Available online at www.sciencedirect.com
SCIENCE DIRECT®
Materials Science in Semiconductor Processing 9 (2006) 390–393
MATERIALS SCIENCE IN SEMICONDUCTOR PROCESSING

Role of deep traps in carrier generation and transport in differently doped InP wafers

N. Sun[a,*], K. Jarasiunas[b], M. Sudzius[b], A. Kadys[b], X. Zhou[a], T. Sun[a]

[a]National Key Laboratory of ASIC, Hebei Semiconductor Research Institute, P.O. Box 179, Shijiazhuang, Hebei, PR China
[b]Institute of Materials Science, Vilnius University, Sauletekio Avenue 9 bld. 3, LT-10222 Vilnius, Lithuania

Available online 3 March 2006

Abstract

We report on investigations of nonequilibrium carrier generation, recombination and transport in differently doped InP crystals by means of time resolved degenerative four-wave mixing technique. The role of deep traps in carrier diffusion and lifetime was monitored through a feedback effect of a space-charged field to carrier transport and provided a photoconductivity type of differently doped InP crystals. Fast transients were used to evaluate the concentration of residual defects in the crystals.

Keywords: InP; Four-wave mixing; Deep centers

1. Introduction

Semi-insulating InP has been shown to be a promising material for long-wavelength optoelectronics and high-frequency devices. Optimization of the crystal properties requires controlling of growth technology and nondestructive evaluation of their electric parameters. We applied four-wave mixing (FWM) technique to study the role of deep impurities in carrier generation, transport, and recombination. By monitoring temporal and spatial carrier distribution, this technique provides access to photoelectric processes [1].

In this work, we used degenerate time-resolved FWM technique for characterization of the photoelectric properties of differently doped InP crystals. Grating decay kinetics provided nonequilibrium free carrier diffusion coefficients and recombination times at different excitation levels. By analyzing the dependence of the diffraction efficiency on excitation energy we evaluated the electrical activity of the defects, their transformation under illumination, and their contribution to carrier transport.

2. Experimental results and discussion

A mode-locked Nd:YAG laser, operating at $\lambda = 1064$ nm wavelength ($h\nu = 1.17$ eV) with pulse duration of 27 ps (at FWHM) has been used for excitation and probing of light-induced free carrier gratings. The laser beam was divided into two parts of equal energy which recombined at an angle Θ to form a grating with period $\Lambda = \lambda/[2\sin(\Theta/2)]$ in the crystal. Grating decay kinetics as well as diffraction efficiency vs. excitation energy, I_0, were studied by Bragg diffraction of the delayed probe beam. More

*Corresponding author. Tel.: +86 311 87091395; fax: +86 311 87814737.
E-mail address: nfsun@heinfo.net (N. Sun).

1369-8001/$ - see front matter
doi:10.1016/j.mssp.2006.01.022

details on experimental setup can be found in [2]. The measurements were carried out in undoped, Fe-doped, and S-doped InP wafers, grown by liquid-encapsulated Czochralski method [3]. Electrical parameters of the wafers are measured using van der Pauw method and the dislocation density was calculated using wet etching study. These data are given in Table 1.

Grating decay kinetics in undoped InP (Fig. 1) have shown strong dependence on excitation energy, as expected from defect-assisted carrier photogeneration [1,2]. In the regime of low excitations, which is most favorable for the effective build-up of the internal space-charge (SC) field between mobile carriers and recharged deep centers [4], the grating kinetics exhibits a slow component, which is not observed at high excitation (compare Fig. 1a and b at $\Lambda = 1.85\,\mu$m). Effective feed back of the SC field to carrier diffusion determines the experimentally measured grating decay time $\tau_G = 3.2$ ns, while the expected diffusive decay time in absence of the SC field would be equal to $\tau_G = \Lambda^2/(4\pi^2\mu_e kT/e) \cong 10$ ps at $\Lambda = 1.85\,\mu$m. For the grating with large period (11 μm), the light-induced SC field is rather weak ($E_{SC} \propto 1/\Lambda$), thus, the carrier recombination is the dominate mechanism in grating decay. At higher excitations (see Fig. 1b) carriers are created by two-step and two-photon transitions, therefore, the carriers concentrations become closer to the bipolar case ($n = p$). The contribution of deep traps to SC field is screened by high-density electron–hole plasma, and a Dember field between mobile carriers develops with the subsequent bipolar diffusive decay.

Table 1
Electrical parameters of differently doped InP wafers

	Undoped InP	InP:S	InP:Fe
μ_h (cm^2/V s)	>4000	>1000	>1000
Dislocation density (cm^{-2})	$< 5\times10^4$	$< 10^4$	$< 10^5$

Similar measurements in InP:Fe (Fig. 2) have not revealed any significant feedback effect of SC field. In this case, transitions from the valance band to Fe determine effective holes generation, while electrons created by two-step transitions are effectively captured by Fe^{3+} state. The grating decay time in InP:S was found very similar for all excitations and varied from 0.7 ns at 0.6 mJ/cm^2 to 0.9 ns at 2.4 mJ/cm^2 (for $\Lambda = 11\,\mu$m). We attribute this to the substantial density of free carriers in the dark-state ($>1\times10^{18}$ cm^{-3}) and consequently weaker SC field.

The measurements of grating decay kinetics $\eta(t) \propto \Delta n^2 \propto \exp(-2t/\tau_G)$ provided grating decay time $1/\tau_G = 1/\tau_R + 4\pi^2 D/\Lambda^2$ at various its periods and allowed determination of diffusion coefficient D and recombination time τ_R. The extracted values are summarized in Table 2. Analysis of diffusion coefficients as a function of excitation energy for n-type undoped InP, pointed out to electrons as

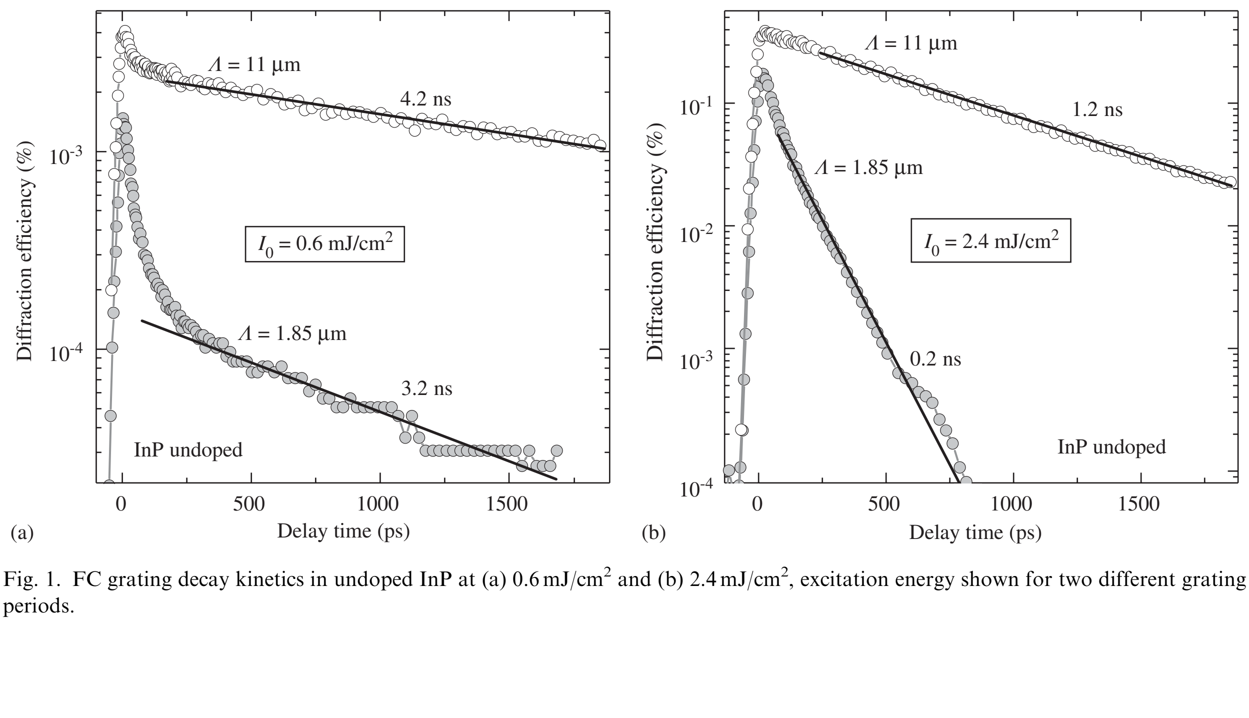

Fig. 1. FC grating decay kinetics in undoped InP at (a) 0.6 mJ/cm^2 and (b) 2.4 mJ/cm^2, excitation energy shown for two different grating periods.