

Review: "Characterization of Indium Phosphide Detectors with Red Laser TCT and Minimum-Ionizing Charged Particles"

Internal review document

Colour coding: **Must fix** (error or missing content required for a complete paper); **Suggestion** (would strengthen the paper); **Note** (housekeeping / open to-do items).

Abstract

- **[Must fix] Fluence inconsistency:** The abstract states "up to 10^{15} n_{eq}/cm²" but only 10^{13} and 10^{14} samples are characterized; 10^{16} sensors show immediate breakdown. Revise to clarify that irradiation was performed to 10^{16} , but results are reported for the characterizable range of 10^{13} - 10^{14} n_{eq}/cm².
- **[Must fix] Quantify "modest" radiation damage:** State a representative CCE value at 10^{14} n_{eq}/cm² relative to unirradiated at a given bias voltage to substantiate the qualitative claim.
- **[Suggestion] Add model outputs:** The model also extracts electron mobility, trapping time, and trapping length — arguably the most physically interesting outputs — which should appear in the abstract.
- **[Suggestion] Temperature dependence:** Improved signal recovery at -20°C is a key practical result absent from the abstract.
- **[Suggestion] Timing resolution number:** The ~25-30 ps timing resolution appears only in the conclusions. State it (with conditions) in the abstract.

Introduction

- **[Must fix] Fluence inconsistency:** Introduction says "up to 10^{14} n_{eq}/cm²", abstract says " 10^{15} ", Methods lists four fluences including 10^{16} . Bring all three into agreement.
- **[Suggestion] Strengthen physics motivation:** Add one sentence explicitly connecting the high electron mobility to the expected timing performance before the section roadmap.
- **[Note] Section title cross-reference:** Introduction refers to "Section X" as "Signal Modeling"; actual title is "Signal Modeling in InP" — check all cross-references.

Methods

- **[Suggestion] Nuclear isomer / activation: move to Results:** The gamma spectroscopy observation of ^{114m}In (49.5-day half-life, 190 keV transition, decay to ¹¹⁴Cd/¹¹⁴Sn) is an experimental result and belongs in Results, where it also directly grounds the activation caveat in the conclusions. The practical reason for the long cool-down period can remain in Methods.
- **[Suggestion] Fluence scaling caveat:** The Si-based scaling convention is noted as possibly not applying to InP, but the issue is not revisited quantitatively in the damage parameter discussion. Either quantify the uncertainty here or cross-reference the results section.
- **[Note] Open to-do: fluence numbers:** Confirm n_{eq}/cm² estimates from Gregor (Ljubljana) — flagged in TODO.md.
- **[Note] Open to-do: author list:** Add Ljubljana co-authors; confirm ANL and UIC affiliations (TODO.md).
- **[Note] Open to-do: seed grant number:** Acknowledgments placeholder "no. xxx" must be filled before submission.

Signal Modeling

- **[Suggestion] Justify hole neglect quantitatively:** State an order-of-magnitude estimate of the hole contribution to the pulse integral from the mobility ratio, rather than just asserting it is negligible.

- **[Suggestion] CCE formula limiting cases:** Confirm in the text that the CCE formula gives 1 at $\tau \rightarrow \infty$ and 0 at $\tau \rightarrow 0$, to help readers follow the derivation.
- **[Suggestion] Restore waveform analysis sketch:** The commented-out schematic figure illustrating the drift triangle, bandwidth, echo train, and ring would substantially help readers follow the three-stage instrumental model.
- **[Note] Stopping power file:** Confirm that `stopping_power_modeling_earl.tex` is deliberately excluded from the current build.

Results and Discussion

Laser TCT

- **[Must fix] No numerical results stated:** The laser TCT subsection has almost no numerical prose. State representative values for pulse height, signal length, rise time at two or more bias voltages from Fig. 3.
- **[Must fix] Polarity asymmetry unexplained:** The polarity asymmetry is shown but not explained or quantified. State the physical reason (electron vs hole drift, mobility asymmetry) and give a representative amplitude ratio between the two polarities.
- **[Suggestion] Reconcile figure captions:** Fig. 2 caption says "displaying negative bias voltages" but Fig. 3 shows both polarities. Unify the caption language and clarify which figure shows what.

Betascope, unirradiated (Sr-90)

- **[Must fix] Quantitative results missing:** Rise times (~ 200 ps) and timing resolutions (~ 30 ps) are stated in a single sentence without conditions (bias, temperature, polarity) and without reference to specific figure panels. Add conditions and figure references.
- **[Must fix] Physically imprecise phrasing:** "Inverse relationship between pulse height and temperature" is ambiguous — if pulse height increases as temperature decreases, say that directly.
- **[Suggestion] Quantify temperature effect:** State the magnitude of the improvement from $+20$ to -20°C in pulse height and collected charge for the unirradiated device.
- **[Suggestion] Broaden comparison to silicon:** The comparison to silicon currently cites only silicon LGADs (with gain). Add a comparison to standard silicon pin diodes, which is more relevant for a material without charge multiplication.

Signal model fits, unirradiated

- **[Suggestion] Quantify Q0 agreement:** State the typical fitted Q0 value and its uncertainty; "good agreement with 8 fC" is qualitative.
- **[Suggestion] State extracted mobility:** The fitted electron mobility from Fig. 8c should be stated and compared to the literature value of $4600 \text{ cm}^2/(\text{V}\cdot\text{s})$ to validate the model.
- **[Suggestion] Discuss trapping time:** The trapping time τ from unirradiated fits (Fig. 8d) is presented but not discussed. Is it consistent with known Fe trap properties in InP:Fe?

Irradiation: I-V and C-V

- **[Suggestion] Nuance the α comparison to silicon:** The comparison ($\alpha_{\text{InP}} \approx 3 \times \alpha_{\text{Si}}$) and the conclusion "less radiation hard" is misleading without noting that the Si value is defined under full depletion while InP α is strongly bias-dependent. Acknowledge this explicitly.
- **[Suggestion] Quantify volume uncertainty:** The effective volume is an upper bound (E-field simulation shows a larger true volume), but the magnitude of the resulting uncertainty in α is not stated. Add an estimate.
- **[Suggestion] Expand C-V discussion:** One sentence for four figures is insufficient. Add a brief physical interpretation of why capacitance is insensitive to irradiation in a bulk quasi-resistive material with no depletion region.

Irradiation: betascope signal

- **[Must fix] State numerical irradiation results:** Timing resolution and collected charge for irradiated samples at representative conditions (400 V, +20°C and -20°C, both fluences) are never stated numerically. Add these.
- **[Must fix] Quantify temperature recovery:** The temperature recovery effect is stated qualitatively. State the fractional improvement in collected charge from +20 to -20°C at each fluence and a representative bias.
- **[Suggestion] Connect rise time trend to physics:** Mention in this subsection that the shorter rise times at higher fluence reflect trapping-limited collection (not just quote the trend), bridging to the conclusions.

Irradiation: signal model fits

- **[Must fix] State CCE numbers:** CCE vs voltage (Fig. 10) and CCE vs fluence (Fig. 11a) are the central quantitative results. State the CCE at 10^{14} n_{eq}/cm² at 300 V and its ratio to the unirradiated value.
- **[Must fix] Discuss trapping distance trend:** The trapping distance vs fluence (Fig. 11b) is presented without prose. State the trend and its physical meaning.
- **[Suggestion] Validate fixed-transit-time assumption:** Briefly note what would change if the transit time and amplitude were not fixed to unirradiated values in the irradiated fits, or confirm the assumption is validated by comparison.

Conclusions

- **[Must fix] Complete placeholder sentences:** "We observe that leakage currents in diodes before the onset of breakdown...", "It was found that...", and "This observation..." are incomplete and must be finished before circulation.
- **[Must fix] Convert bullet list to prose:** The bullet list at the end of the conclusions signals an unfinished manuscript and must be absorbed into prose.
- **[Must fix] State timing resolution in results:** The "below 25 ps" number appears only in conclusions. State it first in the results section.
- **[Must fix] Activation: cite the observation:** The activation caveat references an observation that is currently in Methods. Move the observation to Results (as discussed under Methods above) and cite it here.
- **[Suggestion] Complete polarity asymmetry sentence:** The sentence about hole drift (trailing ellipsis) needs to be completed with a quantitative comparison.
- **[Suggestion] Add comparison to other semiconductors:** A brief comparison of α for InP against SiC, GaAs, and CdTe (flagged in the bullet list) belongs in the irradiation results discussion with a summary mention here.
- **[Suggestion] Sharpen thin-film outlook:** Specify which properties (carrier lifetime, trap density, mobility) are most important to compare between crystalline and amorphous InP, to make the forward-looking statement concrete.

Cross-cutting and General

- **[Must fix] Add performance comparison table:** No table compares InP metrics (CCE, timing resolution, rise time, damage parameter α) to silicon. This is standard in characterization papers and will be expected by referees.
- **[Must fix] Macro usage:** Macros for 113-In, 114-In, 114m-In, 114-Cd, and 114-Sn are defined but usage should be verified; remove any that are unused before submission.
- **[Suggestion] Numerical results for all key figures:** Each key figure needs at least one sentence in the text quoting a representative number, not just a trend description. Figures most in need: Figs. 3 (laser TCT characterization), 6 (betascope unirradiated), and Figs. 10-11 (irradiation model results).

- **[Suggestion] Remove draft artefacts from appendix:** The blue editorial note ("Jenni: added blank page here...") must be removed. Add a reference from the main text directing readers to the appendix.
- **[Suggestion] Reconsider "MIPs" in title:** "Minimum-Ionizing Charged Particles" in the title is slightly imprecise since 90-Sr betas are used. Consider "...with Red Laser Transient Current Technique and Sr-90 Beta Particles" for accuracy.
- **[Note] Caption grammar:** "for a InP 1-ch device" should be "for an InP 1-ch device" in Fig. 6 caption and appendix Fig. A2 caption.
- **[Note] Fig. 2 vs Fig. 3 captions:** Reconcile the inconsistency in which polarity/polarities are shown between the two laser TCT figures.
- **[Note] Taylor figure:** Verify that the zoomed-in E-field figure from Taylor (flagged as done in TODO.md) is the correct version in the current build.