Efficiency Estimation for a Broadband 7 THz Radiation Source with GaAs/AlGaAs Parabolic Quantum Wells

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***Abstract*— The efficiency calculation for an incoherent 7 THz radiation source based on a laterally pumped GaAs/AlGaAs quantum well layer are presented. The smooth parabolic potential with a quartic addition and the digitally graded quasi-parabolic potential are compared. In addition to 12 equispaced electron energy levels (subbands) the 12 continuum states are included to model the drop of efficiency at high electron temperatures. Polar LO phonon and acoustic deformation potential scattering are included, together with averaging by shifted Fermi-Dirac distribution, in calculation of inter-subband scattering rates. Semi-empirical relations are used to relate the electron temperature and drift velocity to the lateral electric field. The obtained mean scattering rates are then used in rate equations to find the subband electron populations which, together with spontaneous photon emission rates, finally give the estimate of the emitted radiation power and its spectrum. The calculations show that the emitted radiation spectrum peaks are above the blackbody level for all considered lattice temperatures 77 - 400K. However, for efficient output at temperatures above 300K the multiple quantum layer design should be used.**

***Index Terms*—Parabolic quantum wells, THz radiation source.**

I. Introduction

The development of terahertz radiation sources is of great importance for numerous applications. The quantum cascade lasers still require low temperatures, below 164 K [1]. Here we consider a LED-like source of incoherent THz radiation which employs spontaneous radiative transitions between size-quantized states. This device can operate at room temperature and have large emitting area.

The parabolic quantum well is a good basic structure for incoherent radiation source due to the equispaced energy levels. However, molecular beam epitaxy prefers "digitised", rather than smooth potentials, obtained by switching between two fixed semiconductor compositions. In [2] we have analysed the GaAs/$Al_{0.42}Ga_{0.58}As$ system (QW depth 0.3509 eV for electrons) and found that optimal digital grading enables achieving 4% root-mean-square deviation of energy levels spacing at 7 THz (ideal ΔE=28.95 meV). It was also shown that the smooth parabolic potential needs 18% quartic addition to compensate for the effect of composition-dependent effective mass. The present work is a continuation of our recent study of this topic [3]. Here we estimate the device operation in a wide temperature range, 77–400 K, and also give comparison with blackbody radiation spectra. The analysed device structure is presented in Fig. 1.

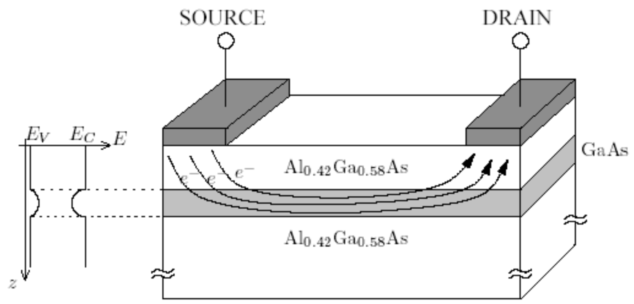

Fig. 1. The laterally pumped quantum well emitter .

II. Models and Calculation Procedure

The used model and calculation procedure (summarised in the abstract) rely on [4, chapter 9] and are described in detail in [3]. The key problem is to describe the high-field transport in the lateral, *x*-direction, which rises the electron temperature T_e and thereby increases the population n_i of higher subbands. To average the inter-subband scattering rates, shifted Fermi-Dirac distributions were used, with 3 parameters: T_e, electron drift velocity v_d, and Fermi energy E_F (the latter being different for each subband). Similarly to [3], instead of solving the Boltzmann equation we use simple empirical relations to describe T_e and v_d dependence on the lateral electric field strength F. The total, doping-defined electron density of n_{sum}=10^{16} m^{-2} was assumed. The total optical power was calculated as $\sum n_i\ E_{if}\ /\tau_{if}$ for all downward, $i > f$ transitions. With relatively long spontaneous photon emission times, in the 0.3 μs range for ΔE=29 meV [4], the achievable optical power is limited to 100 - 200 W/m^2.

III. Results

The main results are presented in Figs. 2 – 4.

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This work has been partly funded by Estonian Science Foundation grants 5911 and 6914, and Estonian Archimedes Foundation. The authors are grateful to Mr. N. Vukmirović for helpful discussions.

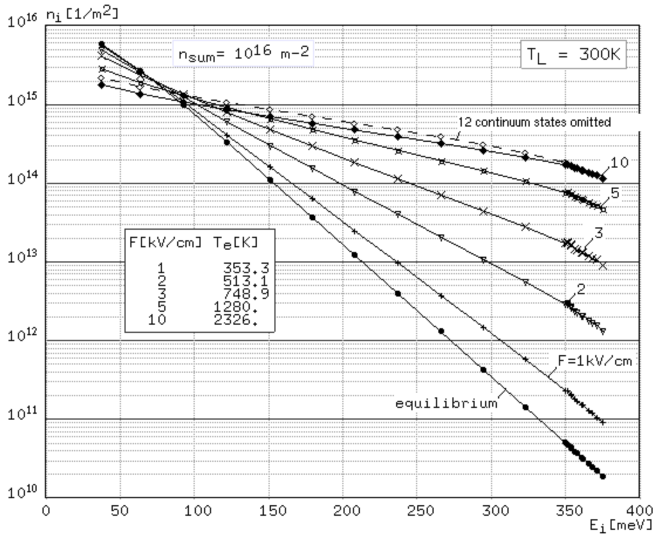

Fig. 2. The calculated subband populations vs. subband energy at lattice temperature 300K for the quasi-parabolic quantum well with 12 bound states. The additional 12 continuum states are formed by surrounding the structure with infinite barriers spaced by 200 nm. The nearly straight form of curves verifies the applicability of Fermi-Dirac (or even Maxwellian) distributions with increased common electron temperature. If the continuum states are omitted the bound states population may increase by approximately 10-20%, but only at high electron temperatures, near 2000K.

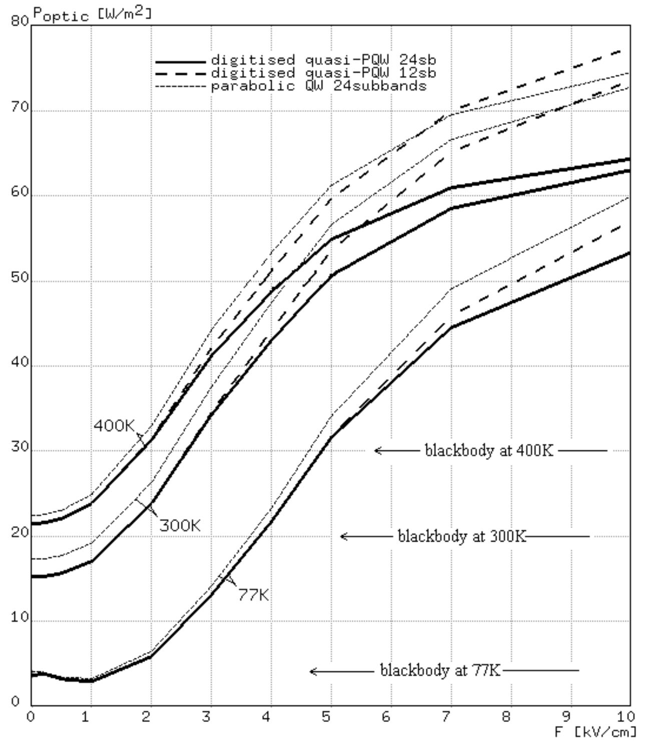

Fig. 3. The generated radiation power versus lateral electric field for lattice temperatures 77, 300, and 400K. The smooth parabolic quantum well (with 18% quartic addition) is compared with digitised quasi-parabolic quantum well. The displayed blackbody power levels correspond to energy interval 29 ± 5 meV. The inclusion of continuum states decreases the generated power at high fields by 15 - 20% due to a decrease of bound states population densities (see Fig. 2). The smooth parabolic potential gives approximately 15% higher output power than the digitised potential due to somewhat larger QW size, and hence larger optical dipole matrix elements.

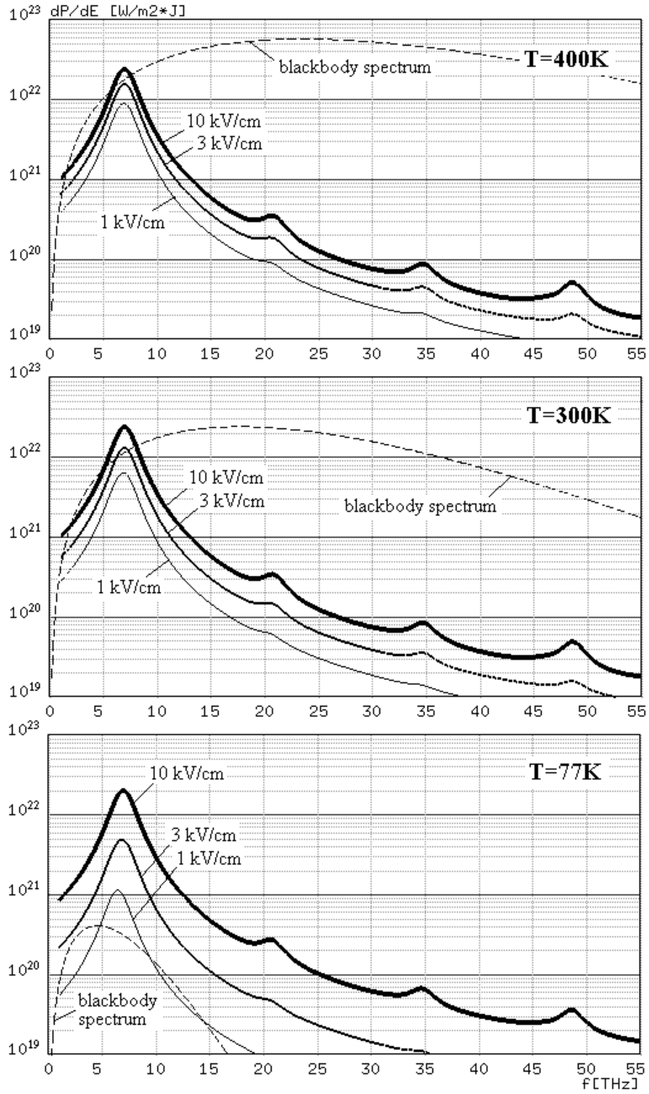

Fig. 4. The generated power spectra for the digitised quasi-parabolic quantum well structure (12 bound states and 12 continuum states) at three lattice temperatures 77, 300, and 400K. The curves for three lateral electric field values are presented and compared with theoretical blackbody spectra. The Lorentzian linewidth (half width at half maximum) parameter Γ is set to 5 meV. The double (even) transitions (14, 28, 42 THz) are excluded due to the wavefunction symmetry properties which yield zero optical dipole matrix elements (ODME). The higher odd transitions (21, 35, 49 THz) have minor importance due to low ODME values compared to adjacent transitions. The closely spaced continuum states give a very low contribution since the optical power is proportional to the 4th power of energy spacing between levels.

References

[1] B. S. Williams, S. Kumar, Q. Hu, and J L. Reno, *Optics Express,* vol. 13, pp. 3331-3339, 2005.

[2] R. Reeder, A. Udal, E. Velmre, and P.Harrison, *Proc. of the 10th Baltic Electronics Conf. BEC2006, Oct. 2-4, 2006, Tallinn, Estonia,* pp.51-54, 2006. Available in IEEE Xplore.

[3] R. Reeder, Z. Ikonic, P. Harrison, A. Udal, and E. Velmre, "Laterally pumped GaAs/AlGaAs quantum wells as sources of broadband Thz radiation," *J. Appl. Phys.,* submitted for publication.

[4] P. Harrison, *Quantum Wells, Wires and Dots*. Chichester: John Wiley & Sons, 2005, ch. 9.