Understanding the Implications of a LINAC's Microstructure on Devices and Photocurrent Models

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ABSTRACT: This poster investigates the effect of a linear accelerator's microstructure (i.e., train of narrow pulses) on devices and the associated transient photocurrent models. The rate the energy is deposited in a material during the microstructure peaks is much higher than the pulse-averaged rate.

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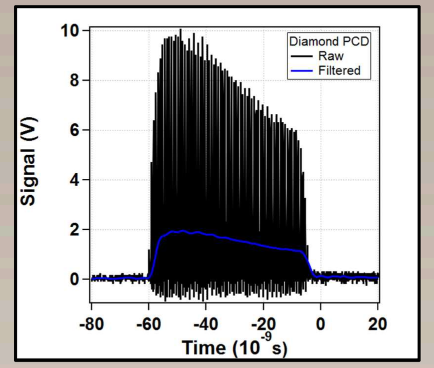
Motivation

To better understand the impact of a linear accelerator's microstructure (i.e., train of narrow pulses) on devices and circuits and the associated transient photocurrent models

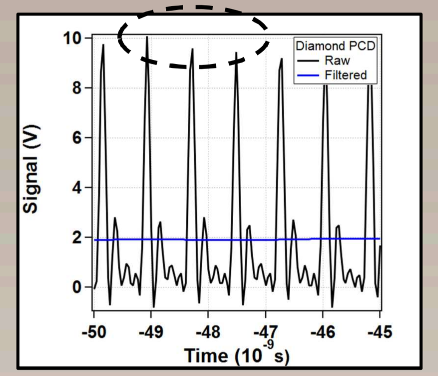
Why Does this Matter?

- Linear accelerators (LINACs) are a common source used to study transient radiation effects in devices and circuits as well as to gather data for model development
- Upset and/or burnout in devices and circuits could potentially occur at lower thresholds than expected at a LINAC when not properly accounting for microstructure effects
  - Rate of energy deposition in a material during the microstructure peaks is much higher than the pulse-averaged rate
- Photocurrent models developed with filtered LINAC data may be inherently inaccurate if the device or circuit is able to respond to the microstructure

Raw and software filtered (time-averaged) diamond photoconductive detector (PCD) signals for a 50 ns pulse envelope



Microstructure

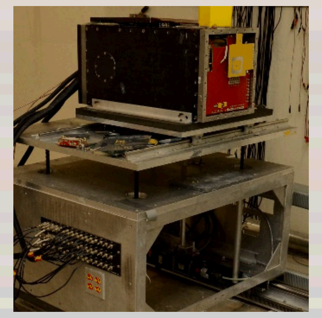


Zoomed plot of data

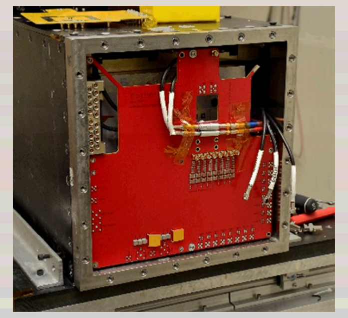
Experimental Details

Little Mountain Medusa LINAC Characteristics	
Operation mode	Electron beam
Average energy	19.2 MeV
Microstructure pulse frequency	1.28 GHz
Individual pulse width	~125 ps
Duty factor of microstructure	15%
Rise/fall times (diamond PCD)	<100 ps (Raw) and <5 ns (Filtered)
Nominal pulse envelope	50 ns to 100 µs

Little Mountain Medusa LINAC



Low noise test fixture (LNTF)

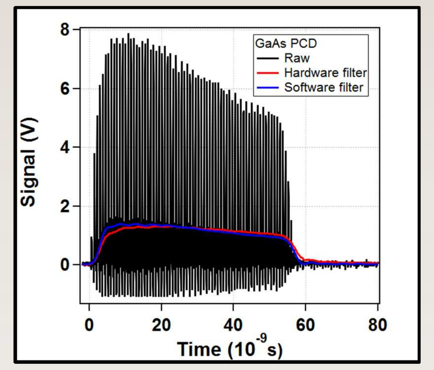


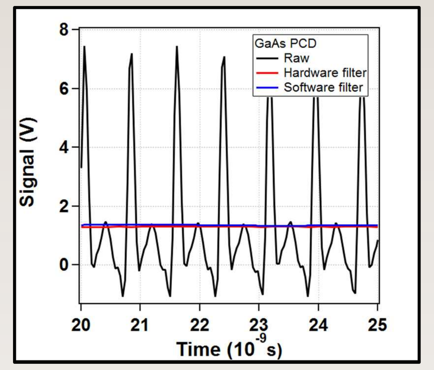
Setup with SiO_2 & GaAs PCDs

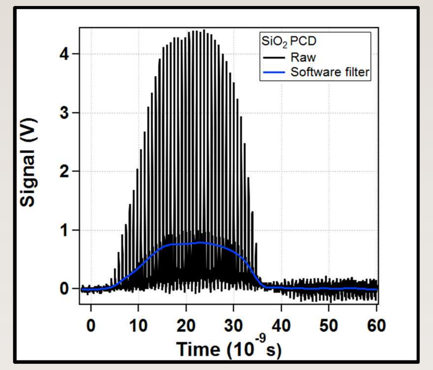
Obtained data on COTS RF BJTs (NPN) and PIN diodes as well as diamond, GaAs, and SiO_2 PCDs

Experimental Results

- Experimental setup (e.g., cable type and lengths, external 50Ω terminators, hardware filters, and scope capabilities) significantly impacts ability to measure microstructure
- GaAs, SiO_2, and diamond PCDs reveal microstructure effects when measured on high-speed scopes and removing filtering and other parasitics within the experimental setup
  - PCDs are an active dosimetry diagnostic used to determine dose/dose rate of each irradiation (correlate PCD response to TLDs or calorimeter)
  - PCDs typically measured through a low pass hardware filter (e.g., 220 MHz) which eliminates microstructure effects and reduces the peak



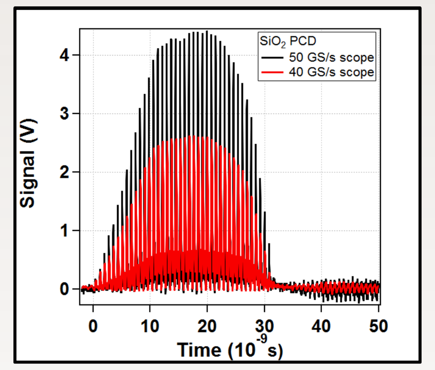




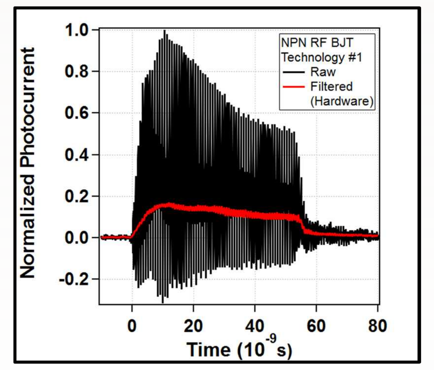
Filtered signal peak is a fraction of the microstructure peak; hardware and software filtered signals are similar and have slower rise/fall times

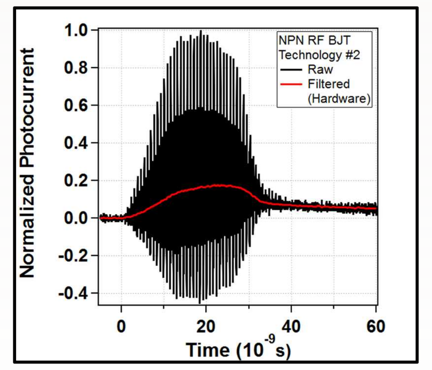
- The plot to the right shows the impact of using a 40 GS/s scope compared to a 50 GS/s scope to measure the microstructure (peak is ~1.7× lower using a 40 GS/s scope)

Measuring the true characteristics of a LINAC microstructure is extremely difficult

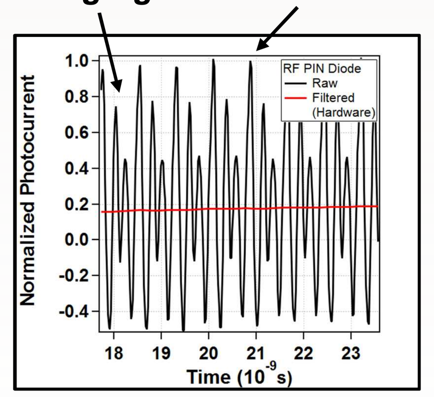


- Commercial off the shelf (COTS) Si RF bipolar junction transistors (BJTs) and RF PIN diodes also respond to LINAC microstructure
- May need to account for microstructure when determining effective dose rate with PCDs if devices exhibit anomalous responses
- During irradiation, the collector was positively biased and the base and emitter were shorted together and connected to the scope (anode connected to scope in diode test)





Ringing Microstructure

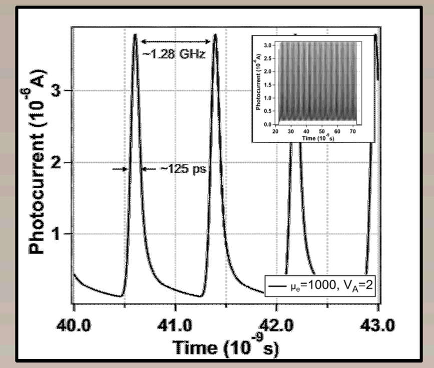


Cable/board ringing more pronounced in RF devices than PCDs, but microstructure still present (refer to RF PIN Diode data on the right)

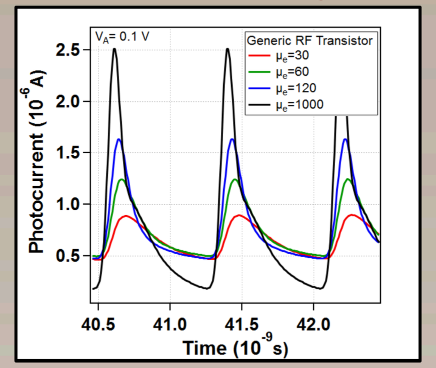
Device Simulations

- Two-dimensional device simulations were performed with Silvaco's suite of technology computer aided design (TCAD) tools
- Device simulations are critical to understand how/which devices will respond to the microstructure and to validate the observed experimental response
- Adjusted device parameters (i.e., mobility, field, and depletion region width) to determine the variation in the response and assign controlling parameters to the microstructure effects
  - Peak of microstructure pulses assumed constant in the model (i.e., did not vary with time similar to the experimental data)
  - Simulated a RF transistor with a depletion region width (W_D) of ~0.7 µm, a Zener diode with $W_D \approx 2$ µm, and a graded *p-n* junction with $W_D > 2$ µm

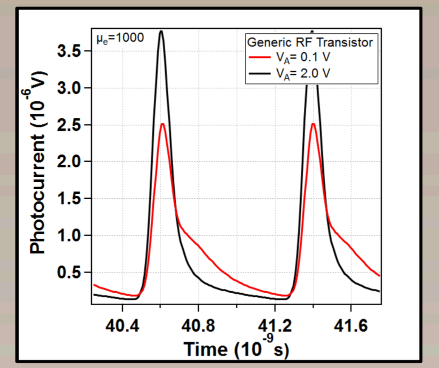
Modeled microstructure in RF transistor



RF transistor with varied mobility

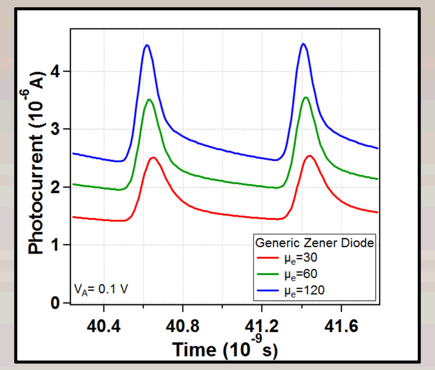


RF transistor with varied bias

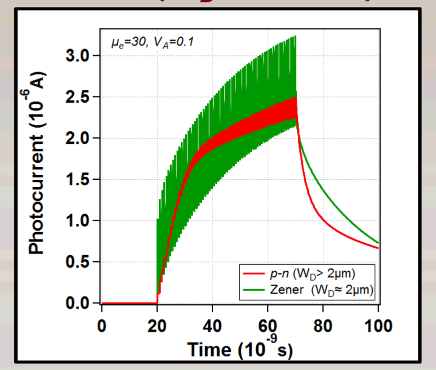


RF transistor responds to microstructure to varying levels depending on the electron mobility (μ_e) and applied bias (V_A)

Zener diode with varied mobility



p-n junction vs. Zener diode (W_D variation)



Slow response and relative lack of microstructure indicates that devices with wider depletion regions will have little to no response to microstructure

- A microstructure sensitivity relationship describing whether a device will respond to microstructure effects can be derived from the device simulation results

$$(\tau_m + c \cdot \tau_e)\mu_e E \ll W_D$$ ← *Little to no response to microstructure*

$$(\tau_m + c \cdot \tau_e)\mu_e E \gtrsim W_D$$ ← *Will respond to microstructure*

τ_m = microstructure period c = constant (assumed << 1) μ_e = electron mobility

E = built-in or applied field W_D = depletion region width τ_e = electron lifetime

Photocurrent Modeling

- Photocurrent models typically created using the pulse-averaged response for the devices and radiation diagnostics
- Several photocurrent models exist in literature; here we selected the Fjeldy photocurrent model for *p-n* junctions [T. A. Fjeldly, *et al.*, *IEEE TNS*, 2001]
- Basic equation governing photocurrent density (assumes electrons dominate prompt response):

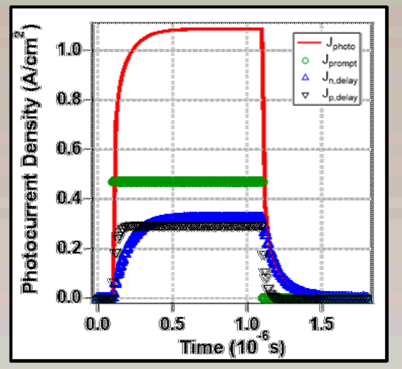
$$J_{photo} = J_{prompt} + J_{n,delay} + J_{p,delay} = qGW_{dep} + G_nL_{nd} + G_pL_{pd}$$

J_{prompt} = drift-based photocurrent density
$J_{n,delay}$ = n-type (p-type) diffusion-based delayed photocurrent density
$G_{n,p}$ = electron/hole generation rates
W_{dep} = depletion region width
L_{nd}, L_{pd} = effective diffusion lengths

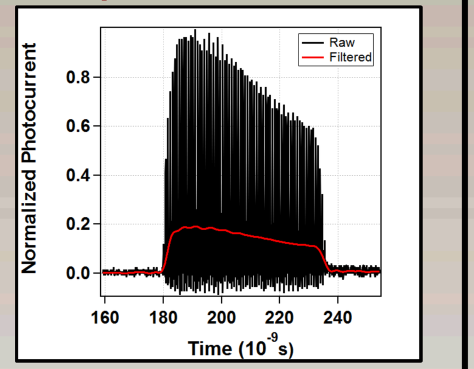
- Photocurrent density calculated for a *p-n* junction assuming a 1 µs square wave pulse and using the raw and filtered PCD data
- Relationship between the prompt and delayed components depend on values selected for model parameters
- The filtered and raw PCD data are captured in the generation rate term

The drift-based prompt photocurrent dominates the microstructure response observed in the p-n junction calculation

1 µs square wave pulse (arbitrarily chosen)



Calculated raw/filtered photocurrents



Summary

- COTS RF transistors and RF PIN diodes as well as GaAs, SiO_2, and diamond PCDs exhibit microstructure effects
- Experimental setup can significantly impact microstructure effects
- Filtered signal peak is much less than the raw microstructure peak (potential hardness assurance and modeling implications)
- Device simulations and photocurrent models able to capture microstructure effects and are critical to understanding how/which devices will respond to the microstructure and validating test data
- If microstructure not accounted for properly, dosimetry and burnout/upset thresholds could be inaccurate

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