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Different approximations for carriers lifetimes in HgCdTe quasi-neutral regions

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***Abstract*—In mid- and far-infrared HgCdTe photodetectors, the maximum operating temperature is determined by the dark current, which in turn depends on charge carriers lifetimes. The ability to reduce dark current and operate at the radiative limit allows for significantly higher operating temperature, but in this new scenario some approximations, commonly and historically applied in the literature to estimate and optimize lifetimes and dark current, in some cases should be avoided.**

***Index Terms*—minority carrier lifetime, focal plane arrays, HgCdTe, dark current, diffusion current, incomplete dopants ionization**

I. INTRODUCTION

A promising material for third-generation infrared (IR) detectors is mercury cadmium telluride ($\mathrm{Hg}_{1-x}\mathrm{Cd}_x\mathrm{Te}$), whose outstanding properties [1]–[3] allow to fabricate large format multi-waveband focal plane arrays (FPAs) IR detectors. HgCdTe-based heterostructures can achieve background-limited photodetection performance at near-room temperatures by using sophisticated chemical compositions and doping profiles.

Fig. 1 shows two possible architectures suitable for High Operating Temperature (HOT) detectors, nBn barrier detectors [4] and full-depleted detectors [5].

The dark current density J_dark receives contributions mainly from Auger and Shockley-Read-Hall (SRH) generation mechanisms. The Auger generation rate usually outweighs the SRH in quasi-neutral regions (QNR) unless the dopant concentration is greatly reduced, while in depleted regions the SRH often limits the device (for definitions of QNR and depleted regions, see [6, Ch. 1-2]). In this work, we mainly focus on the contribution to J_dark coming from the diffusion current in the QNR, i.e., charge carriers diffusing to contacts (they don't drift because there is negligible electric field surrounding them).

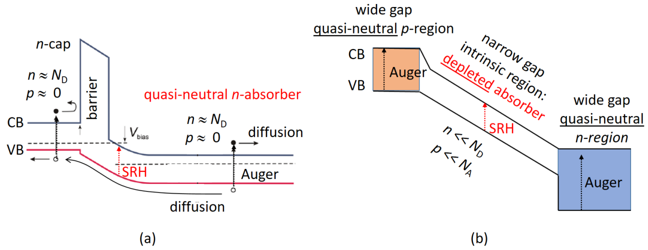

Fig. 1. (a) Qualitative band diagram of a typical nBn barrier detector [4] and (b) of a full-depleted or Auger-suppressed photodetector [5].

J_dark determines the maximum operating temperature and it depends on the electron and hole density n and p, both directly and through the lifetime of the minority carriers τ [7]–[10]. Thus, predicting detector performance requires calculating n and p as functions of temperature and doping, which is not a trivial issue. In this paper, we discuss some of the simplest approaches used in the literature to this end, and show that the widely used approximation which assigns the donor N_D and acceptor N_A concentrations respectively to n and p is not always appropriate.

II. LIFETIME AND CARRIER DENSITY

The SRH lifetime τ_SRH is connected to defect density and carrier capture cross sections [11], and it can be considered a technological parameter. The ensuing SRH diffusion current can be expressed in a simplified form as [8], [10]

$$J_\mathrm{diff,\,SRH} = \frac{q t n_i^2}{\tau_\mathrm{SRH}(n+p+2n_i)}.$$

where t is the QNR width, q is the elementary charge and n_i is the intrinsic density.

The Auger lifetimes are given by [7], [9]

$$\tau_\mathrm{A1} = \frac{2\tau^i_\mathrm{A1} n_i^2}{n(n+p)}, \quad \tau_\mathrm{A7} = \frac{2\tau^i_\mathrm{A7} n_i^2}{p(p+n)}$$

where $\tau^i_\mathrm{A1,A7}$ are the intrinsic A1, A7 Auger lifetimes [12]. The ensuing generation rate

$$G_\mathrm{A} = \frac{n_i^2}{n\tau_\mathrm{A1}} + \frac{n_i^2}{p\tau_\mathrm{A7}}$$

determines the Auger diffusion current according to [5], [8], [9], [13]

$$J_\mathrm{diff,\,A} = qtG_\mathrm{A} = qt(n+p)\left(\frac{1}{2\tau^i_\mathrm{A1}} + \frac{1}{2\tau^i_\mathrm{A7}}\right).$$

We can notice that $J_\mathrm{diff,\,SRH}$ decreases for increasing carrier density, whereas $J_\mathrm{diff,\,A}$ increases. As a result, in QNR $J_\mathrm{diff,\,SRH}$ can become negligible with respect to $J_\mathrm{diff,\,A}$ if n and/or p is large, differently from what happens in depleted regions.