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High optical power dependence of the *EL2* recovery in GaAs

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Abstract

In this work, a new way of achieving the recovery from the *EL2* metastable state is reported and analyzed theoretically. Despite being an old problem, no definitive picture of the *EL2* center has been established to date. For this reason, long past the days of effervescent research on the *EL2*, new models and investigations keep appearing in the literature as, for example, the recently proposed autocatalytic model to describe the inter-defect correlation during the thermal recovery process [A. Fukuyama, T. Ikari, Y. Akashi, M. Suemitsu, Phys. Rev. B 67 (2003) 113202]. In the course of a re-evaluation of the *EL2* for nanosecond volume holographic storage, we found that a strong laser pulse is capable of destroying the metastable state and decided to investigate further this effect. The experiment reported here consists of monitoring the transmission of a $\lambda = 1.05$ μm continuous-wave (CW) laser, used to populate the metastable state, while subjecting the sample to the incidence of a strong $\lambda = 1.06$ μm laser pulse. A full simulation of the problem has been carried out and the results could be fit very well by assuming a recovery induced by electron–hole recombination and a nonlinear free-carrier production mechanism. It is perhaps worth noting that such a fast recovery induced by the nanosecond laser may prove to be an interesting tool to initiate a recovery process (even at low temperature) in a controlled way to check the predictions of the recently proposed autocatalytic recovery process.

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1. Introduction

Midgap electronic levels in GaAs have interesting and complex physical properties. The dominant native defect, known as *EL2* center, has been linked with compensation mechanisms in

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semi-insulating (SI) GaAs and is known to undergo a photoinduced transition into a metastable state ($EL2^*$) under suitable conditions [2,3]. The characteristic feature of the metastable state is the quenching of a number of physical properties such as the optical absorption (bleaching) [3], photoconductivity [4], photocapacitance [5,6], electron paramagnetic resonance (EPR) [7] and photoacoustic signals [8]. At low temperatures (<100 K), the lifetime of the metastable state is quite long, characterizing a photoelectric memory effect [6] that may be erased by different processes, as discussed below. As far as devices are concerned, the $EL2$ has important consequences in the operation of radiation detectors [9], in the response time of fast photodetectors [11], in the lock-on behavior of high voltage switches [12], and in low-frequency oscillations in MESFETs [10]. Its optical metastability has once been considered for holographic storage, as in photorefractive crystals [13]. In fact, the re-evaluation of this possibility in the nanosecond domain was the initial motivation of the present work.

The $EL2$ is usually present in commercial samples grown by the liquid-encapsulated-czochralski (LEC) method at a concentration of about $N = 1\text{–}2 \times 10^{16}\,\mathrm{cm}^{-3}$. Despite being known for over 20 years now, its microscopic structure is still a subject of controversy. It seems firmly established by now, however, that the center contains at least an Arsenic antisite (As_{Ga}), and doubts still persist whether or not it is associated with other centers such as an Arsenic interstitial (As_{Ga}–As_i) or vacancies. The most recent structure proposed consists of a three-center-complex made by association of an Arsenic vacancy (V_{As}), an Arsenic antisite and a Gallium antisite (Ga_{As}) [1,14].

The stable $EL2^{0/+}$ defect energy level is localized at around 0.75 eV below the conduction band [15]. Photons with energy $\gtrsim 0.7$ eV are able to induce optical transitions to the bands. Besides these transitions, which either ionize ($EL2^0 \rightarrow EL2^+ + e^-$) or neutralize the center ($EL2^+ \rightarrow EL2^0 + h^+$), there are two sub-bandgap absorption bands superimposed, related to an intracenter absorption. Photons with energy between ~1.0 and ~1.3 eV, induce transitions from the normal to the metastable state (quenching) and photons with energy between ~0.75 and ~1.0 eV induce the reverse transition, i.e., from the metastable to the normal state (recovery) [3]. The strong lattice relaxation that accompanies the transition to the metastable state relocates the energy levels in such a way as to bleach the optical absorption band.

The lifetime of the metastable state is affected by several factors, such as temperature [16], free carriers [17], light [3,18] and electric field [19,20]. Thermal recovery, i.e., thermally stimulated $EL2^* \rightarrow EL2^0$ transition, is achieved when the metastable state overcomes a potential barrier of about 0.34 eV [16]. For this reason, lifetimes longer than a few hours can be achieved below 77 K for undoped samples. After analyzing the recovery in doped samples, Mittonneau and Mircea [17] demonstrated that the recovery process is also very considerably accelerated in the presence of free electrons, a process which the authors have tentatively termed Auger de-excitation. They have found that the recovery rate is proportional to the concentration of free electrons and is strongly affected by the temperature. Dreszer and Baj [21] later demonstrated that the thermal recovery process is controlled by an acceptor state of the metastable $EL2$ ($EL2^{*(-/0)}$) which is resonant with the conduction band. This acceptor state has also been found to participate in the very efficient recovery observed under visible illumination [18].

Since the photoinduced recovery is the focus of this work, we shall discuss it in more detail. As said before, the photoinduced recovery of photoquenched $EL2$ has an absorption band which peaks at 0.86 eV [3]. For the 1.18 eV ($\lambda = 1.05$ μm) and 1.17 eV ($\lambda = 1.06$ μm) radiation used here, the optical recovery cross-section S_r^* is about two orders of magnitude lower than the optical quenching cross-section S_n^*. Therefore, at these wavelengths we should expect the system to achieve the metastable state (optical quenching) under illumination and remain there. If these two optical cross-sections were the only factors governing the recovery/quenching then, under whatever optical power, the ratio N^0/N^* of the $EL2$ populations in the normal and metastable states, respectively, should be kept close to the ratio of the cross-sections $S_r^*/S_n^* \sim 1\%$, since both processes are proportional to the light intensity. However, the experiments