maximums and increases threshold energy.
It would be interesting to investigate the dependence of the threshold energy on the composition of the barriers. As it can be shown in Fig. 1, there is a severe maximum for the case of pure quantum wells.

Experimental spectrum

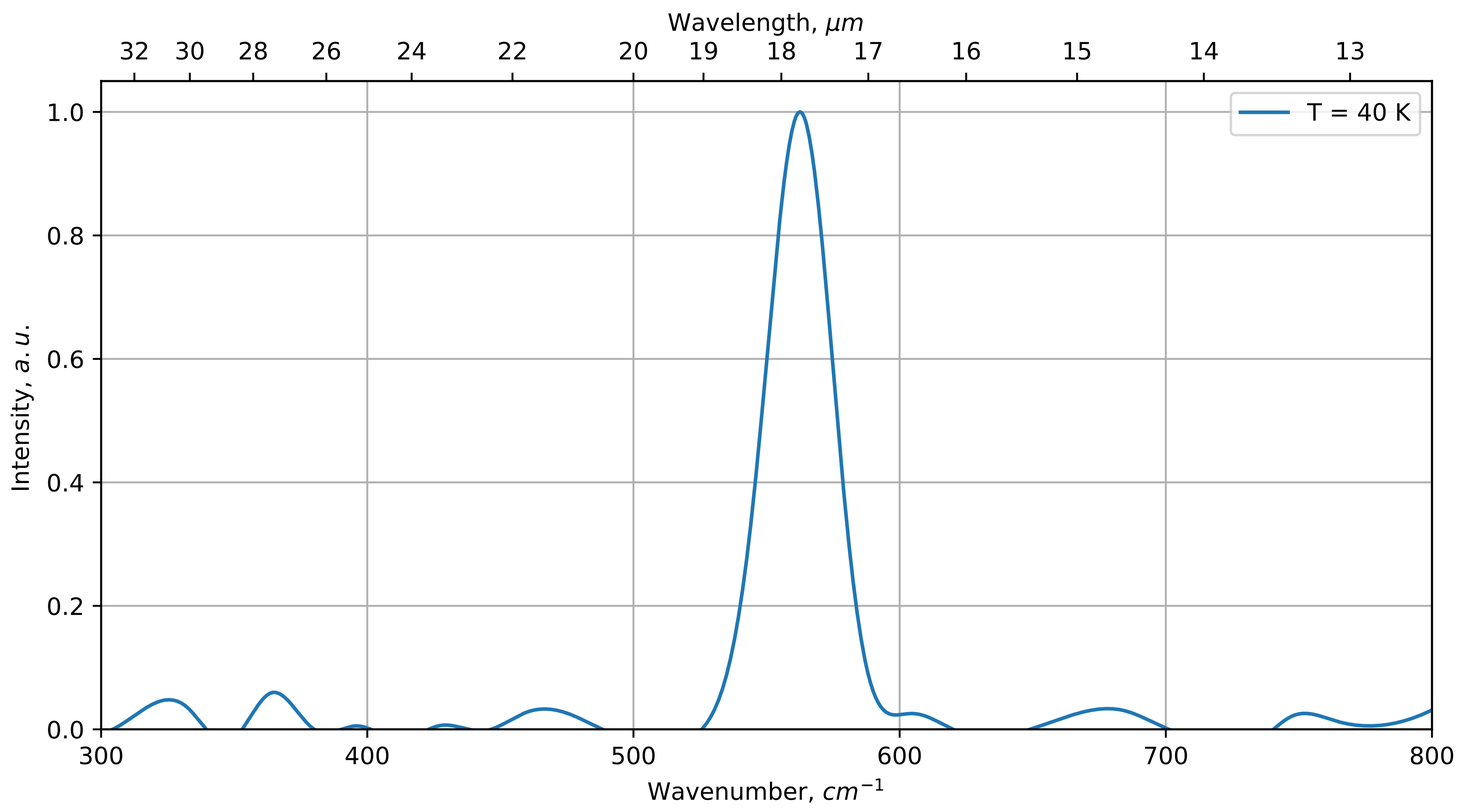

Figure 3: Stimulated emission spectra