Charge transport dynamics studies of planar GaAs:Cr sensors by laser excitation

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Introduction

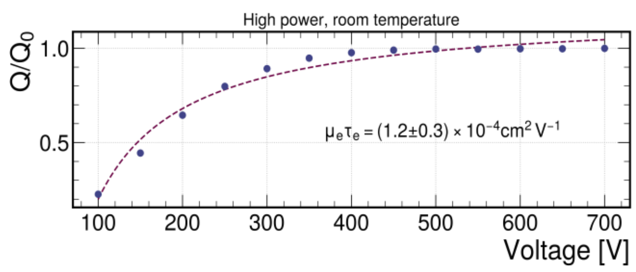
Advancements in crystal doping via chromium compensation and annealing processes have significantly enhanced the performance and efficiency of GaAs detectors. However, chromium doping introduces deep energy levels that can trap charge carriers, affecting the detector's response and efficiency. To align with the trend of crystal doping, it is essential to study the transport properties and the $\mu\tau$ product as a critical parameter of charge trapping.

Measurements

- Studies were done on planar diodes with sizes of 5 × 5 × 0.5 mm^3 active, metallized area was 3 × 3 mm with metal thicknesses of 25-50 nm.
- The laser intensity, modulated between 40- 100 mW, was sufficient to generate electron-hole pairs at a depth of 1- 3 µm beneath the metal layer.
- Experiments were conducted using varying polarities of direct current biases, across a temperature range of 5 to 25 °C, and at the different laser intensities.

Results

- By integrating over the full charge collection time and normalizing against the input charge Q_0 we used the Hecht equation to fit the data and extract the $\mu\tau$ product.



$$CCE = \frac{Q}{Q_0} = \frac{\mu_e t_e V}{d^2}\left[1 - exp\left(\frac{d^2}{\mu_e t_e V}\right)\right]$$

Figure 1. Charge collection efficiency as a function of applied voltage. Purple line represent the Hecht equation fit.

Table 1. Mobility-lifetime variations in GaAs:Cr where electrons are the majority charge carrier.

$(\mu\tau)_e$ [cm^2 / V]	Condition
(4.78 ±0.07)× 10^{-4}	Low power, room temp.
(1.2 ±0.3)× 10^{-4}	High power, room temp.
(1.38 ±0.03)× 10^{-4}	Low power, 5°C
(3.6 ±0.1)× 10^{-6}	High power, 5°C

Table 2. Mobility-lifetime variations in GaAs:Cr where holes are the majority charge carrier.

$(\mu\tau)_h$ [cm^2 / V]	Condition
(1.8 ±0.1)× 10^{-6}	Low power, room temp.
(0.9 ±0.1)× 10^{-6}	High power, room temp.
(1.19 ±0.09)× 10^{-6}	Low power, 5°C
(0.88 ±0.03)× 10^{-6}	High power, 5°C

Placing the sample on a moving stage, we obtained spatial maps of the charge distribution. Highlighted bright areas indicate the edges of metallization, while the underlying regions reveal varied surface morphology according to the conditions to which the sample was exposed.

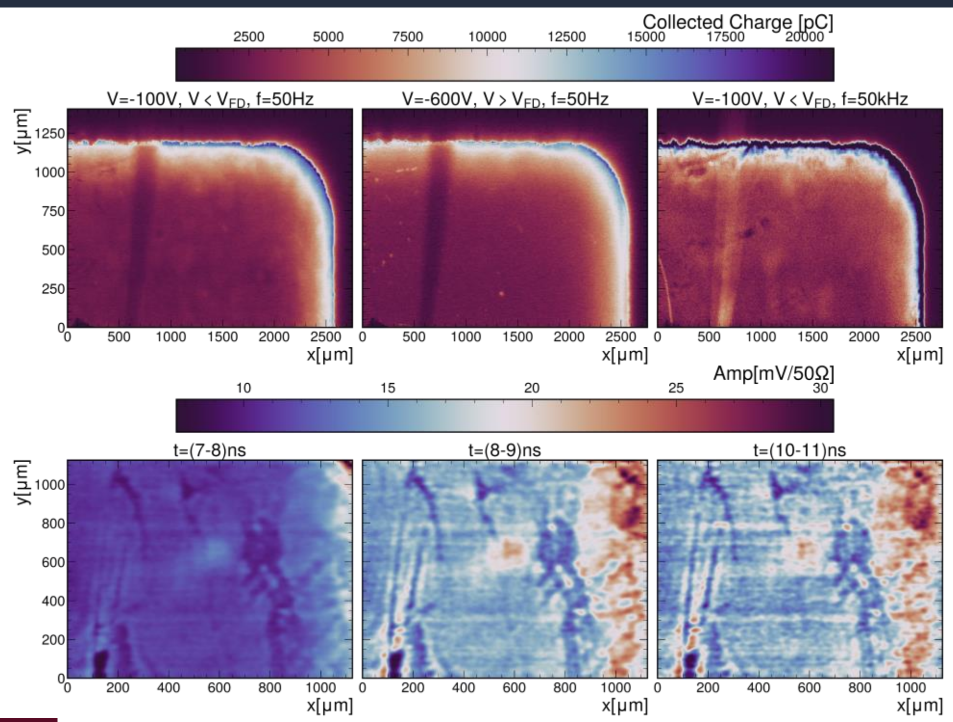


Figure 2. Top image: Collected charge over 35 ns at varying laser rates at 25 °C. Bottom image: Detailed view of changes in amplitude within a zoomed-in area, recorded over different time sections while the sample was at a constant voltage (V= -600 V) and a temperature of 5 °C.

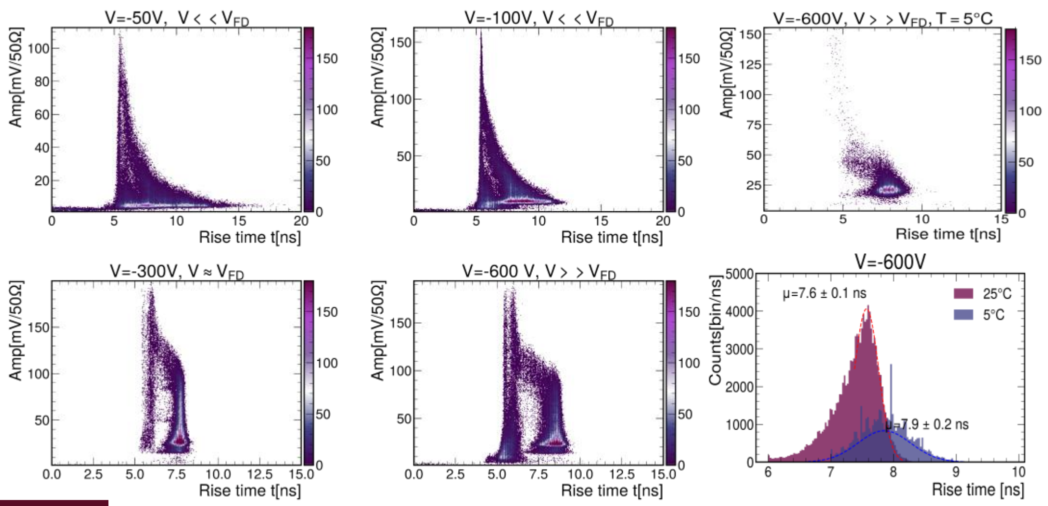


Figure 3. Amplitude versus rise time distributions for different voltages. Plots correspond to the specific area detailed in top image of Figure 3, under identical laser settings. The two rightmost plots illustrate the impact of two temperature ranges on rise time at constant voltage.

Conclusion

Transient current measurements allowed us to determine the μτ product and fit results using the Hecht equation. Our analysis showed minor surface morphology variations due to charge trapping. From the captured waveforms we reconstruction of electrical field profiles in regions where τ_{TR} >> t_{DR}, where we noted an irregular increase in field strength with rising voltage, demonstrating the material's nonlinear response. Additionally, the field strength's decrease through the depth implies a gradient in doping, typical for materials with non-uniform doping profiles.

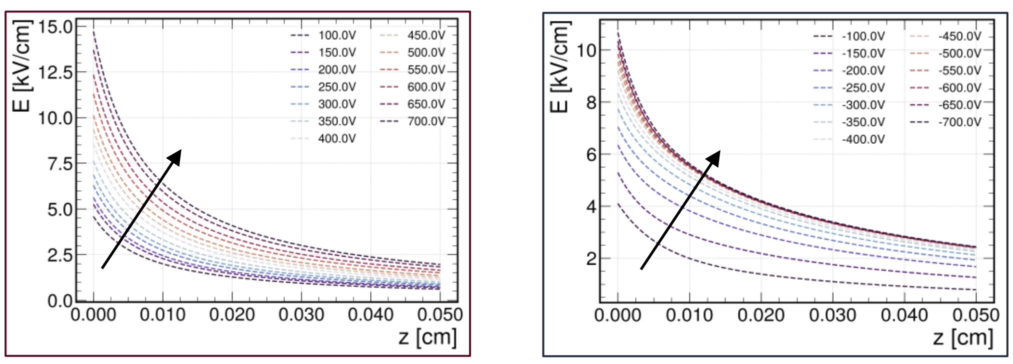


Figure 4. Electrical field profiles calculated for GaAs:Cr samples. The left plot represents reconstructed electrical field where electrons are the major charge carriers, while the right plot shows where holes are the major charge carriers.

1. D. Greiffenberg, et al., Sensors, 21 (2021) 1550-1-22.
2. E. Belas, et al., Journal of Physics D: Applied Physics, 53 (2020) 475102-1-8.
3. H.T. Philipp, et al., Nuclear Instruments and Methods in Physics Research A, 925 (2019) 18-23.