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Minority Hole Mobility in n+ GaAs

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Minority hole mobility in n^+GaAs

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The minority hole diffusivity, or equivalently the hole mobility, was measured in n^+GaAs with the zero-field time-of-flight technique. The minority hole mobility was measured for the donor doping range of 1.3×10^{17} cm^{-3} to 1.8×10^{18} cm^{-3} and was found to vary from 235 to 295 cm^2/V s. At the lower doping level, the minority hole mobility is comparable to the corresponding majority hole mobility, but at 1.8×10^{18} cm^{-3} the minority hole mobility was 30% higher than the majority carrier hole mobility. These results have important implications for the design of devices such as solar cells and *pnp*-heterojunction bipolar transistors.

Recent measurements of minority hole diffusivity, or equivalently minority hole mobility, in n^+GaAs showed that minority hole mobility was greater than the majority hole mobility in comparably doped *p*-type GaAs.[1,2] This result is in striking contrast with results for minority electron mobilities which have been found to be lower than majority electron mobilities[3–6] and also contrasts with a recent theoretical prediction of low minority hole mobilities.[7] In degenerately doped silicon, however, both minority hole and electron mobilities have been found to be greater than majority mobilities.[8,9] For bipolar device engineering there is a great need for minority mobility data in n^+GaAs. In this letter, we report direct measurements of the zero-field minority hole mobility for doping densities from 1.3×10^{17} to 1.8×10^{18} cm^{-3}.

The zero field time-of-flight (ZFTOF) technique was used to measure the minority hole diffusivity, D_p.[6] In this technique a specially designed photodiode is photoexcited with a high-speed laser (3–5 ps FWHM). Carriers are generated near the surface and diffuse in a zero-field environment to the *pn*-junction that is 1 μm from the surface. A mode-locked YAG laser, synchronously pumping a dye laser containing Rhodamine 6G dye was used for photogeneration. The excitation wavelength is 600 nm, which corresponds to an absorption length 0.2 μm. To extract D_p, the measured transient response is fit to a numerical simulation.[6] Steady-state internal quantum efficiency (IQE) analysis was also performed on the same films used in the ZFTOF study in order to investigate the surface recombination velocity and the diffusion length.

Devices for this study were grown on (100) p^+GaAs substrates by molecular beam epitaxy (MBE) in a Varian GEN-II system. Silicon and beryllium are the *n*- and *p*-type dopants, respectively. The device structure used in this study is shown in Fig. 1 and described in Table I. As shown in the figure, the emitter surface is passivated with $Al_{0.27}Ga_{0.73}As$ to provide a low surface recombination velocity at the emitter-AlGaAs interface, thereby eliminating it as a fitting parameter in the transient analysis. A thin 1 μm emitter layer was chosen to minimize recombination and reabsorption effects and to maximize the sensitivity to diffusivity. Its thickness was accurately controlled by monitoring reflection high energy electron diffraction oscillations during film growth. Mesa isolation by wet etching with NH_4:H_2O_2:DI (10:3.5:500) was used to fabricate the diodes of area 500×500 μm.[2] An alloyed AuGe:Ti:Au contact to the emitter was electron beam evaporated and alloyed at 400 °C for 90 s. Electrical contact to the substrate was facilitated by the alloyed indium layer formed during substrate mounting for MBE. To minimize circuit effects, the devices were packaged in a high-speed package.[6]

Film properties were characterized by Hall mobility measurements and secondary ion mass spectroscopy (SIMS) analyses. Prior to the Hall measurements, the thick cap was etched off the Hall devices. The majority carrier Hall mobilities shown in Table I were found to agree with the upper bound of reported experimental data.[10] (A Hall factor of 1 was assumed in the Hall analyses.) SIMS analysis yielded consistent values of total silicon concentration, which are also shown in Table I. Silicon is an amphoteric dopant in GaAs, and these data imply compensation ratios (N_A/N_D) between 0.11 and 0.33. The SIMS analysis also verified that the emitter layer thickness was correct and that the emitter doping profile was uniform.

Our previously reported measurement at the highest doping level was performed with a large portion of the junction (~54%) shadowed by the emitter contact metallization and by a black wax that was applied over the mesa perimeter.[1] Covering the perimeter is necessary be-

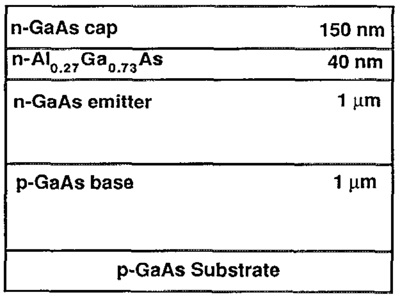

FIG. 1. Cross section of zero field time-of-flight diode used for measurements of minority hole diffusivity.

TABLE I. The base and emitter concentrations, compensation level in the emitter, and majority carrier Hall mobility in the emitter for *n*-GaAs devices for measuring the minority carrier hole diffusivity.

Concentration				
Base ($\times 10^{16}$ cm^{-3})	Emitter Hall ($\times 10^{17}$ cm^{-3})	Emitter SIMS ($\times 10^{17}$ cm^{-3})	Compensation ratio (N_A/N_D)	Hall mobility (cm^2/V s)
18	1.3	1.5	0.14	4650
0.7	2.7	3.0	0.11	4150
18	6.8	8.5	0.22	3170
1.4	18	25	0.33	2390

cause generation along the perimeter can significantly distort the measured signal. This is a particular problem for these devices because the cap layer is thick; consequently, generation in the emitter is lower than generation on the perimeter, where the photon flux is not attenuated by the cap layer. Simulations using a lumped element RC transmission line model[6] indicate rapid lateral signal propagation in the sample with the emitter doped at 1.8×10^{18} cm^{-3}. However, this is not the case for the devices with emitters doped in the mid-10^{17} cm^{-3} range. Therefore low levels of shadowing were necessary. With all devices used in this study, contacts were moved off the mesa onto polyimide layers and metallization was used to shadow the perimeter thereby reducing the shadowing to $<8\%$.

For the three lower doped samples, steady-state IQE analysis showed that essentially all carriers generated in the n^+ GaAs emitter layers were collected, so the ZFTOF analysis contained only one fitting parameter, D_p. For the sample with emitter doped at 1.8×10^{18} cm^{-3} two fitting parameters were necessary, D_p and τ_p. The resulting minority hole mobilities are shown in Fig. 2 along with a curve representing the majority hole mobility, a theoretical prediction of the minority hole mobility by Lowney and Bennett,[7] and a measurement of the minority hole mobility at 4×10^{18} cm^{-3} by Slater.[2] For the doping concentration of 1.8×10^{18} cm^{-3}, the minority hole mobility is 30% larger than the majority hole mobility while at the lower doping levels they are comparable. Over the investigated concentration range the minority hold diffusivity is roughly constant, but the majority hole diffusivity varies by nearly a factor of two. The theoretical prediction of the minority carrier hole mobility is much smaller than our measured results, which suggests that more work is needed to understand the important scattering mechanisms in n^+GaAs.

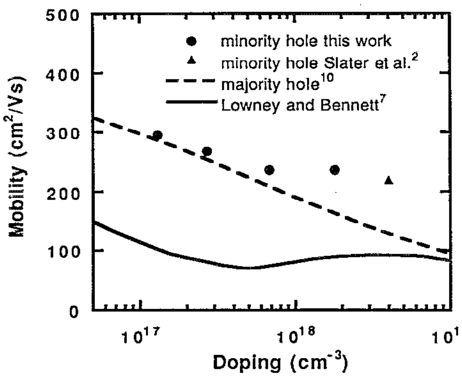

FIG. 2. The minority hole diffusivities resulting from zero field time-of-flight measurements. Also shown is a line representing the majority hole mobility, theoretical prediction of the minority hole mobility by Lowney and Bennett, J. Appl. Phys. **69**, 7102 (1991), and a measurement of the minority hole mobility at 4×10^{18} cm^{-3} by Slater *et al.*, IEEE Electron Device Lett. **12**, 54 (1991).

Because recombination was minimal in the three lower doped emitters, τ_p could only be deduced for the most heavily doped emitter of 1.8×10^{18} cm^{-3}. IQE fits for the most heavily doped emitter yielded a diffusion length of 1.4–1.7 μm. Combining this with the diffusion coefficient implies a lifetime of 3.3–4.8 ns, which agrees with the value deduced from the transient analysis and with the expected radiative limited lifetime for n^+GaAs doped to 1.8×10^{18} cm^{-3}.[11]

In summary, the minority hole diffusivity in silicon doped n^+GaAs was found to be roughly constant over the doping range of 1.3×10^{17} to 1.8×10^{18} cm^{-3}. At the highest doping concentration D_p was found to be 6.0 cm^2/s, which corresponds to a room-temperature zero-field mobility of 230 cm^2/V s. This is 30% higher than the majority hole mobility at this doping. At the lowest doping concentration, D_p was found to be 7.5 cm^2/s, which corresponds to a room-temperature zero-field mobility of 295 cm^2/V s. These results have important implications for the design of GaAs devices such as solar cells and pnp-heterojunction bipolar transistors.

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