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

Kulikov N.S., Rumyantsev V.V., Zholudev M.S., Utochkin V.V., Morozov S.V.
neilkulikov@gmail.com

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 stimulated radiation. An obvious way to reduce the rate of such a process is to increase the Auger threshold energy [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, cause of conservation laws.

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

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

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

In most cases, this leads to the fact that the CCHC process is dominant.

Algorithm description

The energy-momentum law can be calculated for HgCdTe heterostructures in Kane model 8x8 [2]. It can be interpolated with Akima cubic splines. It provides enough smoothness but also helps to avoid parasitic oscillations.
The function 1 can be optimized with Lagrange method. Starting points are 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 [1]:

$$\varepsilon_{th,max} = 2T; \tag{3}$$

References

References

[1] VV Rumyantsev, NS Kulikov, AM Kadykov, MS Zholudev, MA Fadeev, V Ya Aleshkin, S Winnerl, NN Mikhailov, SA Dvoretskii, VI Gavrilenko, et al. Hgcdte based quantum well heterostructures for long-wavelength lasers operating in 5-15 thz range. In *Journal of Physics: Conference Series*, volume 1092, page 012126. IOP Publishing, 2018.

[2] M. Zholudev, F. Teppe, M. Orlita, C. Consejo, J. Torres, N. Dyakonova, M. Czapkiewicz, J. Wróbel, G. Grabecki, N. Mikhailov, S. Dvoretskii, A. Ikonnikov, K. Spirin, V. Aleshkin, V. Gavrilenko, and W. Knap. Magnetospectroscopy of two-dimensional hgte-based topological insulators around the critical thickness. *Phys. Rev. B*, 86:205420, Nov 2012.

Experimental spectrum

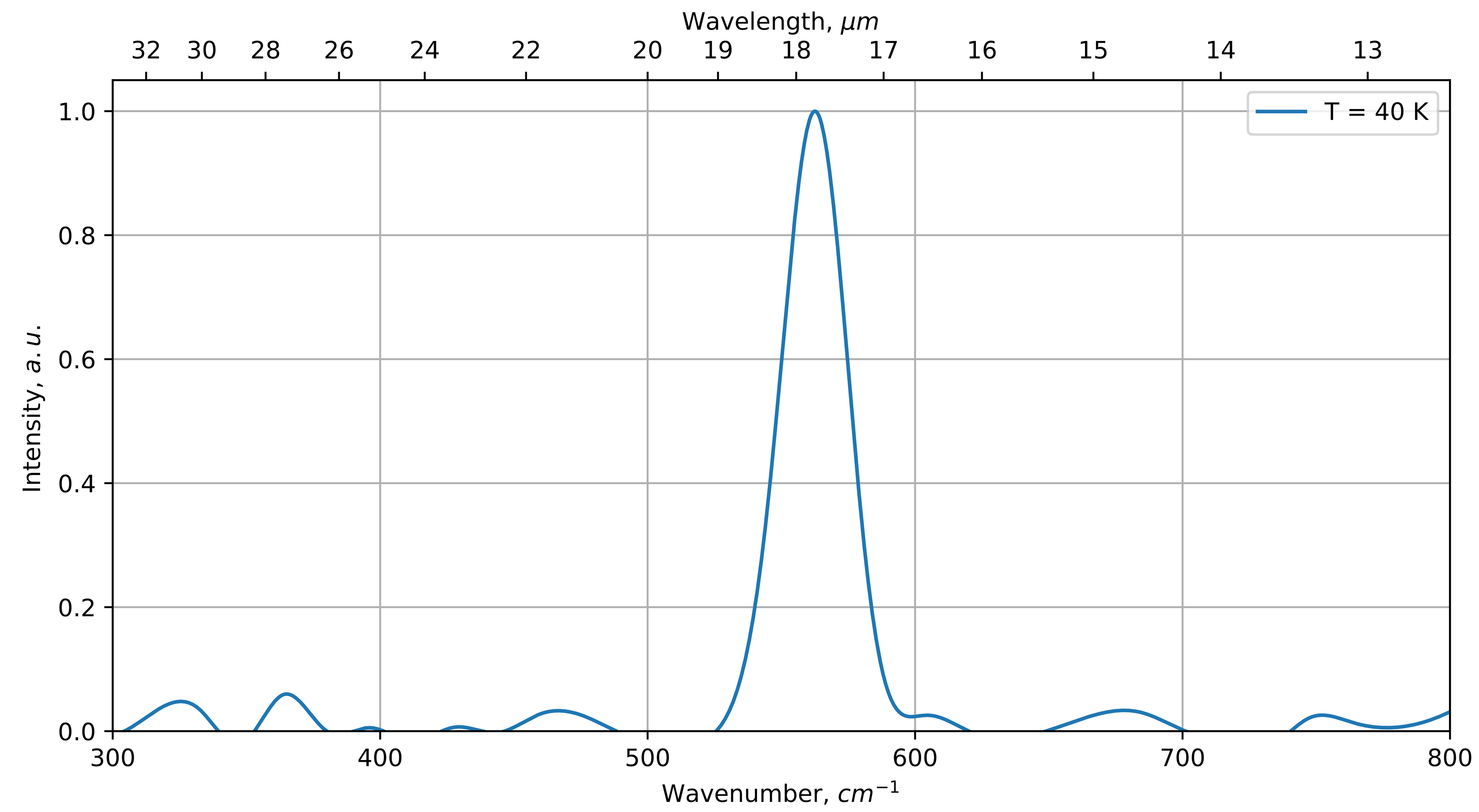

Figure 1: Stimulated emission spectra

Auger threshold energy vs. barriers

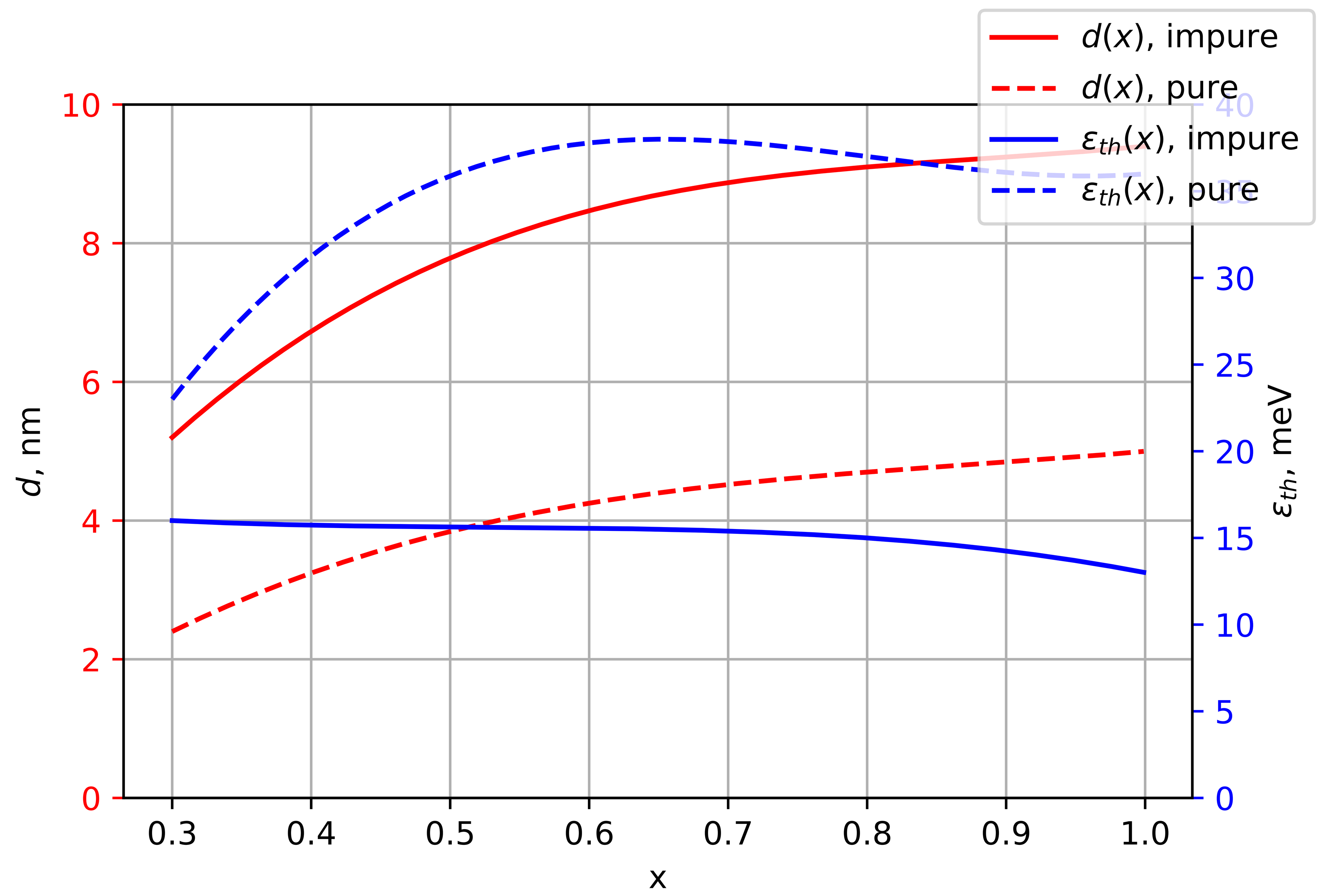

Figure 2: The dependence of Auger-threshold energy and required QW thickness on the concentration of Cd in barriers with fixed temperature and ε_g.

Comparison at various Cd%

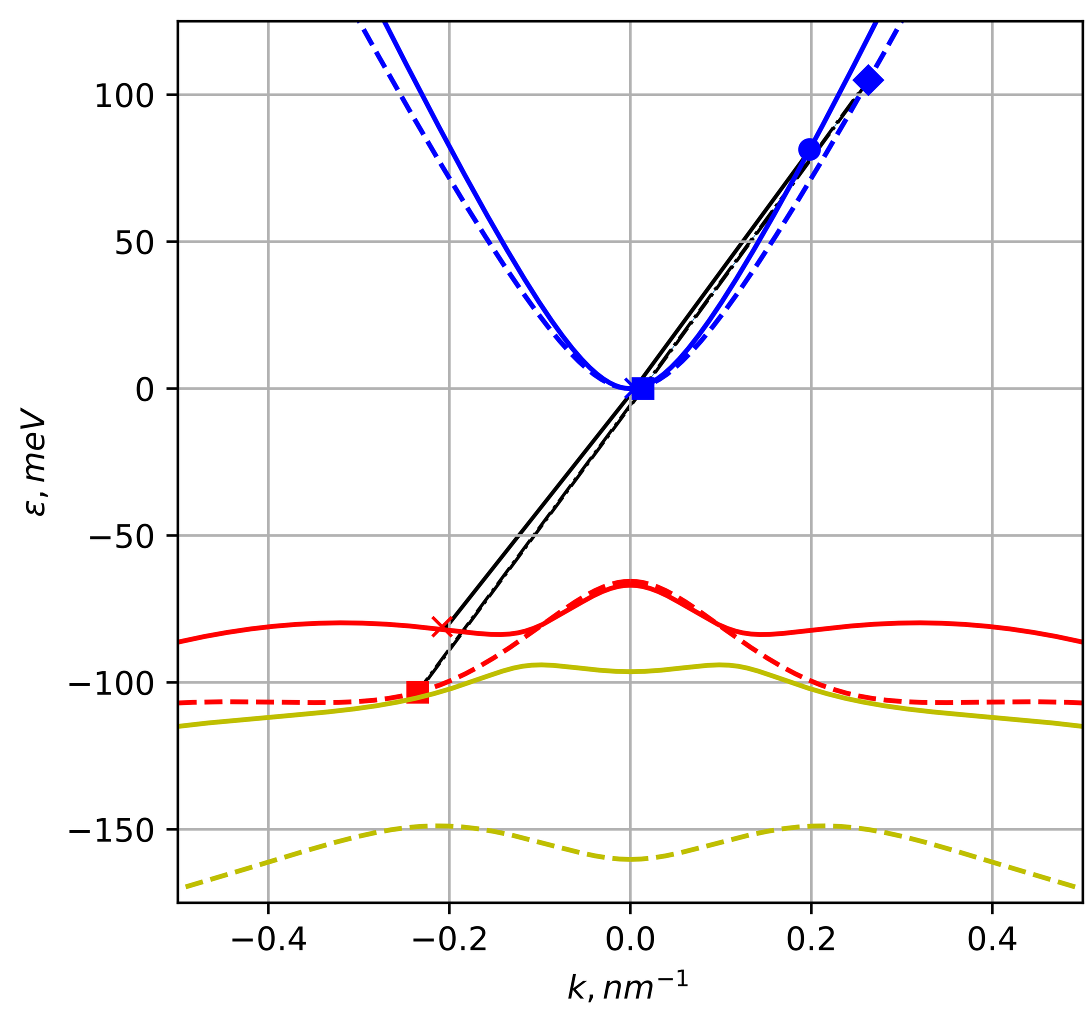

Figure 3: Threshold Auger processes in $Hg_{1-x}Cd_xTe$ QWs for $x = 0.1$, $x = 0$.

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 $\lambda \approx 18$ μm close to 40 K.
On Fig. 1 we can see the SE spectre at T = 40 K. 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 shown in Fig. 2 there is a severe maximum for the case of pure quantum wells.