Defense Threat Reduction Agency

Single-Event Effects Induced by Pulsed Laser Irradiation

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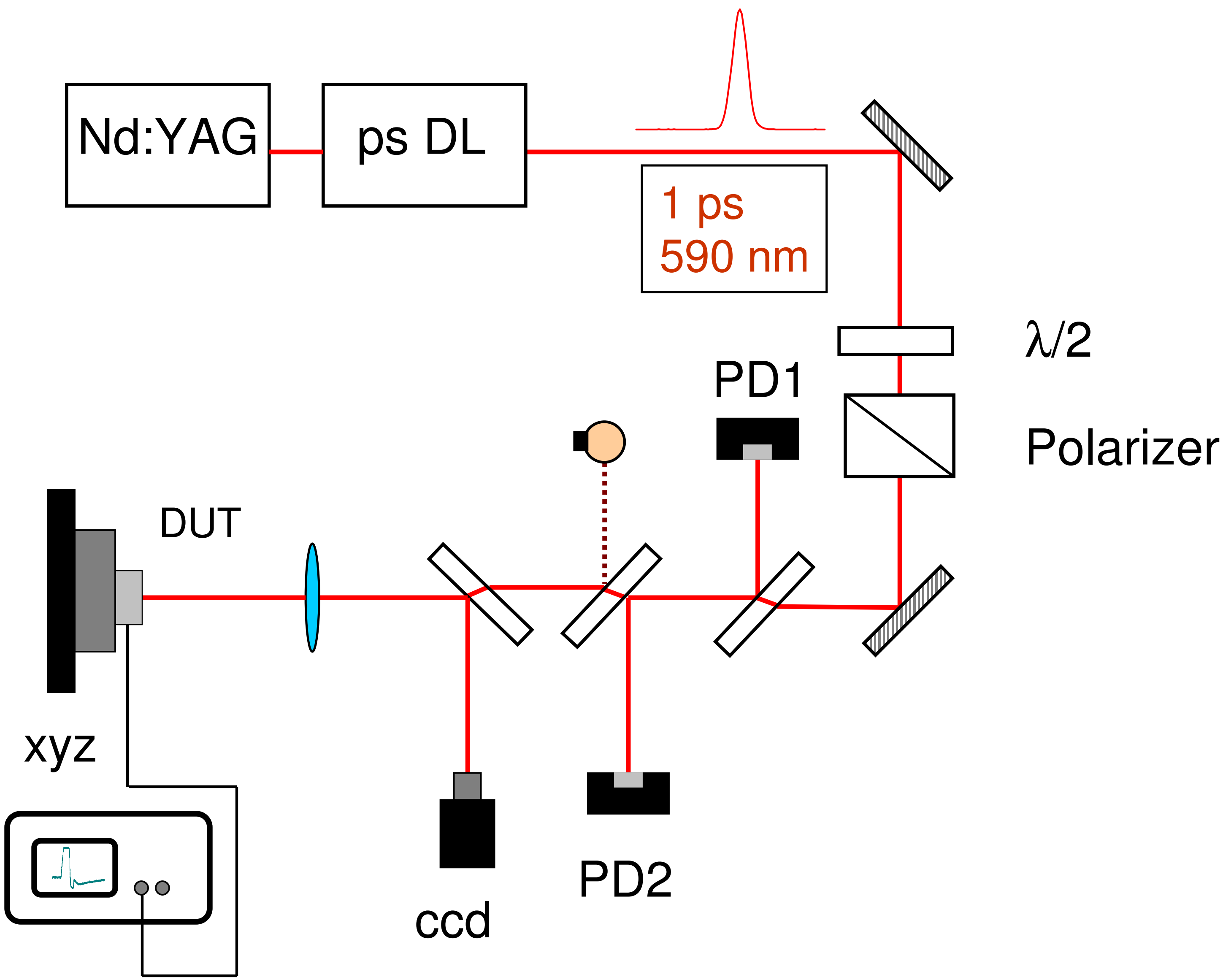
NRL

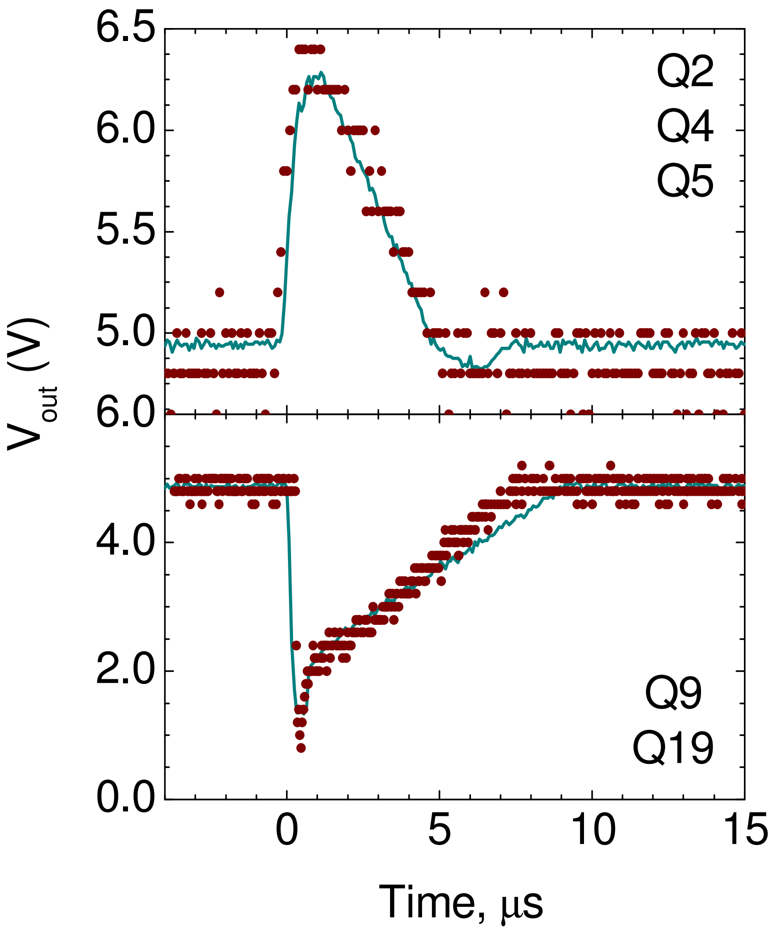
Pulsed Picosecond Laser

- Indispensable tool for SEE characterization
- Above-band gap (single photon)pulsed laser can inject:
  - a well-characterized quantity of charge
  - in a well-defined location
  - at a well-defined time
  - with a well-defined charge-deposition profile
- Several examples

Single-Photon Absorption SEE Experiment

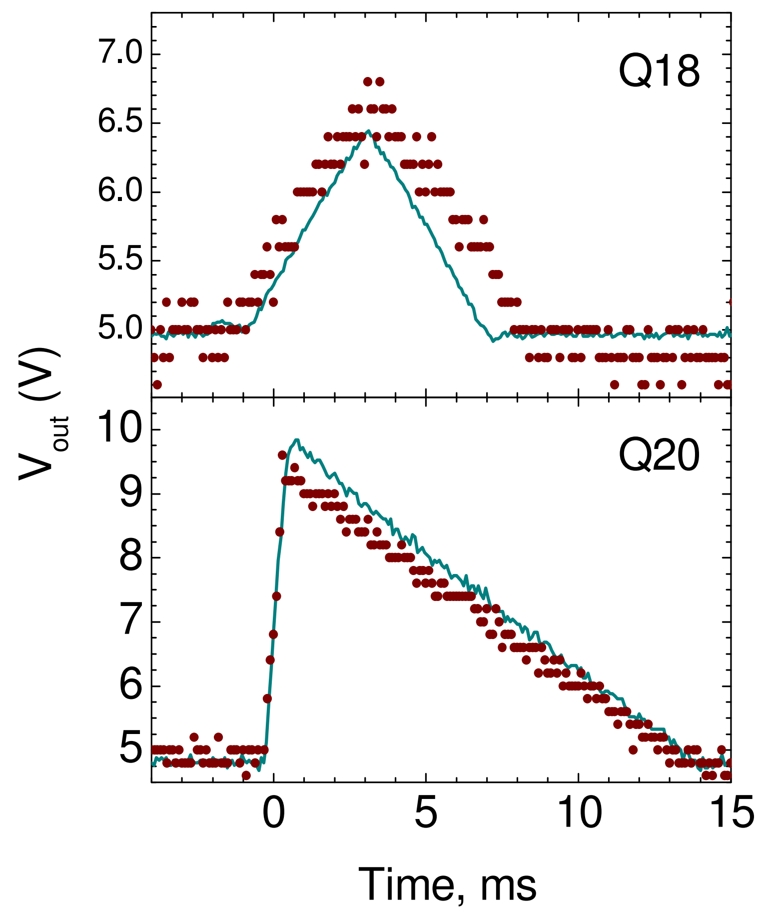


Analog Single-Event Transients: Comparison of Pulsed Laser Light and Heavy Ions



LM124
Voltage Follower:

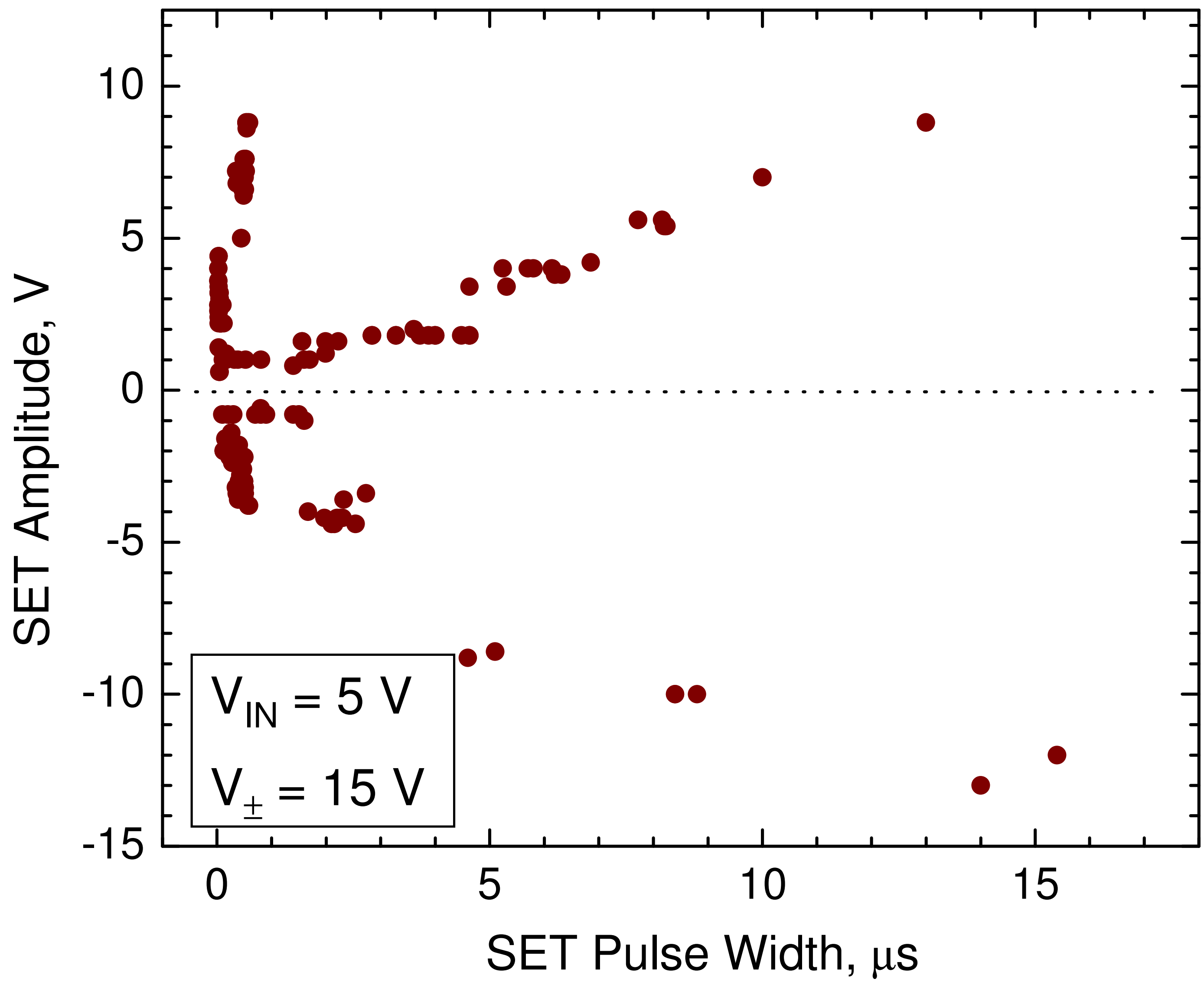
V_{dd} = +/-15 V
V_{in} = 5 mV



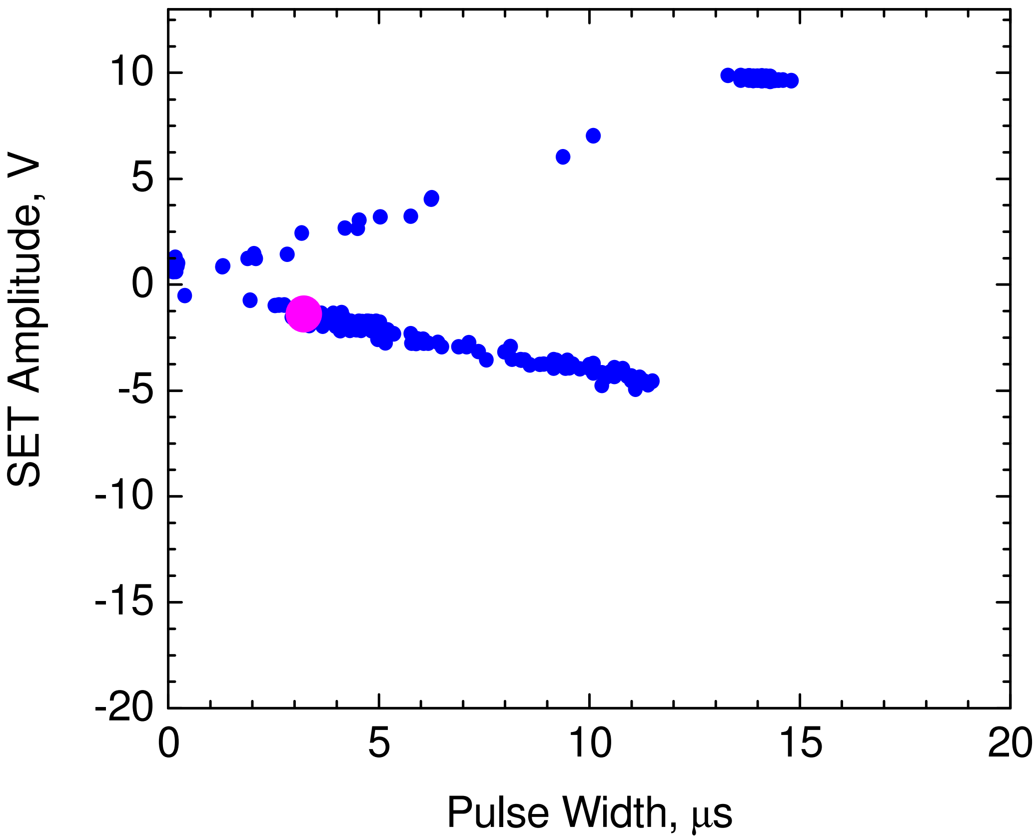
*Pease, et al., **49**, Dec. 2002, 3163-3170*

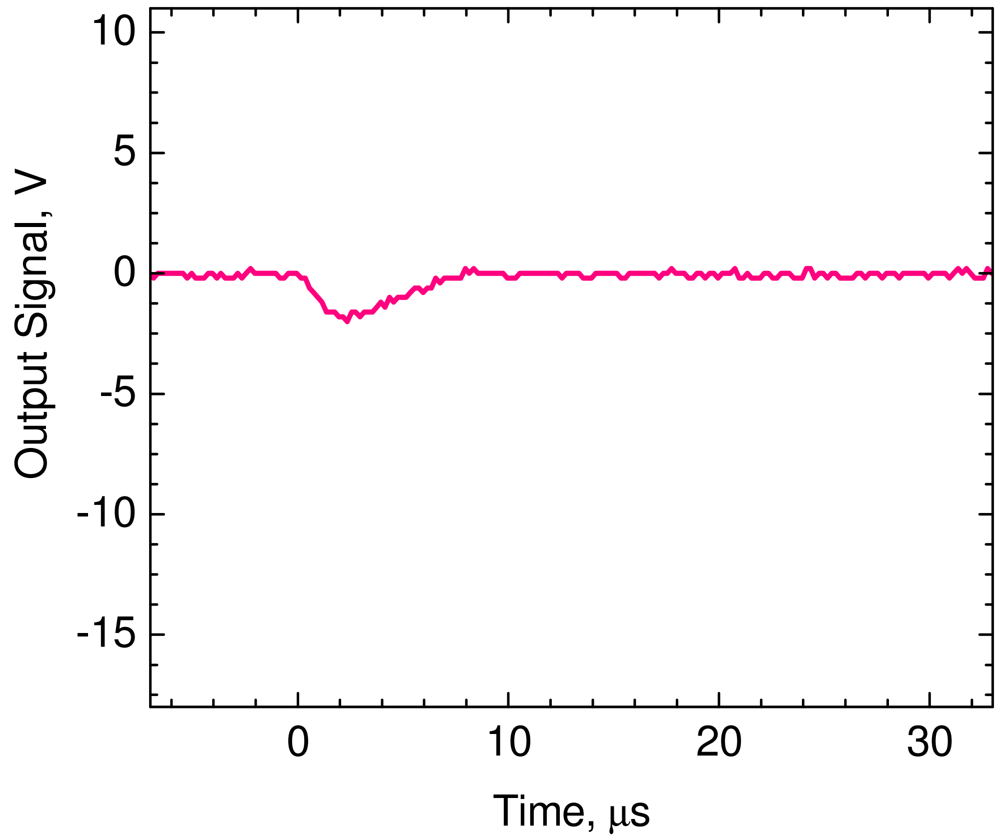
Heavy Ion SET Pulse Width Data: LM124

LET = 53.9 MeV·cm²/mg; Voltage Follower



Pulsed Laser SET Data: LM124 Q20





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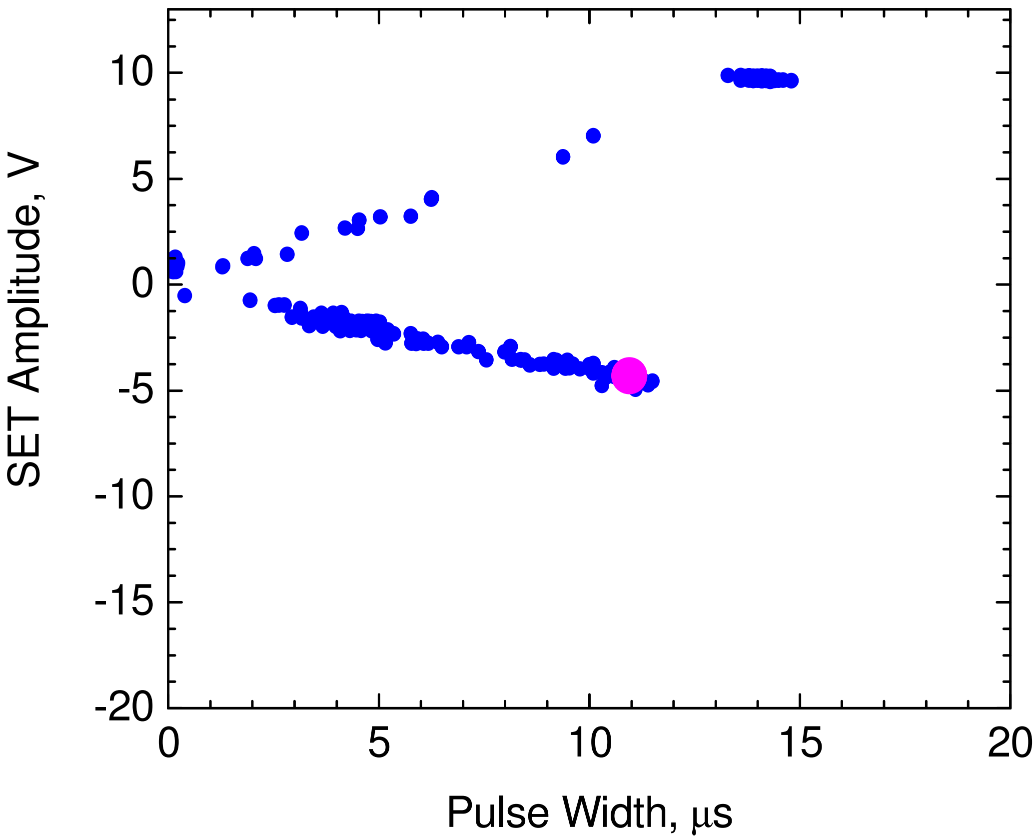

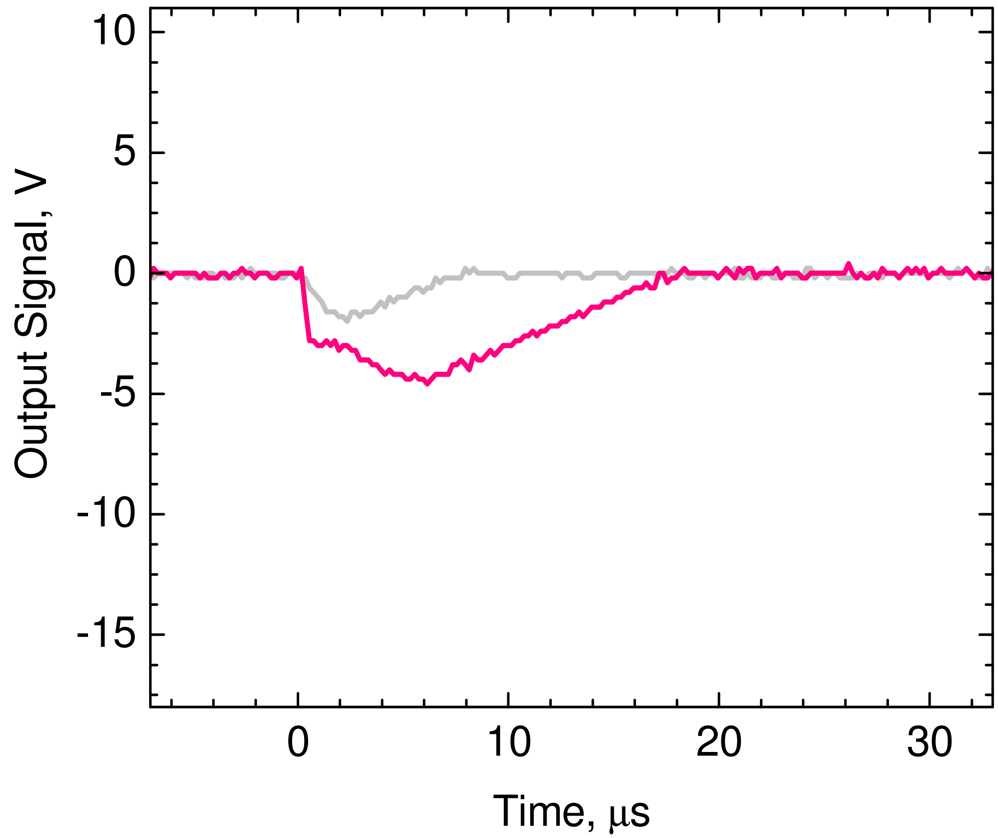

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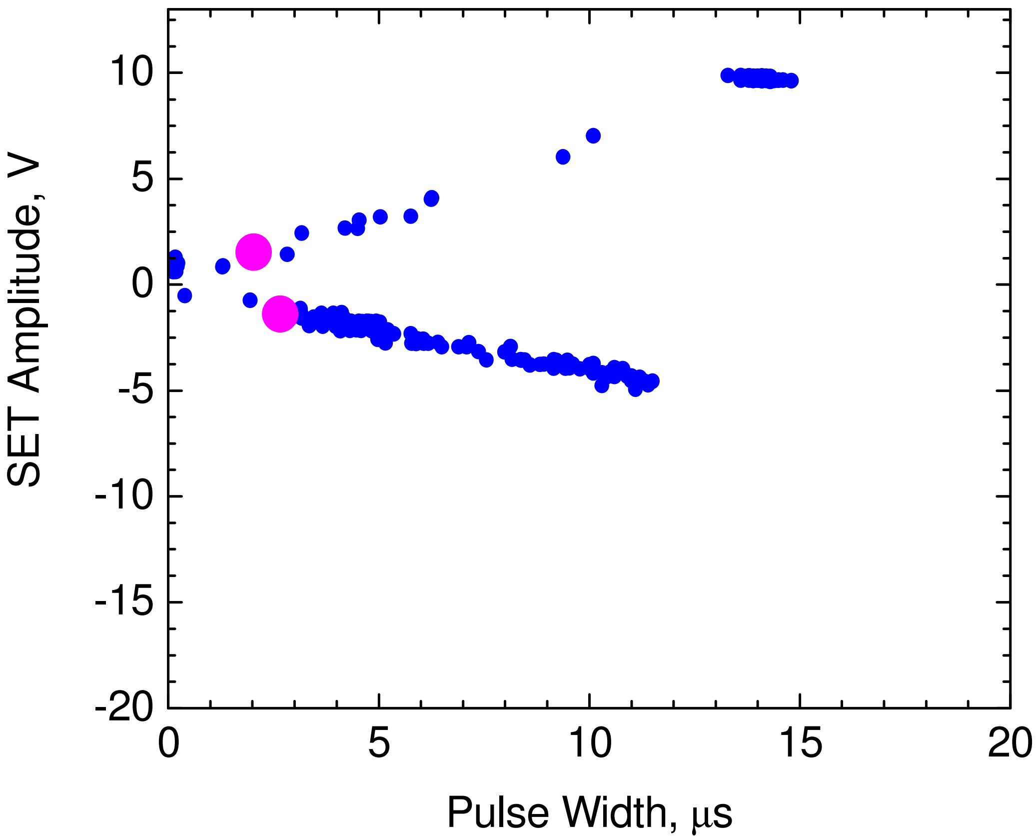

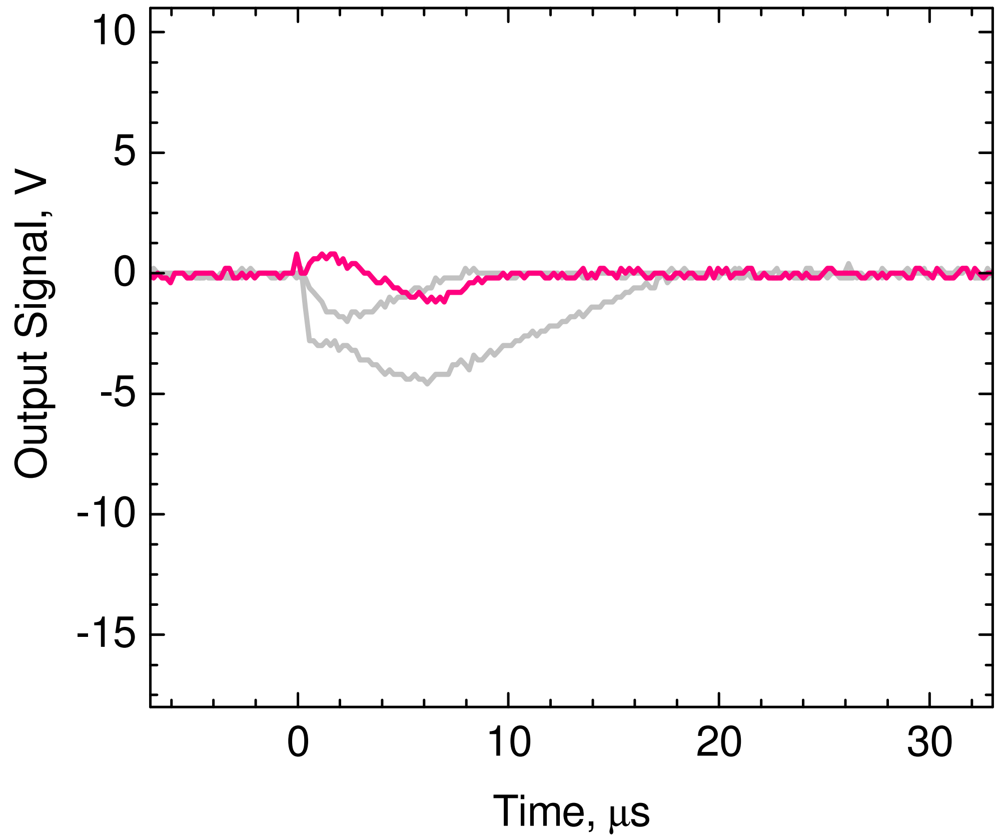

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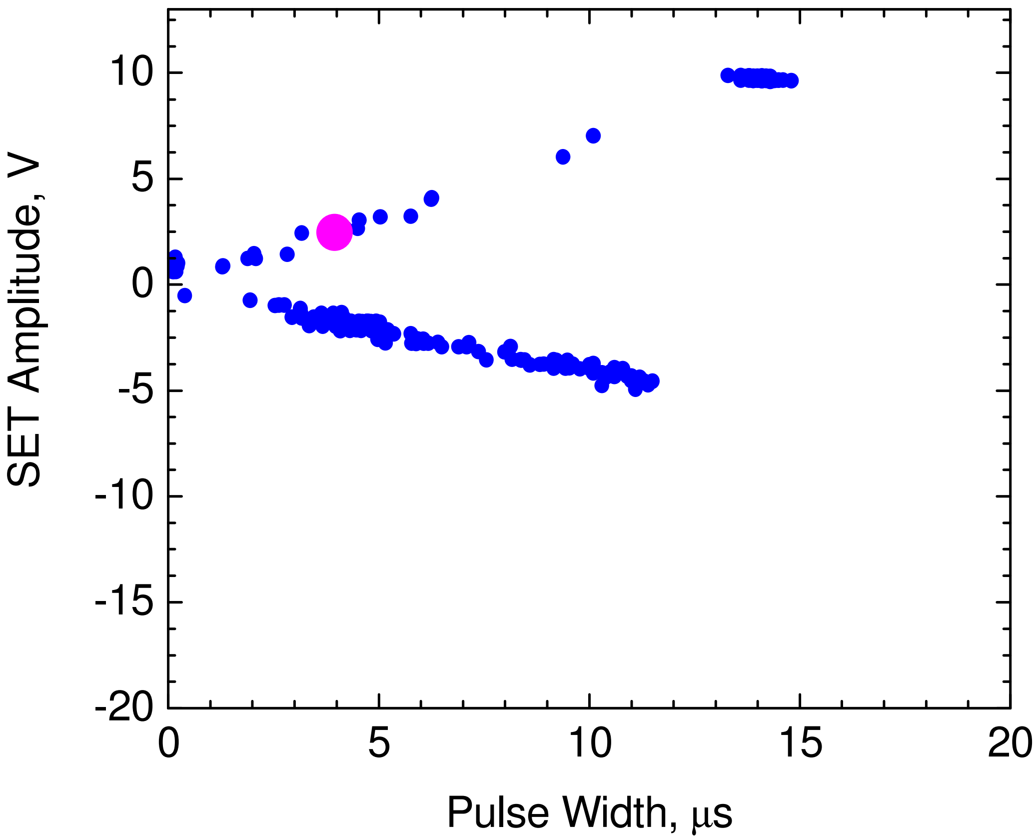

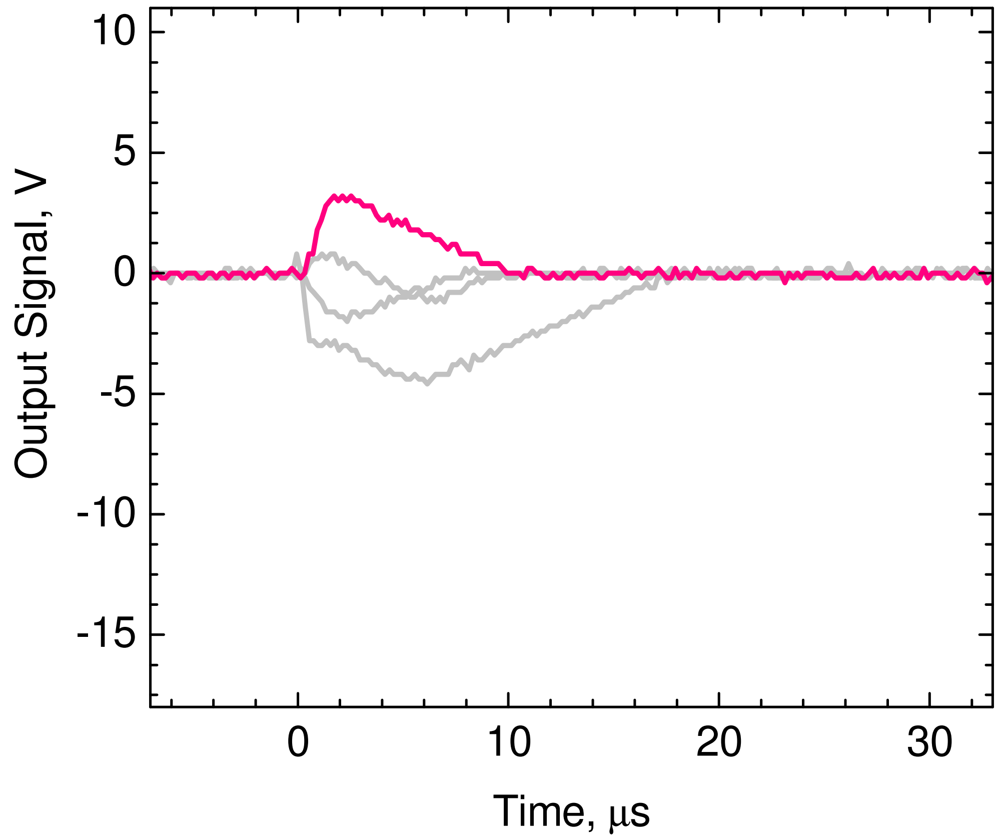

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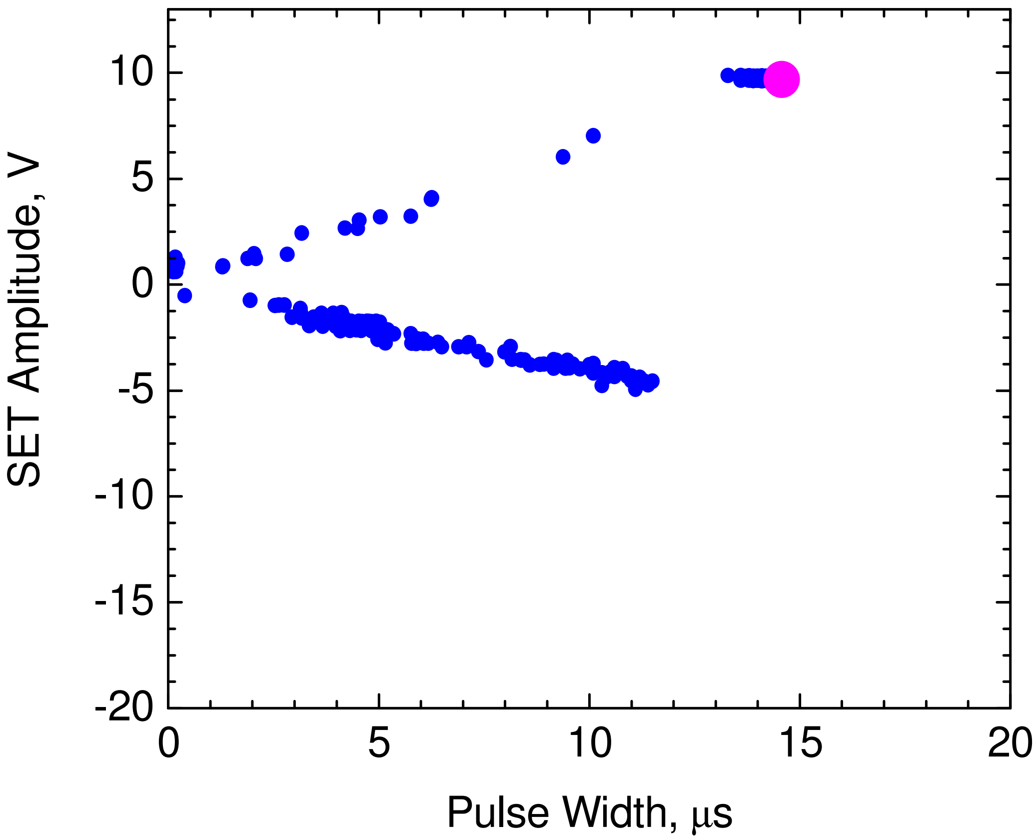
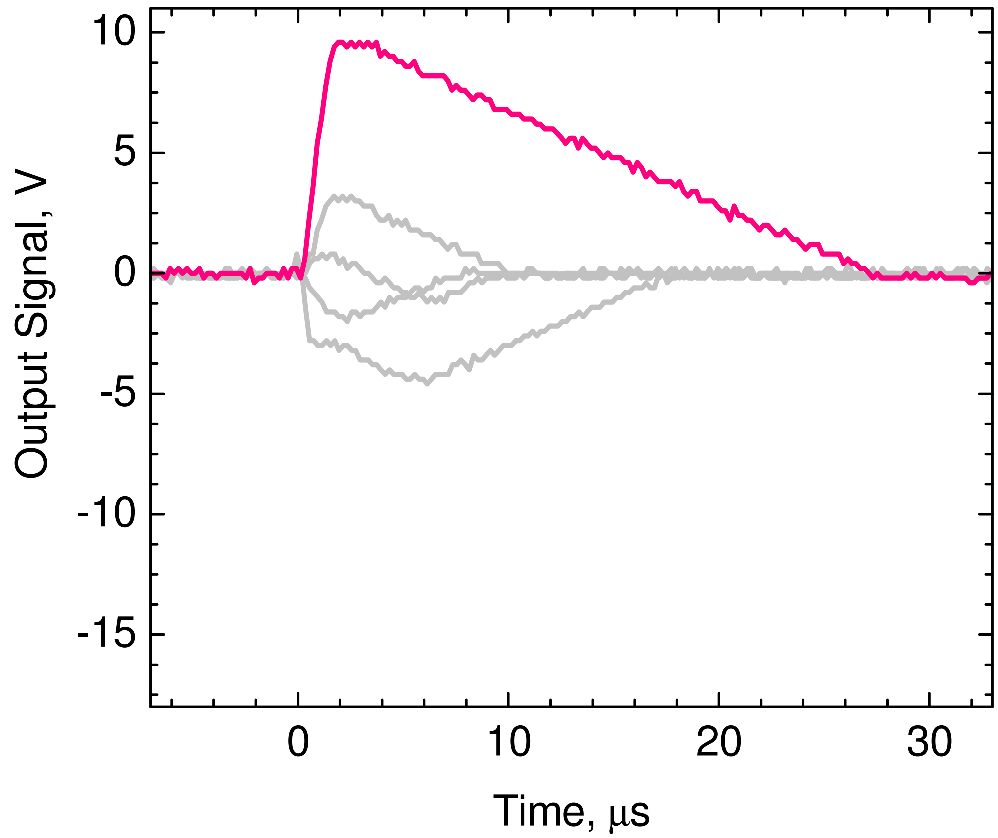
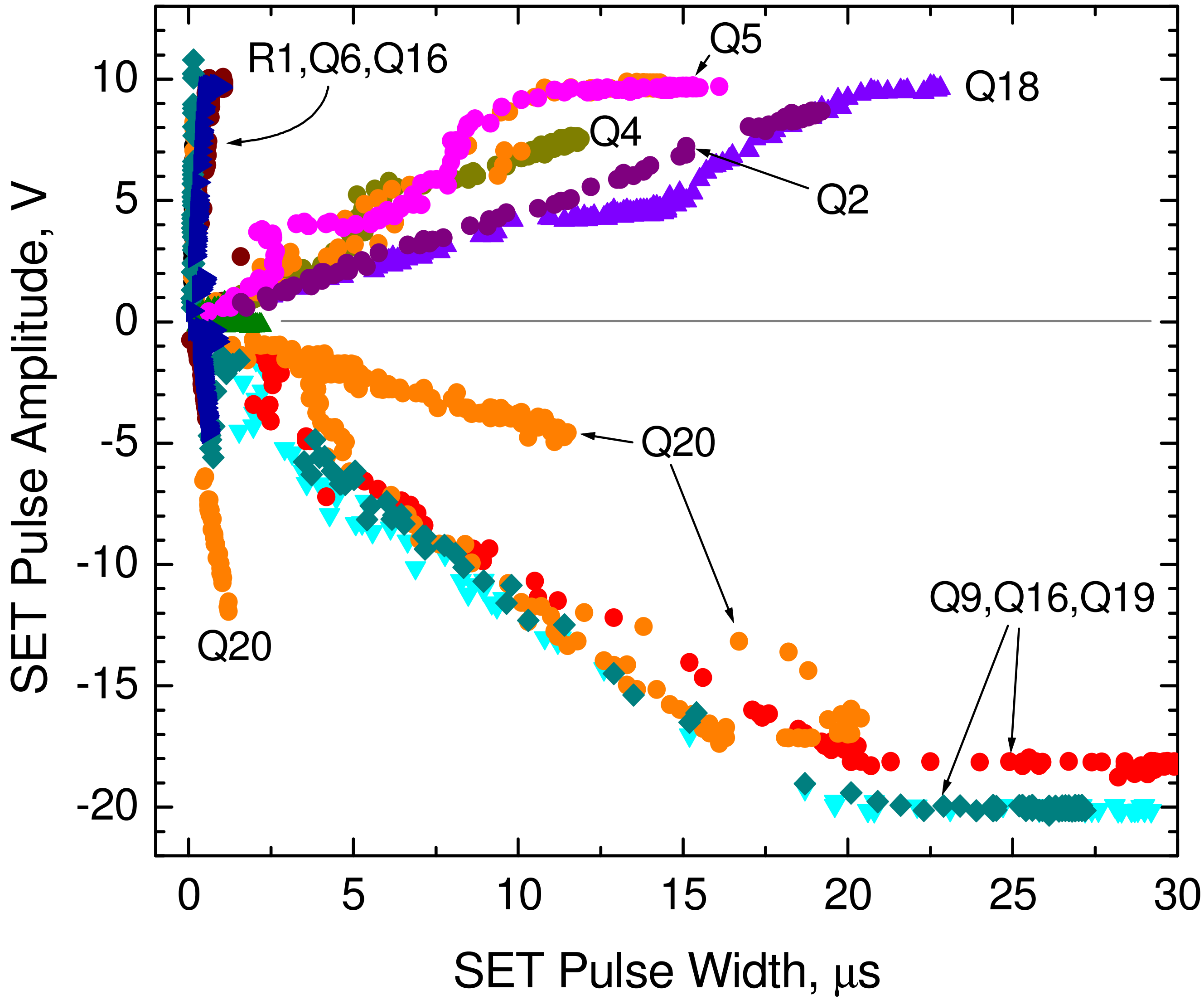
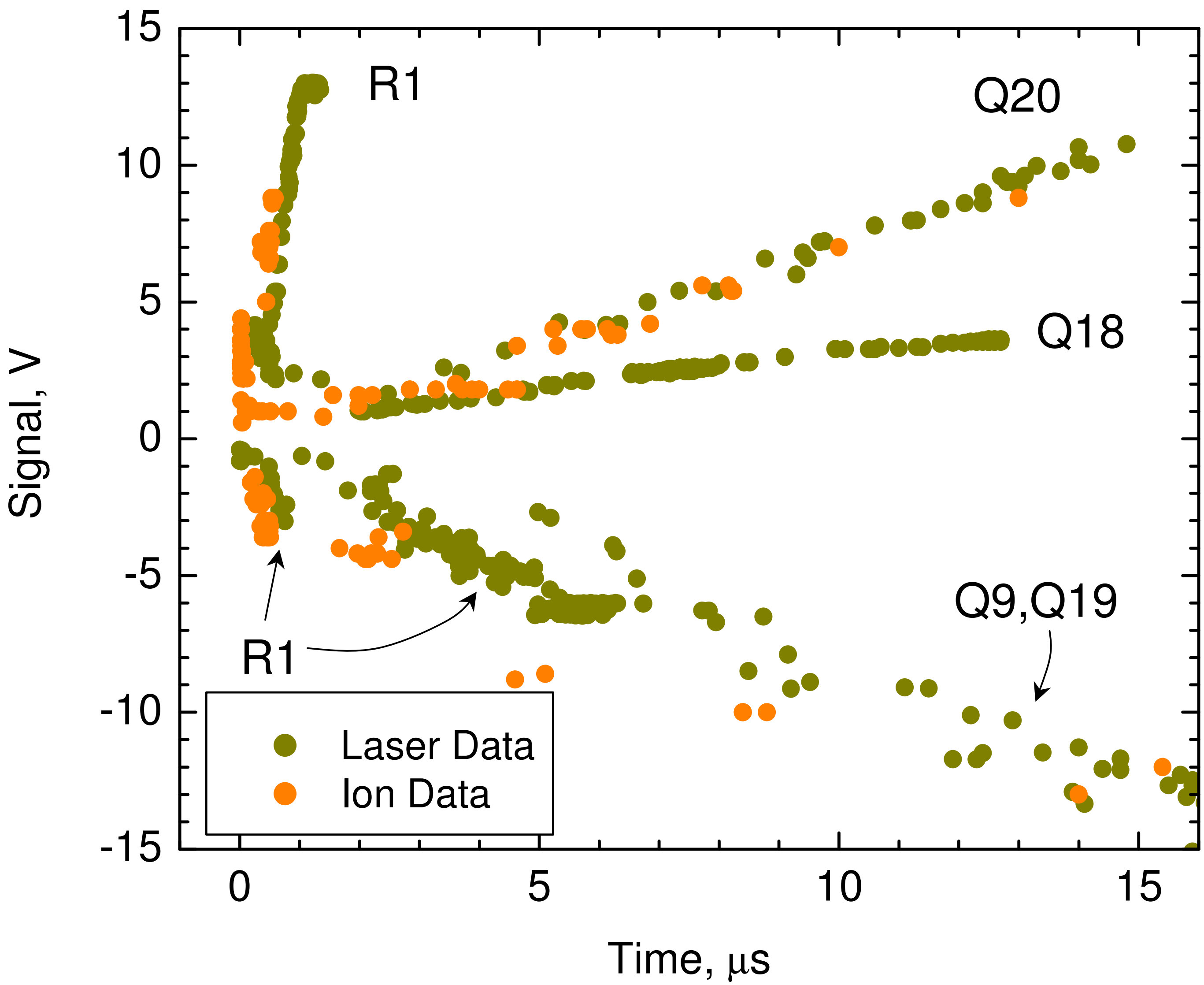




Pulsed Laser Data: All Nodes



Comparison of Heavy Ion and 590 nm Laser SET Pulse Width Data: LM124



<u>1.3 GeV Xenon</u>

- $V_{IN} = 5$ V
- $V_{\pm} = 15$ V

<u>590 nm Laser</u>

- $V_{IN} = 1$ V
- $V_{\pm} = 15$ V

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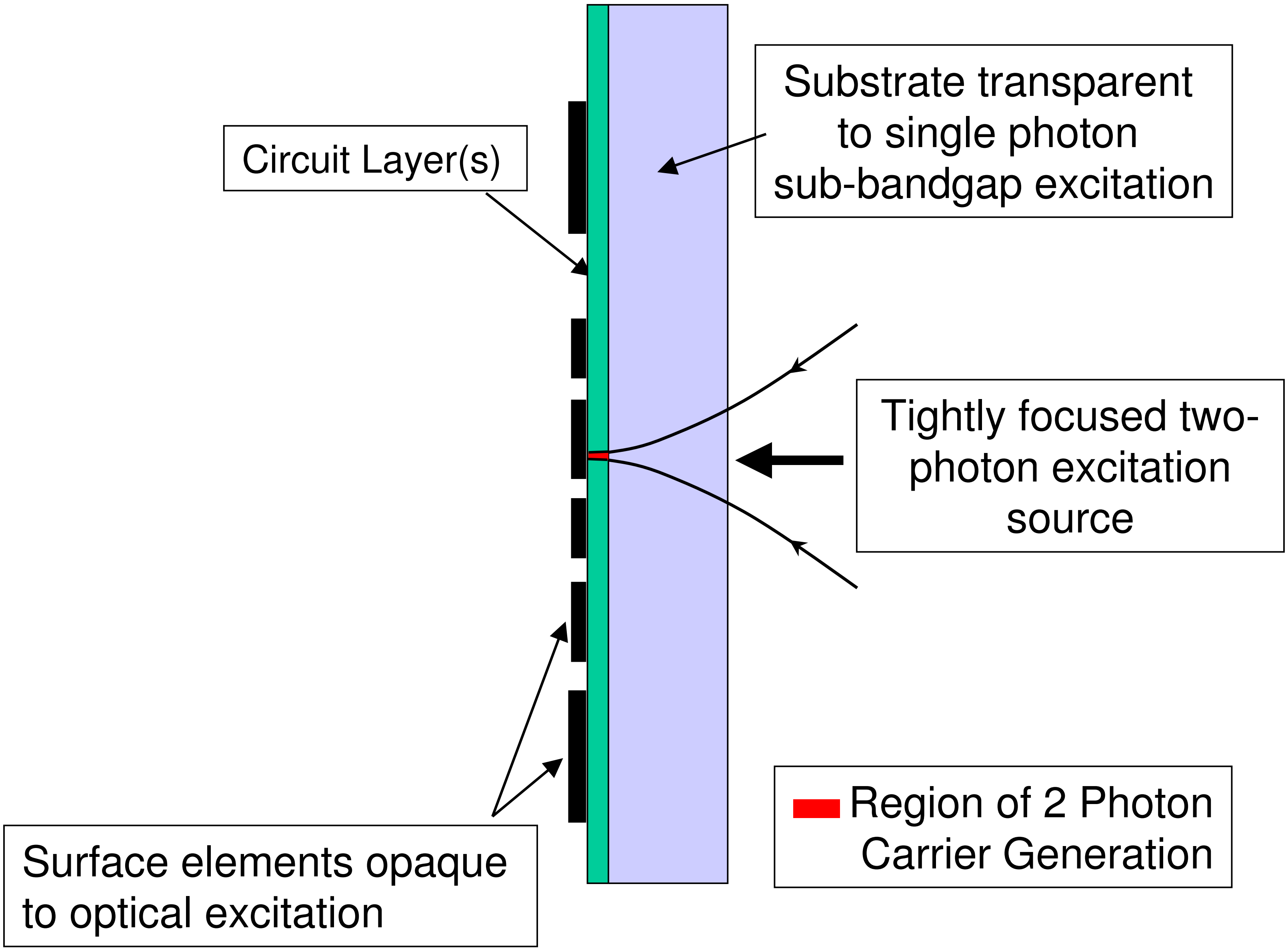
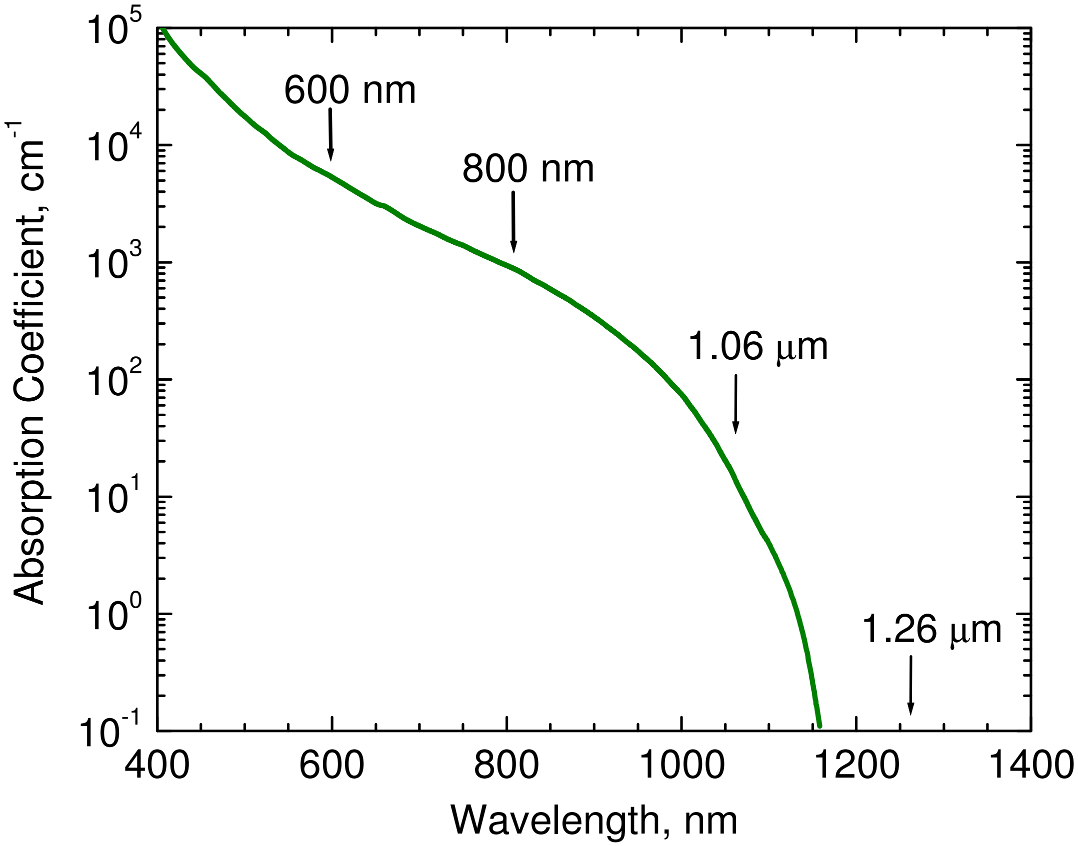
Backside "Through-Wafer" TPA Illumination



Two-Photon Absorption SEE Experiment



- Because the laser pulse wavelength is sub-bandgap the material is *transparent* to the optical pulse
- Carriers are generated by nonlinear absorption at high pulse irradiances by the simultaneous absorption of two photons
- Carriers are highly concentrated in the high irradiance region near the focus of the beam
- Because of the lack of exponential attenuation, carriers can be injected at any depth in the semiconductor material
- This permits 3-D mapping and backside illumination

Two-Photon Absorption SEE Experiment

Carrier generation equation:

$$\frac{dN(r,z)}{dt} = \frac{\alpha I(r,z)}{\hbar\omega} + \frac{\beta_2 I^2(r,z)}{2\hbar\omega}$$

- Because the laser pulse wavelength is sub-bandgap the material is transparent to the optical pulse
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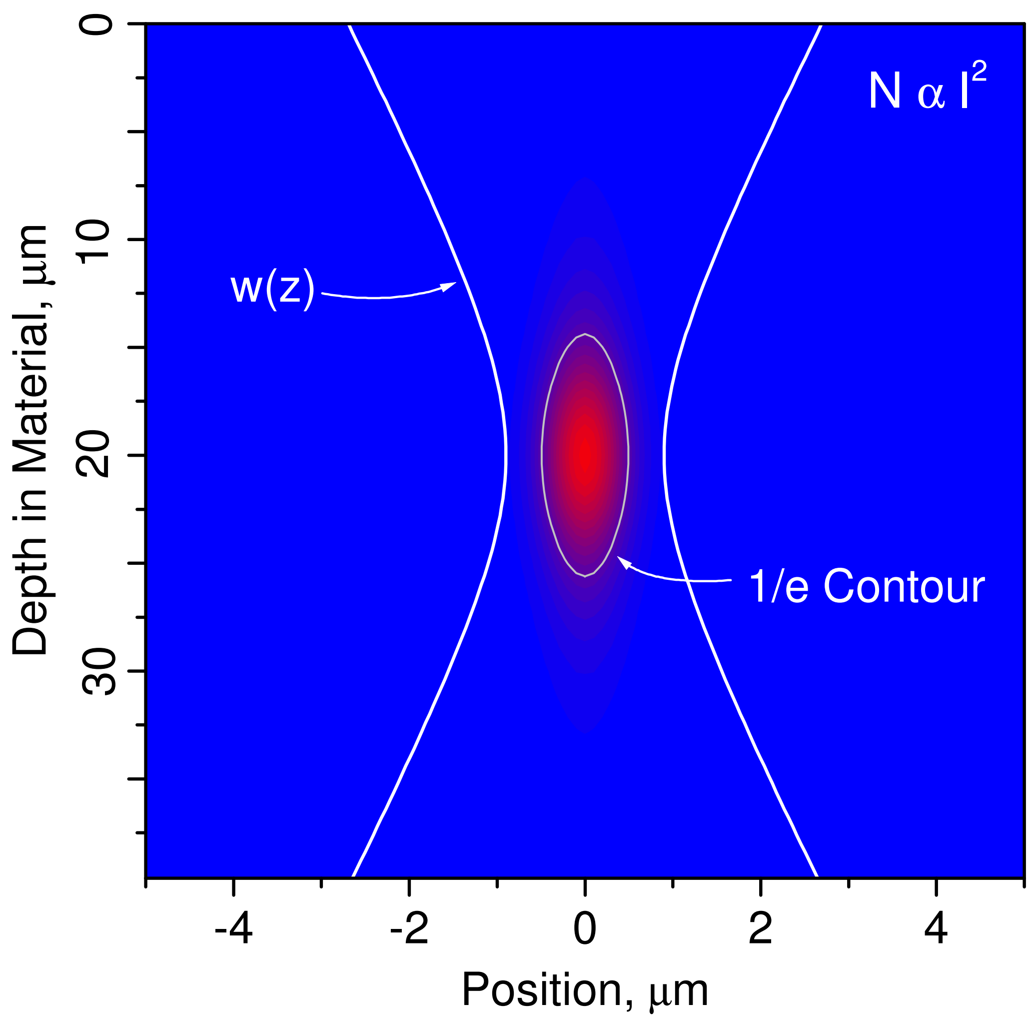

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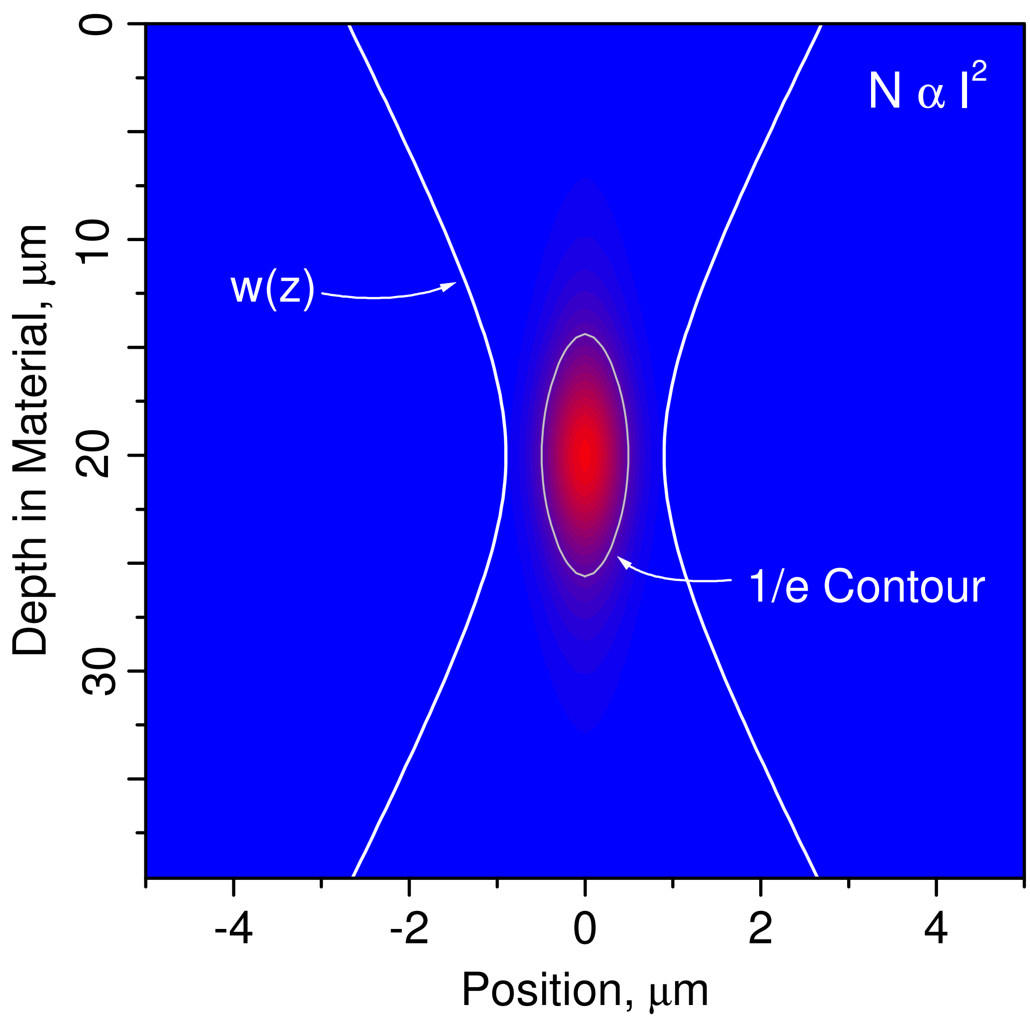

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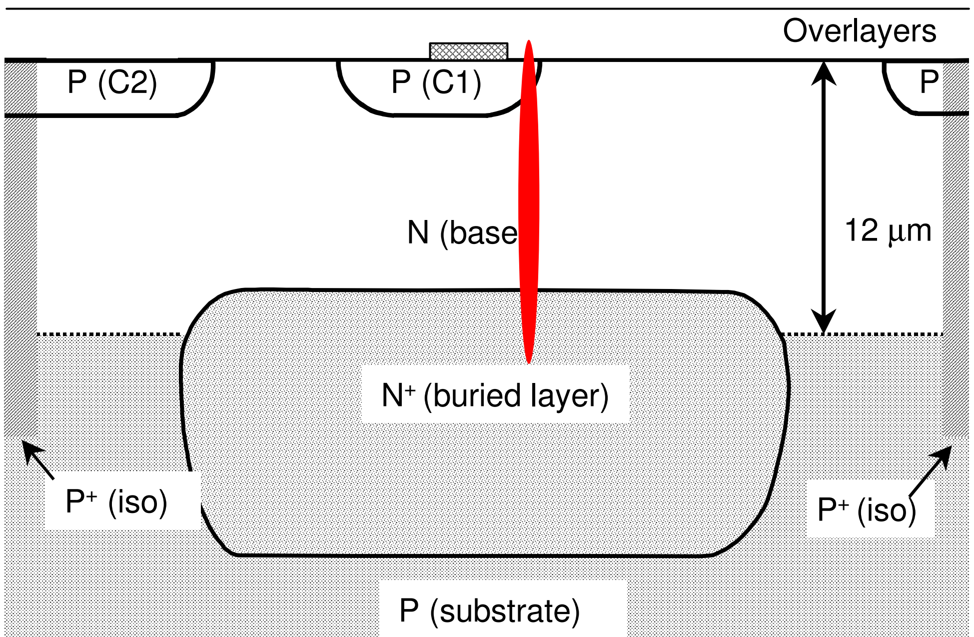

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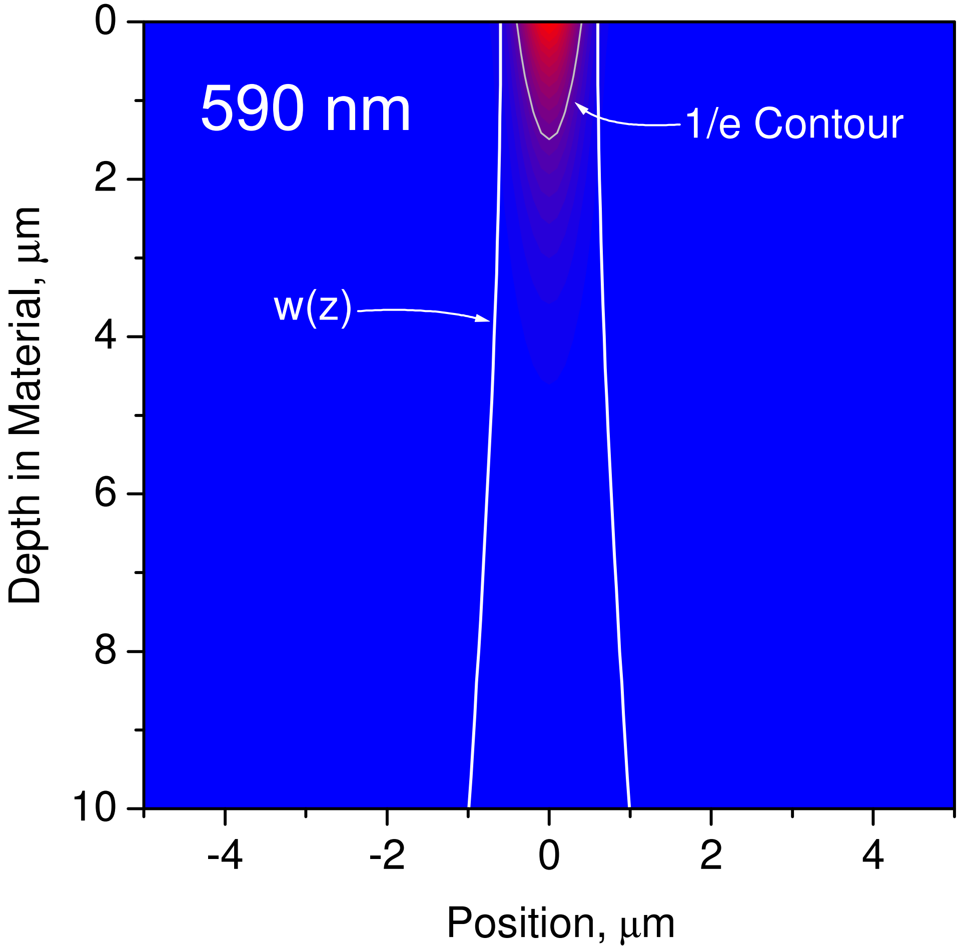

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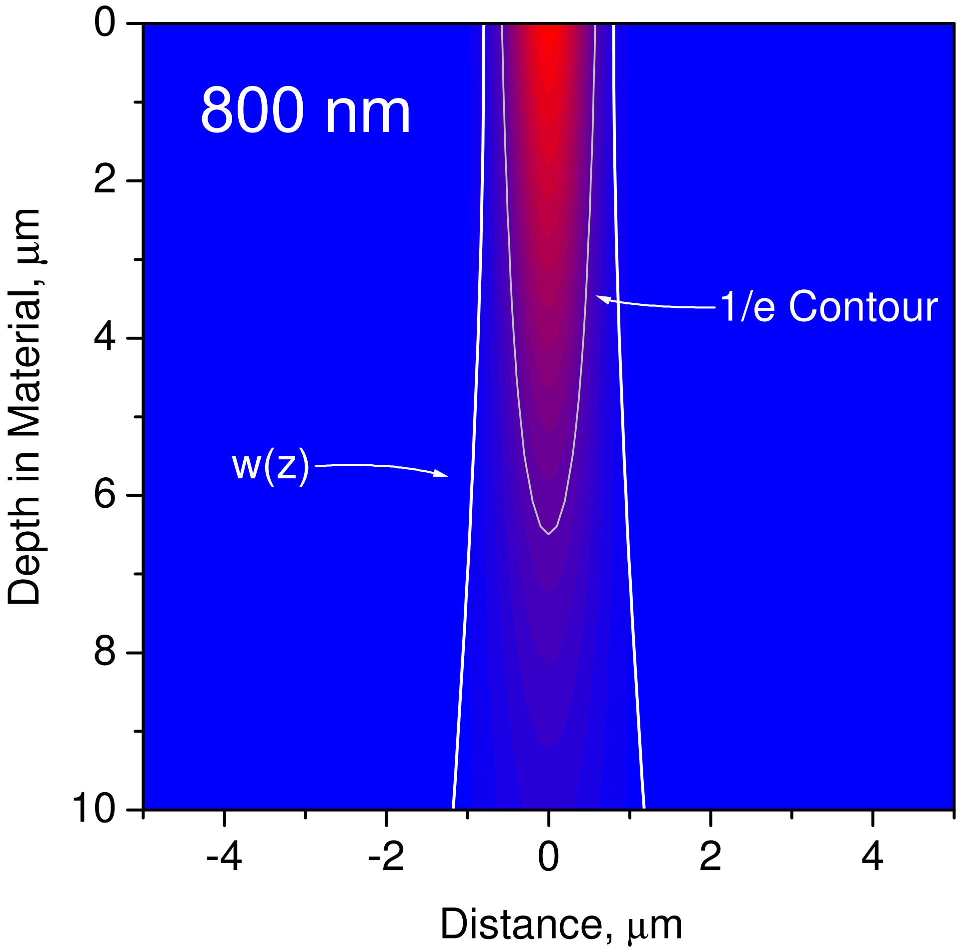

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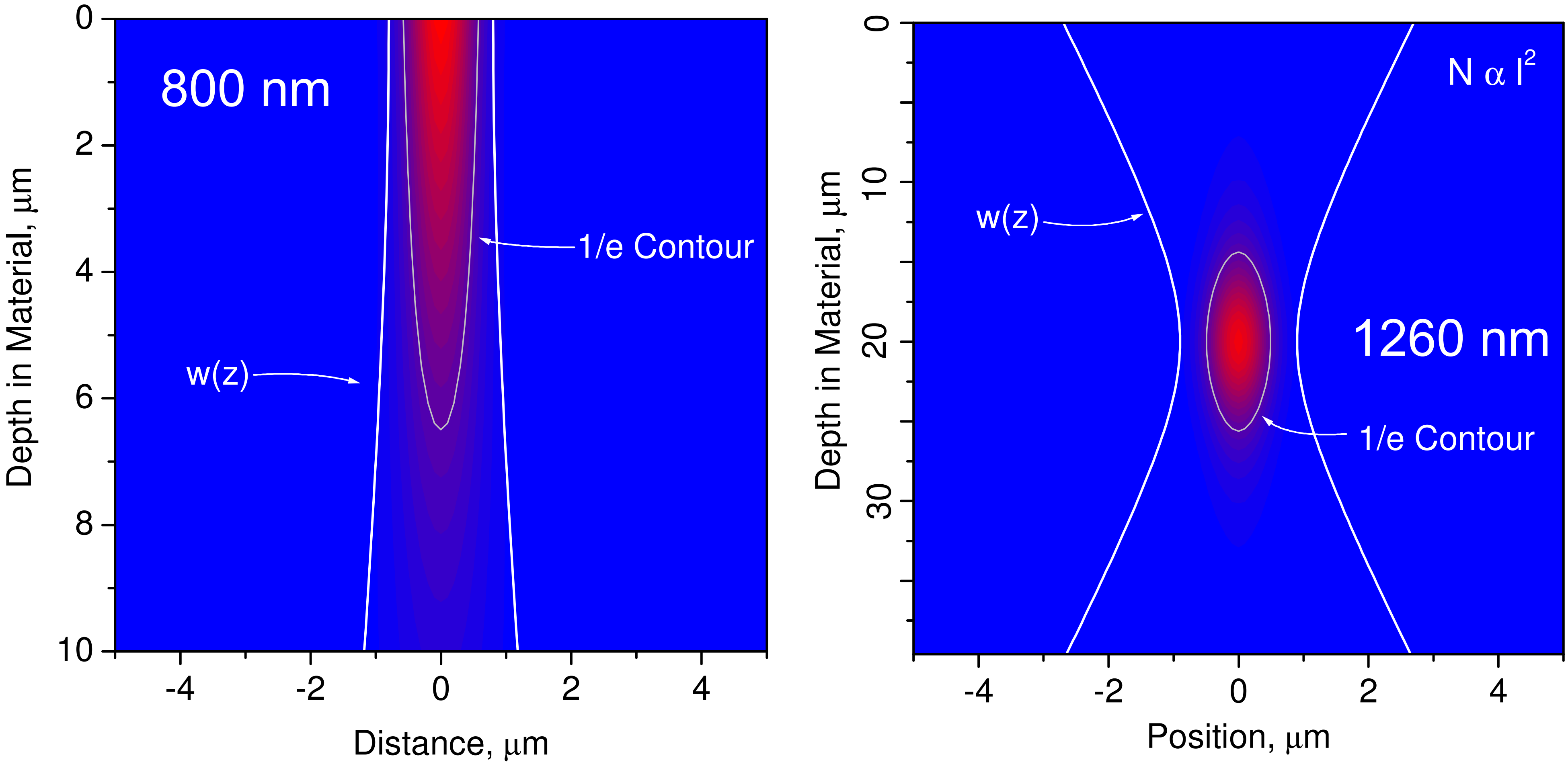

Two-Photon Absorption SEE Experiment

COMPLEMENTARY TECHINQUE

- Not intended to replace "conventional" (above band gap) pulsed laser
- Not intended to replace heavy-ion irradiation
- WILL NOT replace these tools
- Is another "Tool" in our "SEE Toolbox"

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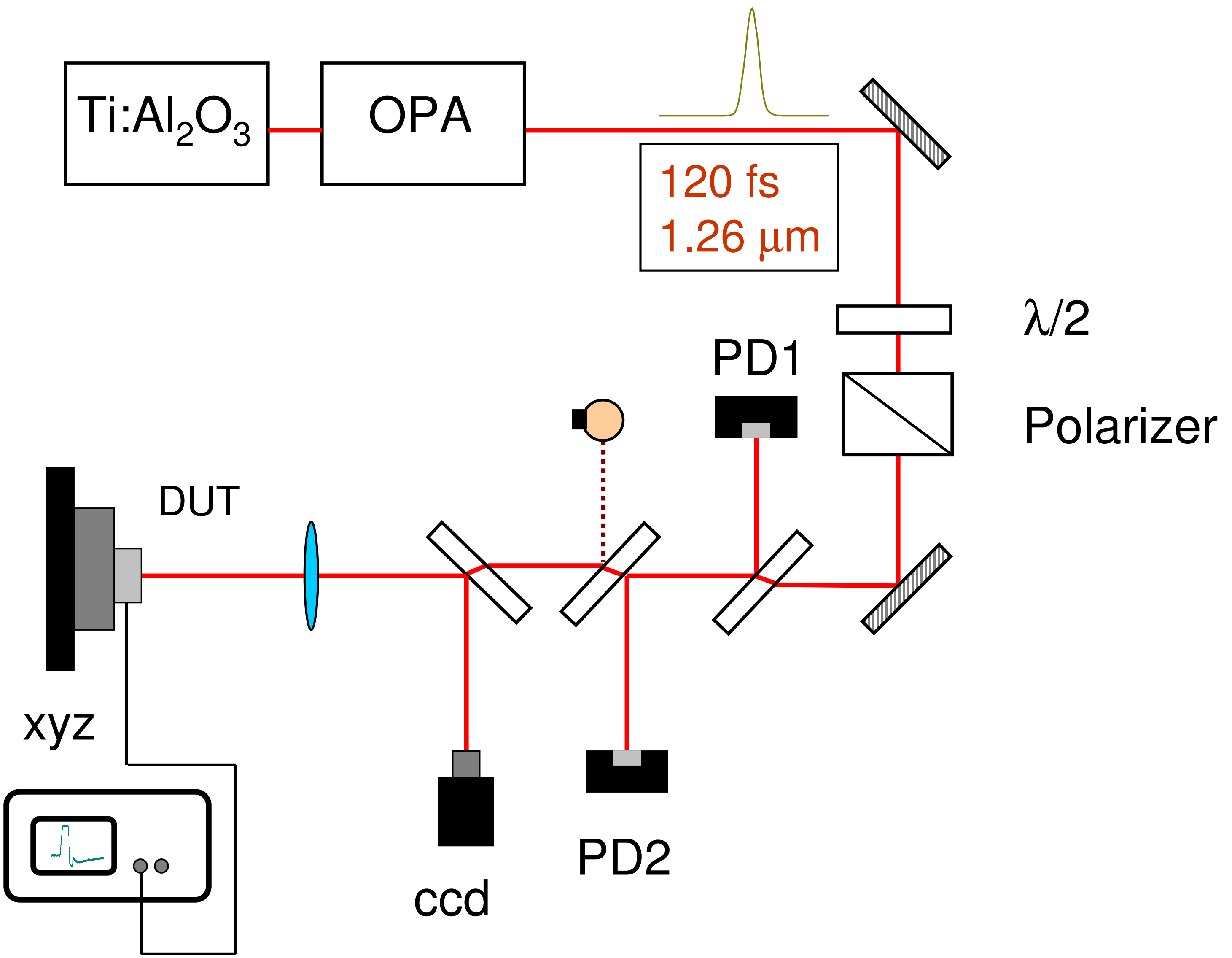
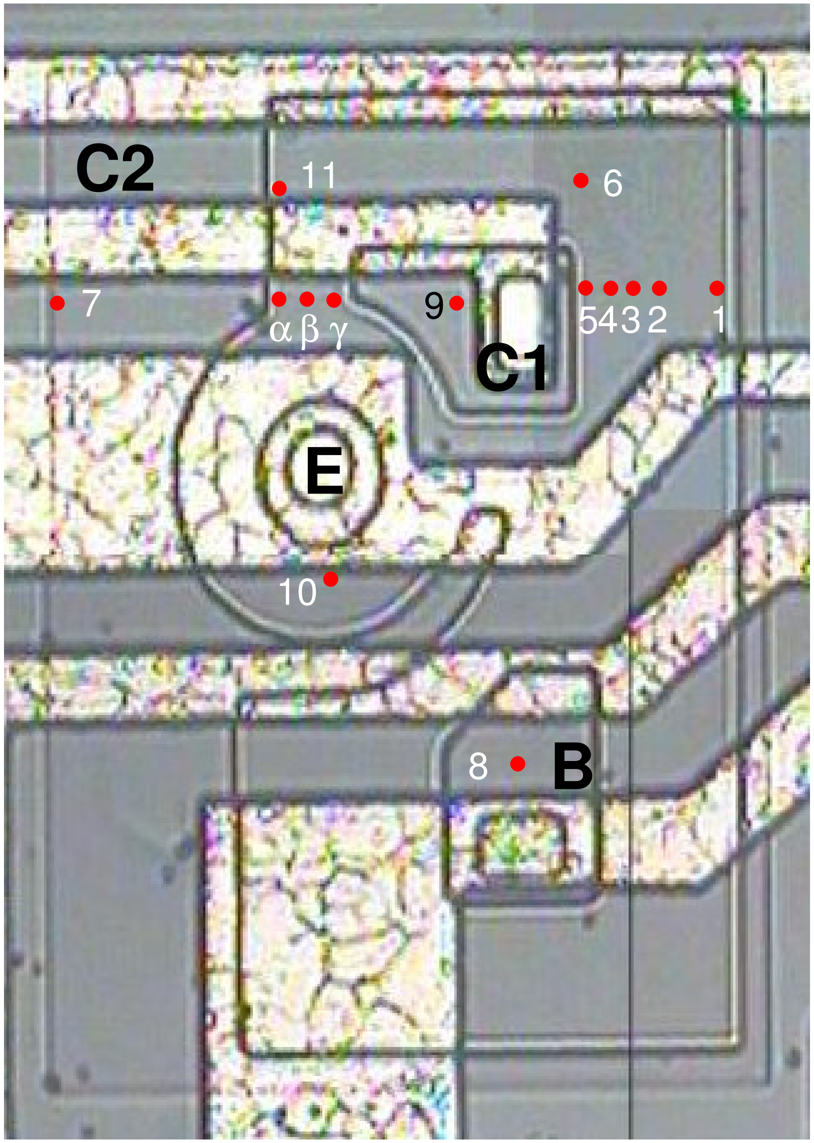
Sub-Bandgap, Two-Photon Absorption SEE Experiment



Three-Dimensional Mapping of SEE Sensitivity

(LM124 Q20: General Characteristics)



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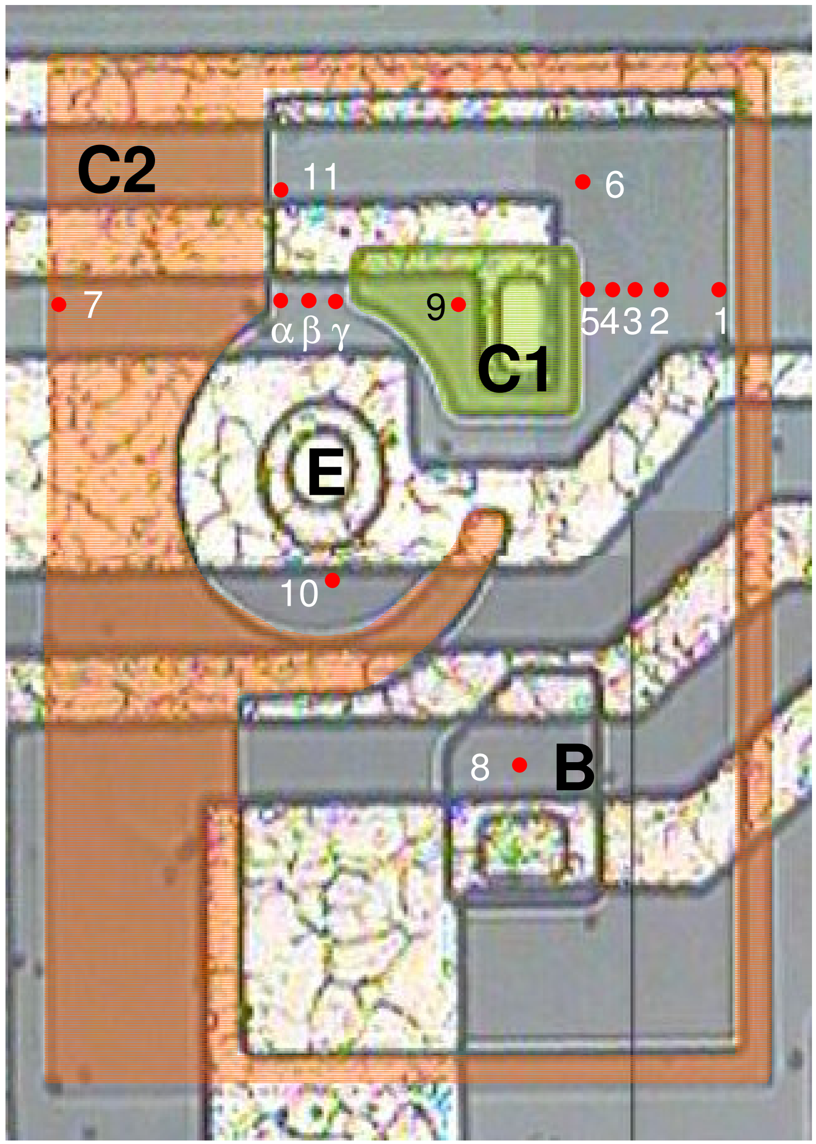

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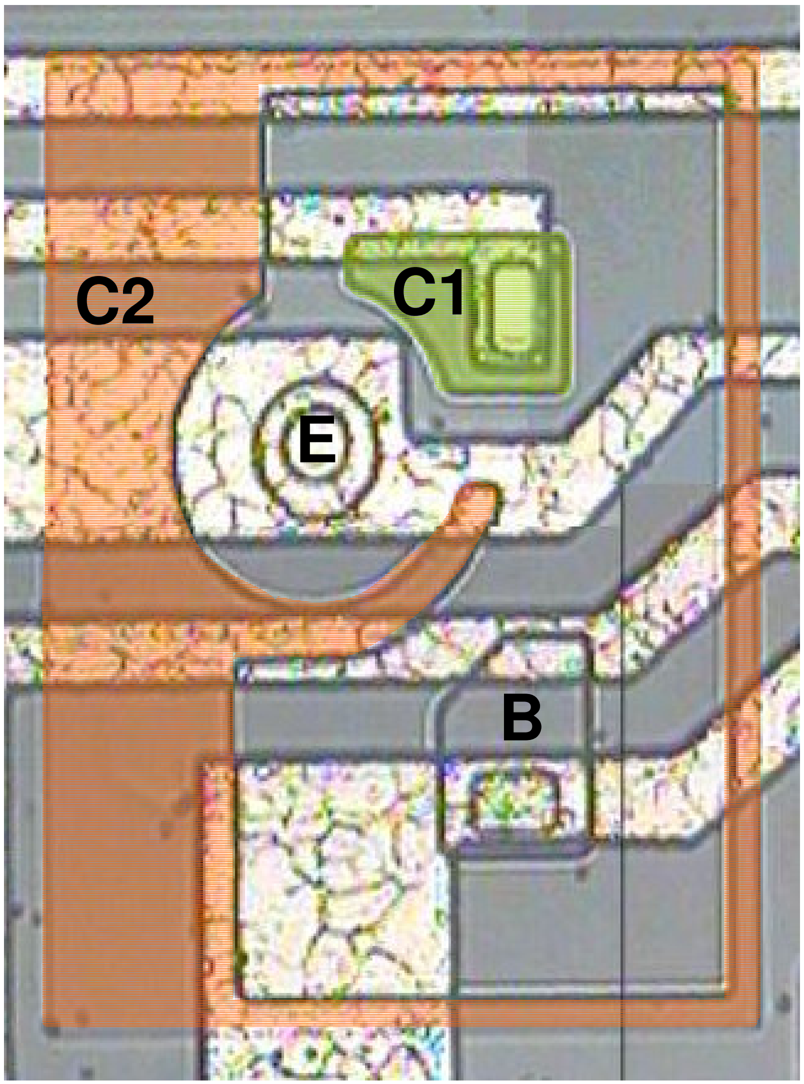
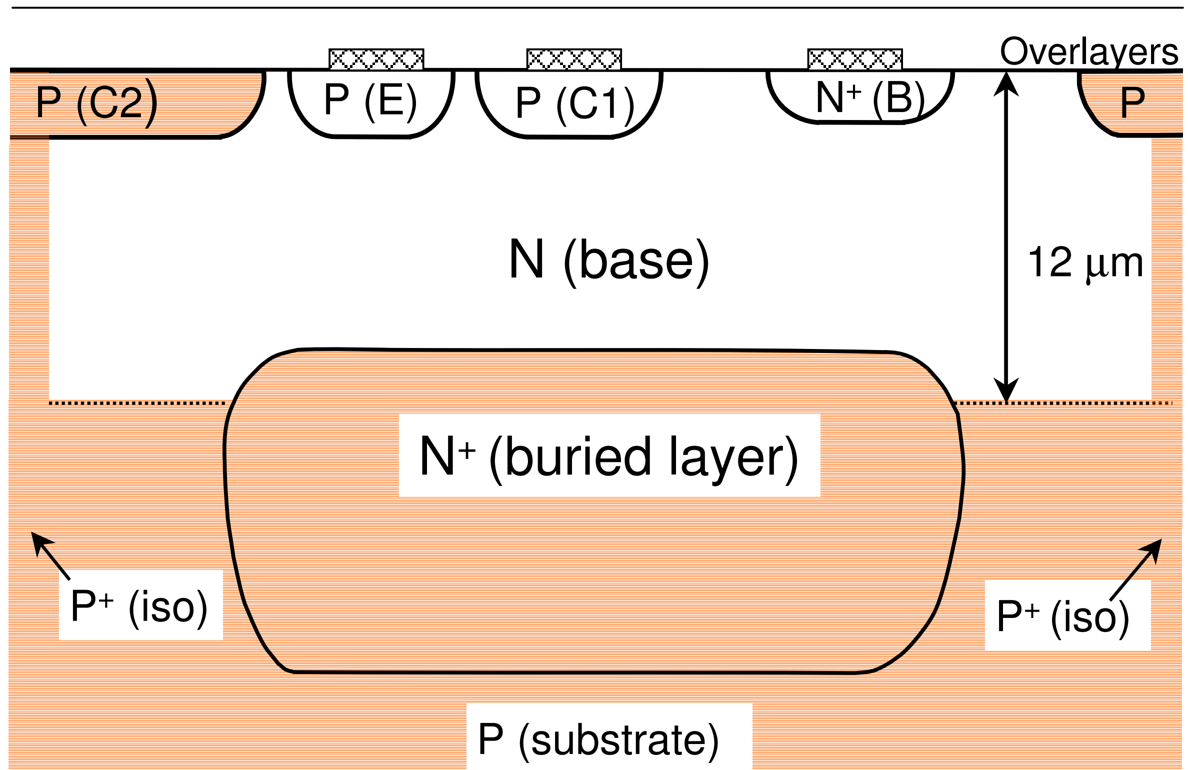
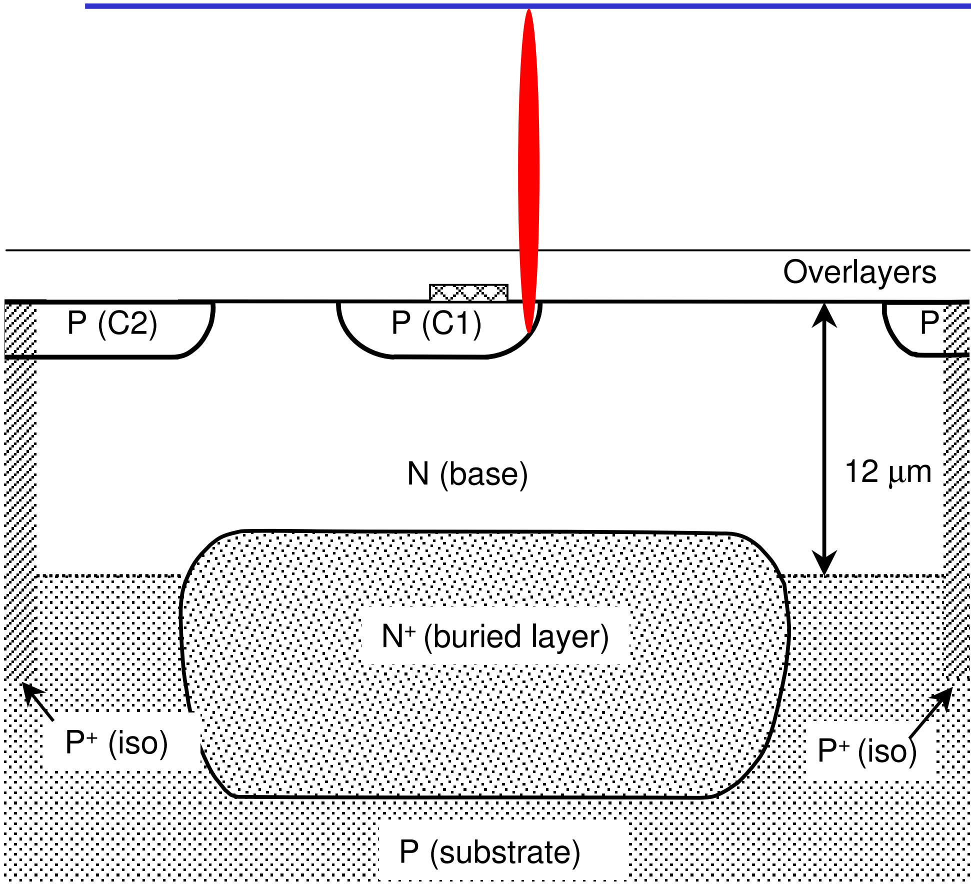
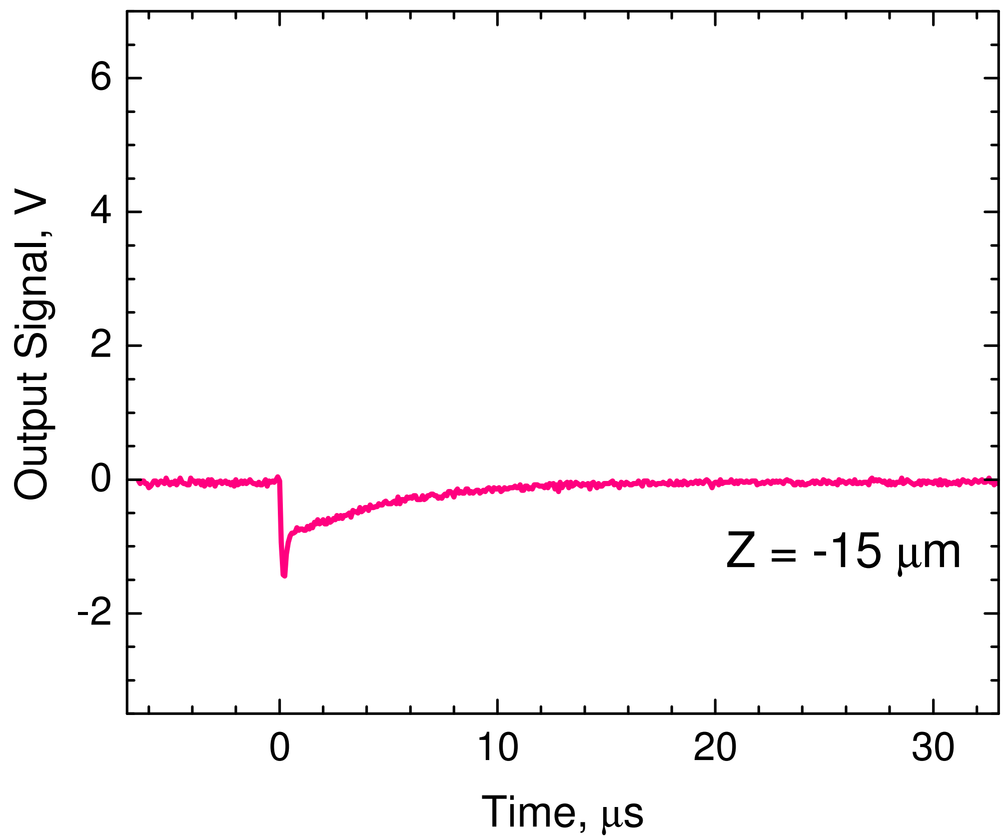




"Z" Dependence: LM124 Q20 TPA: C1-epi Junction

(Inverting Configuration; gain of 20)





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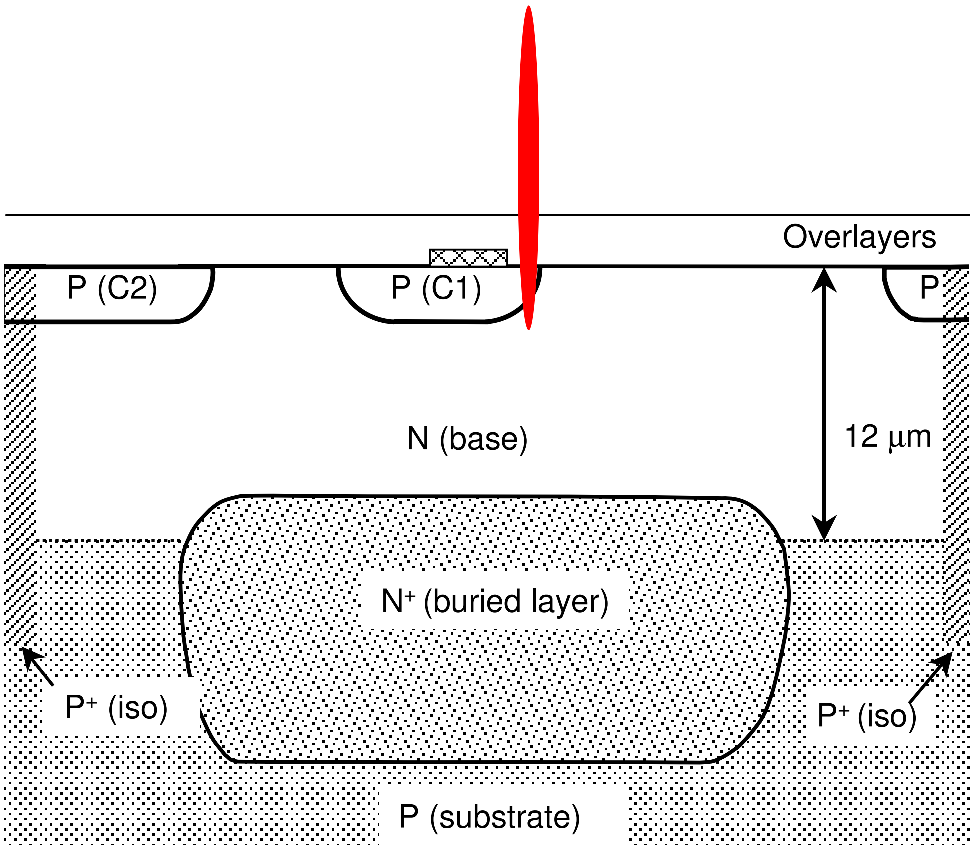

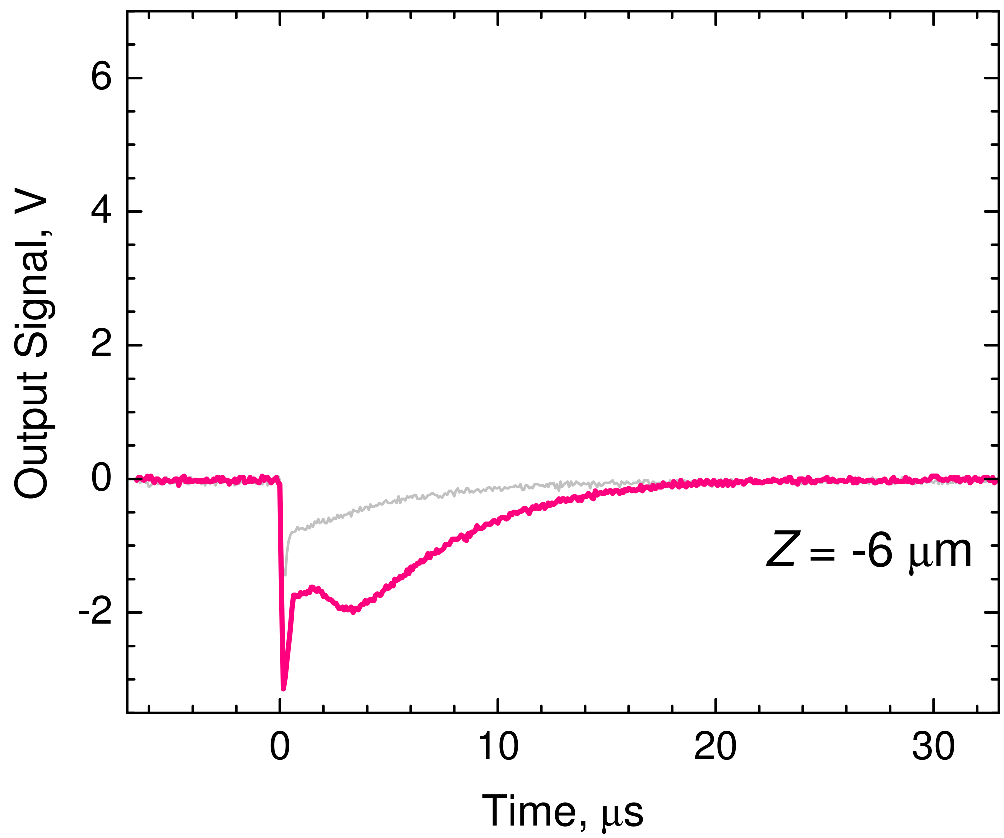

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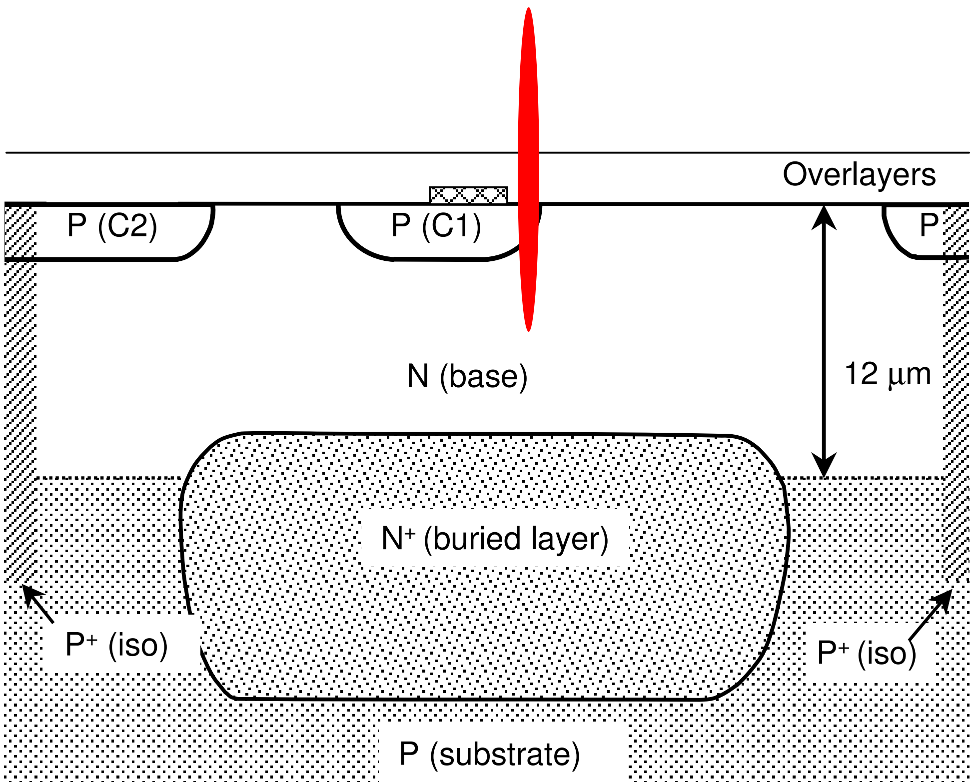

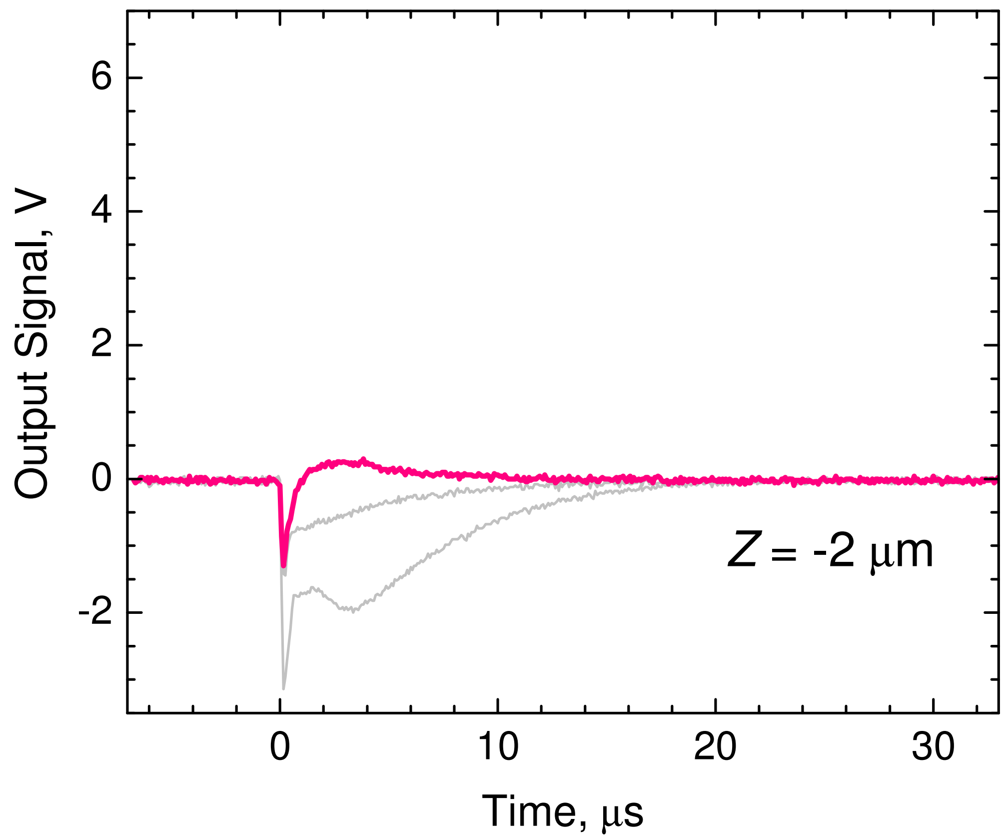

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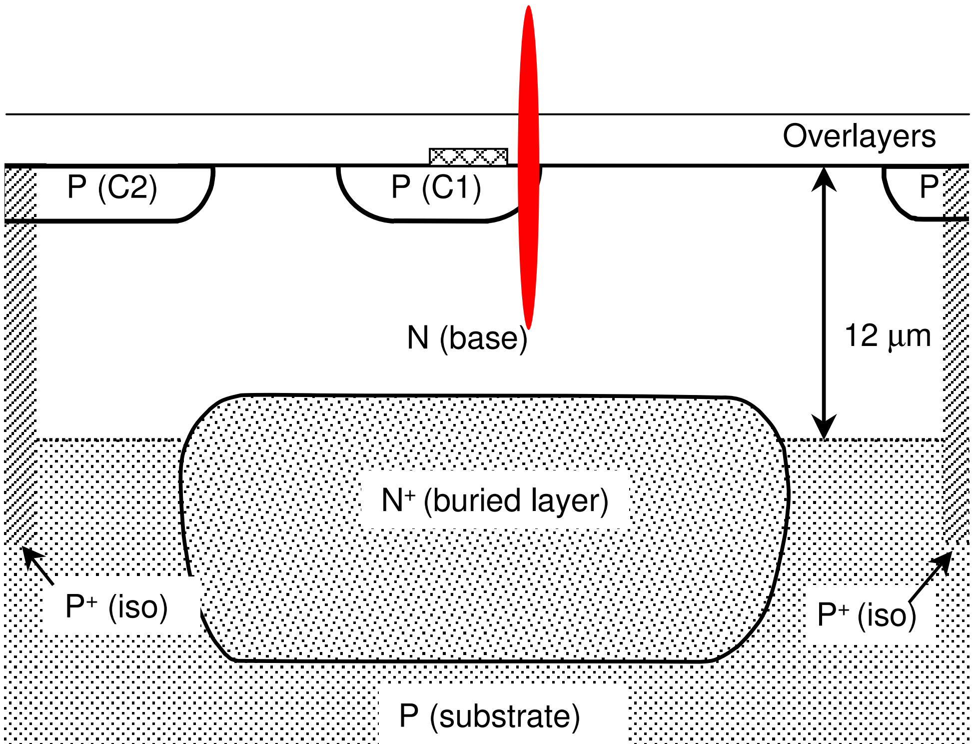

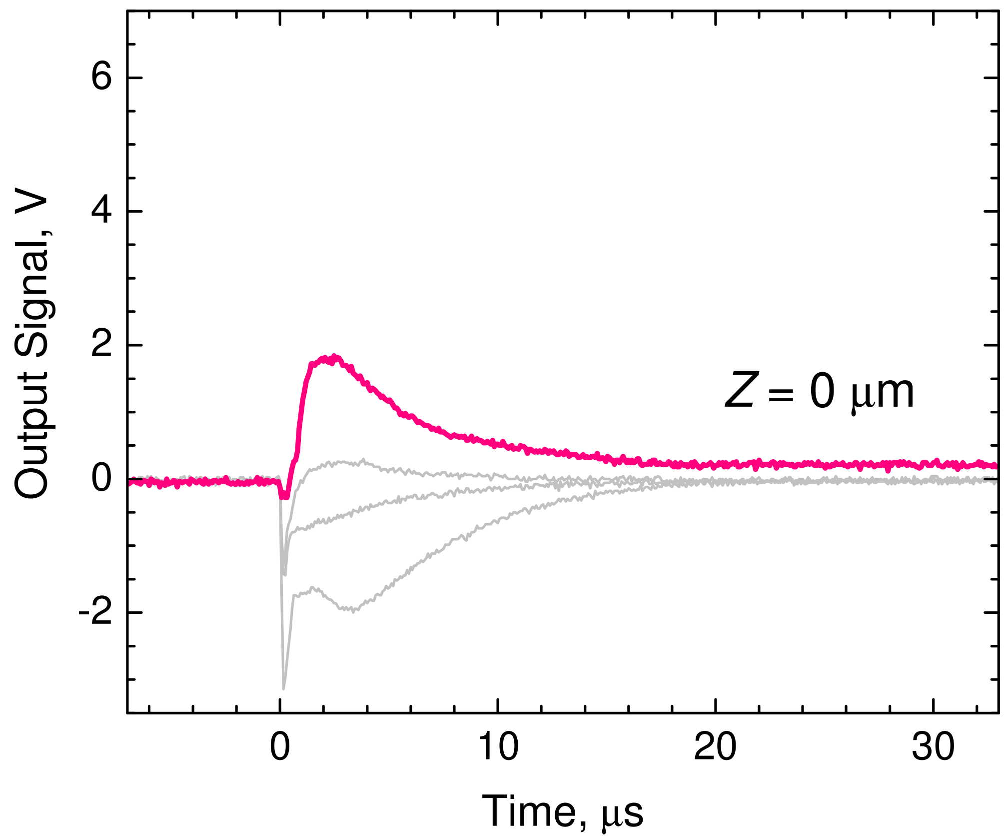

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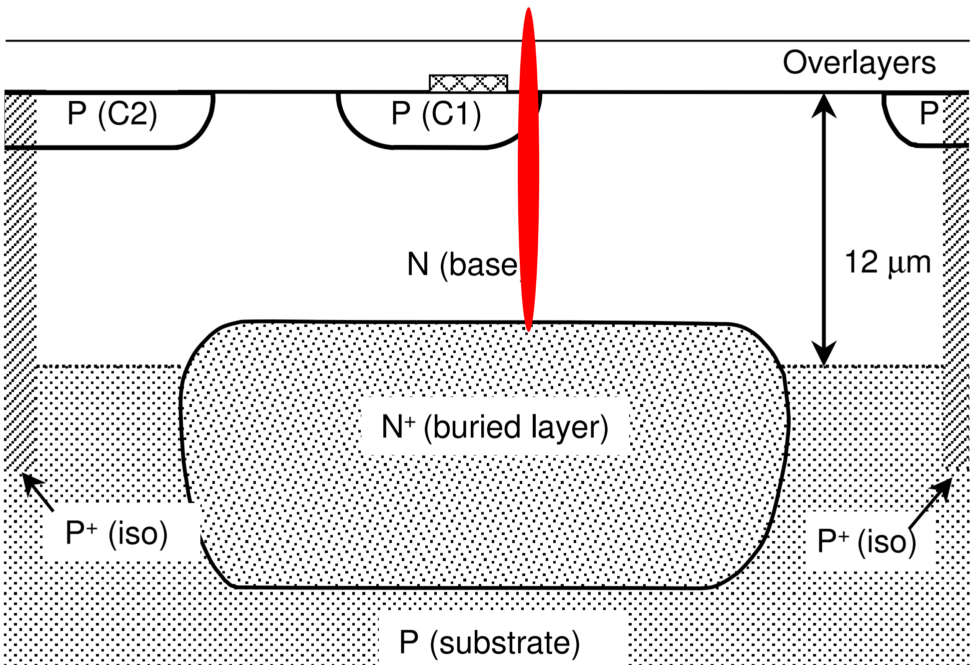

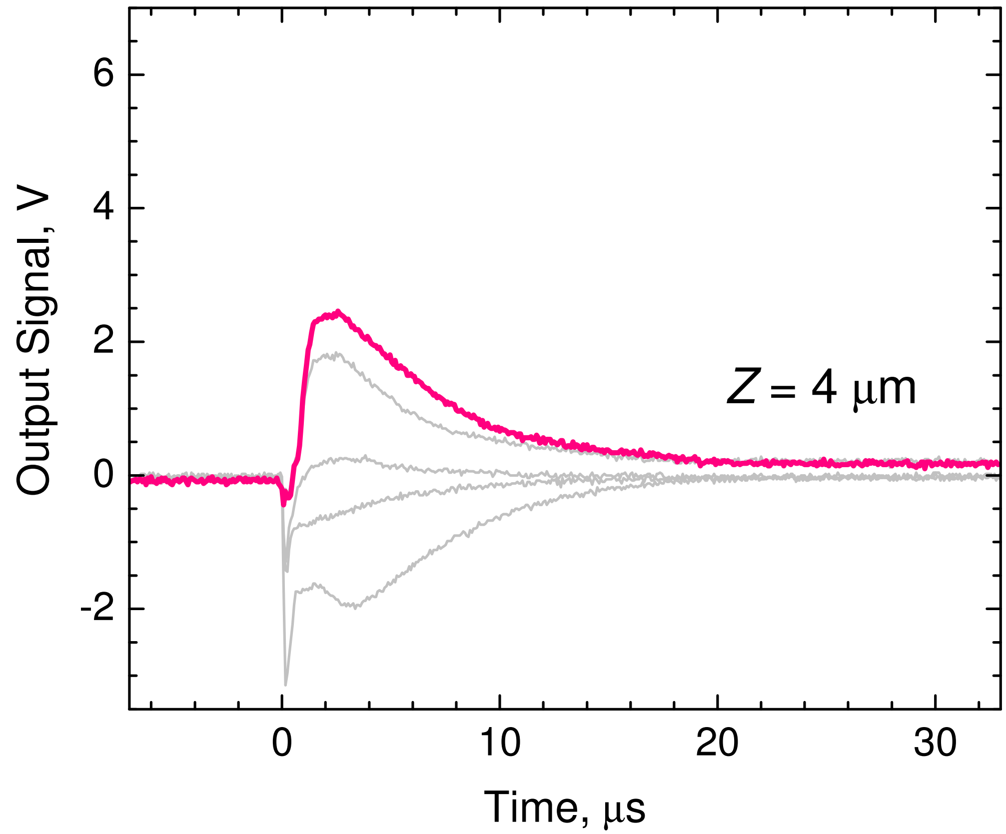

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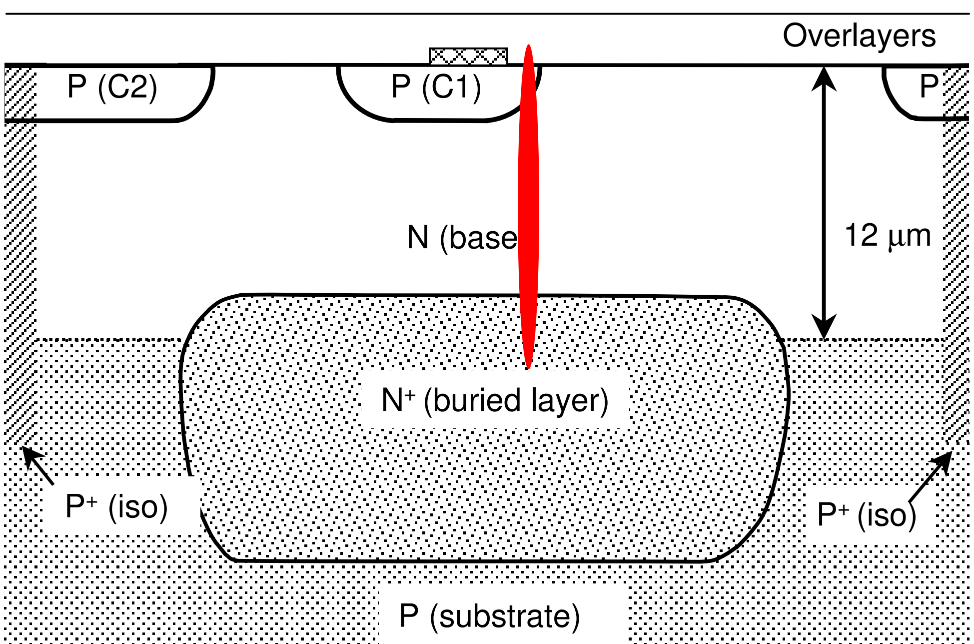

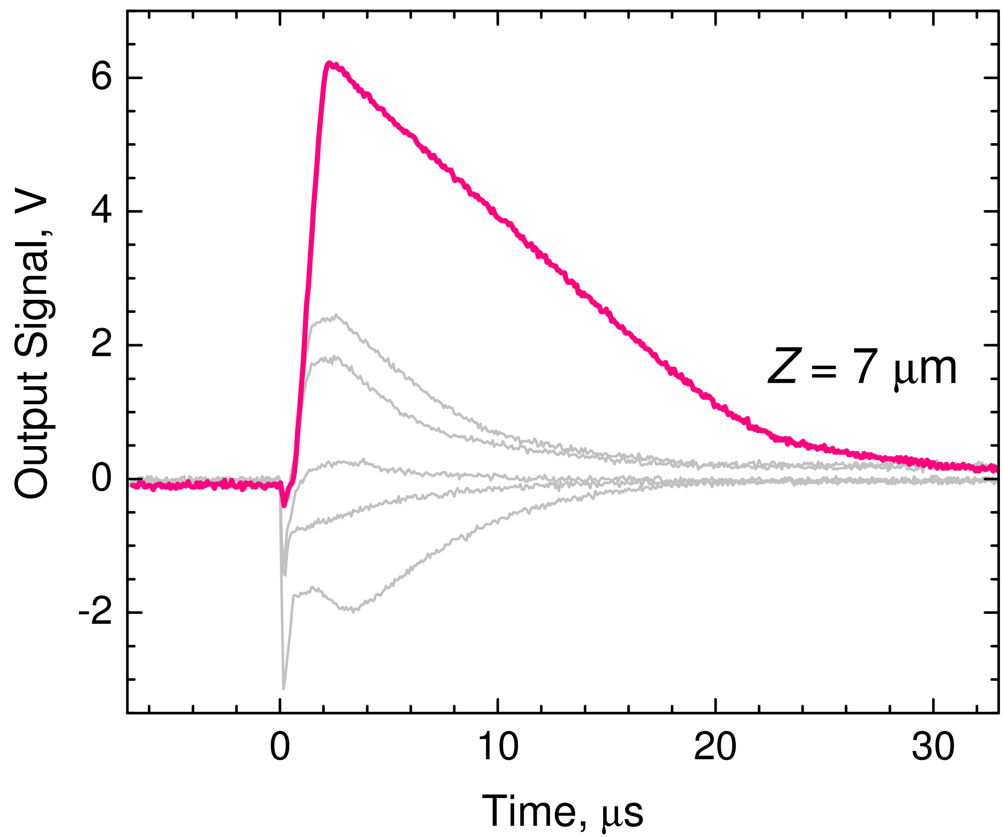

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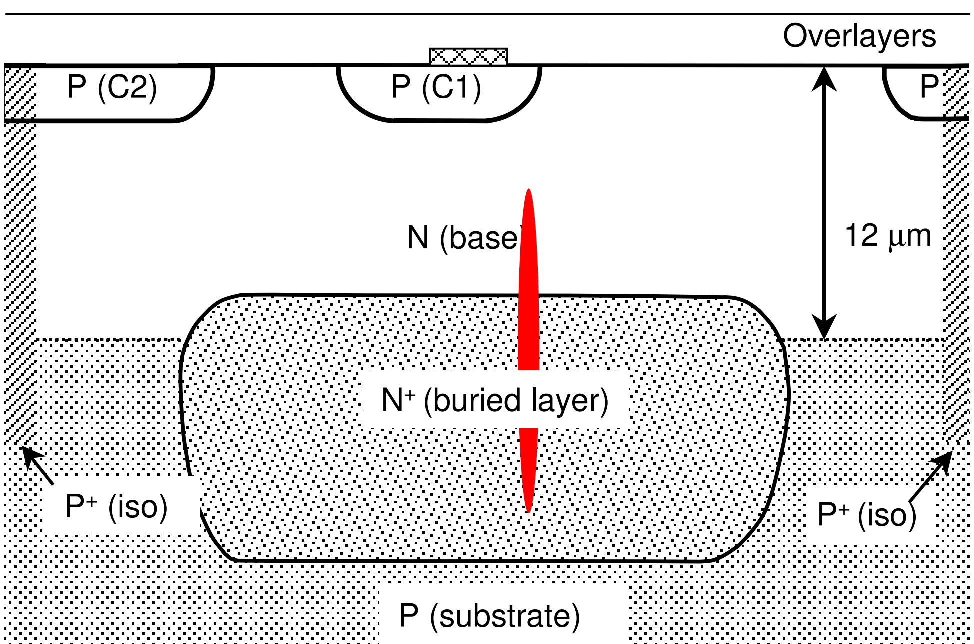

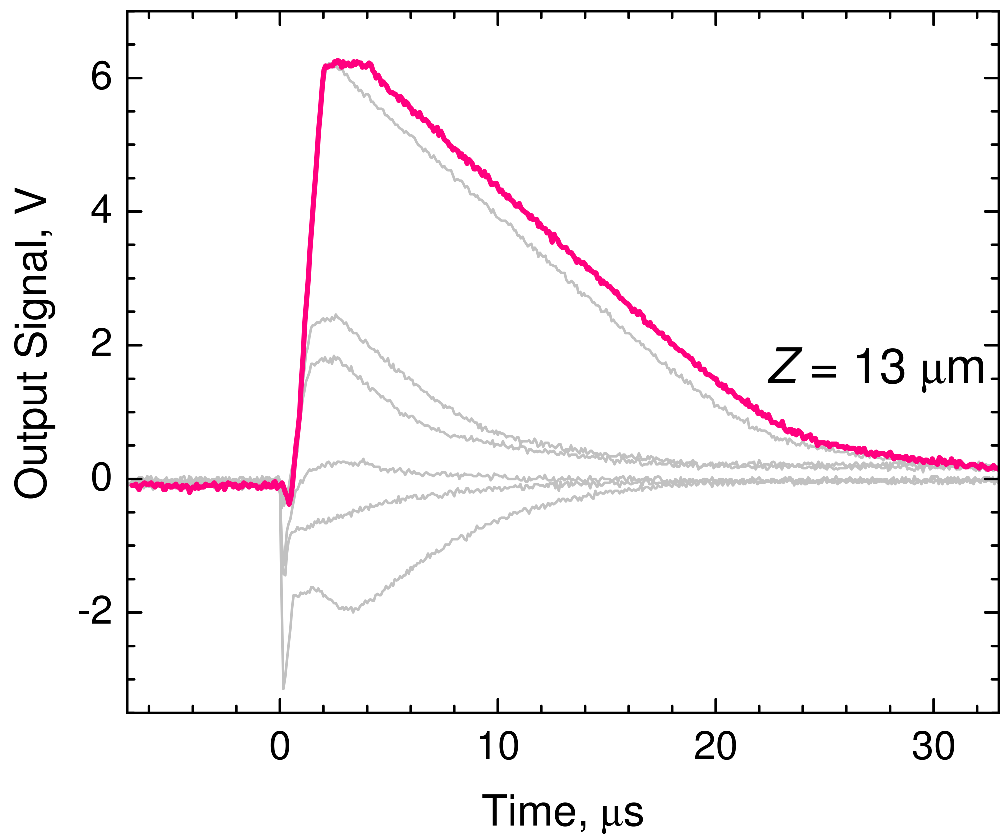

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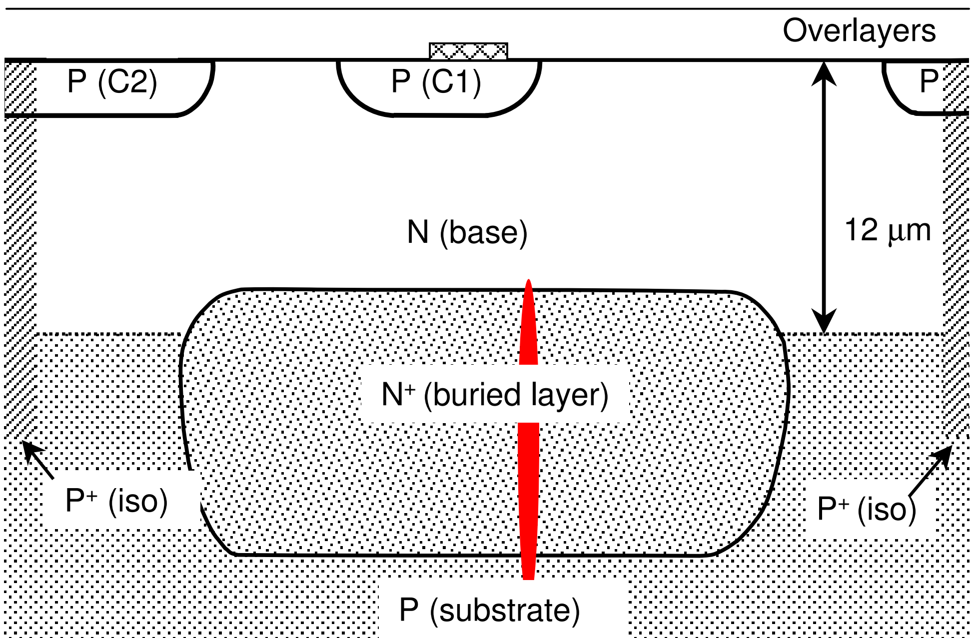

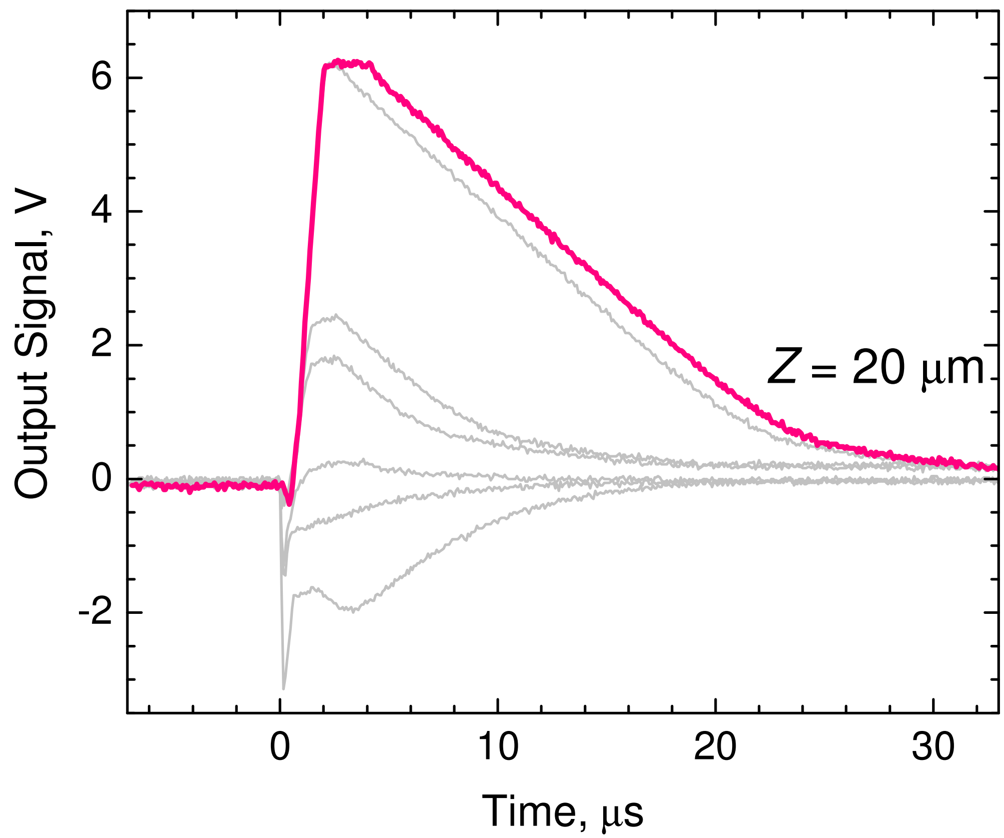

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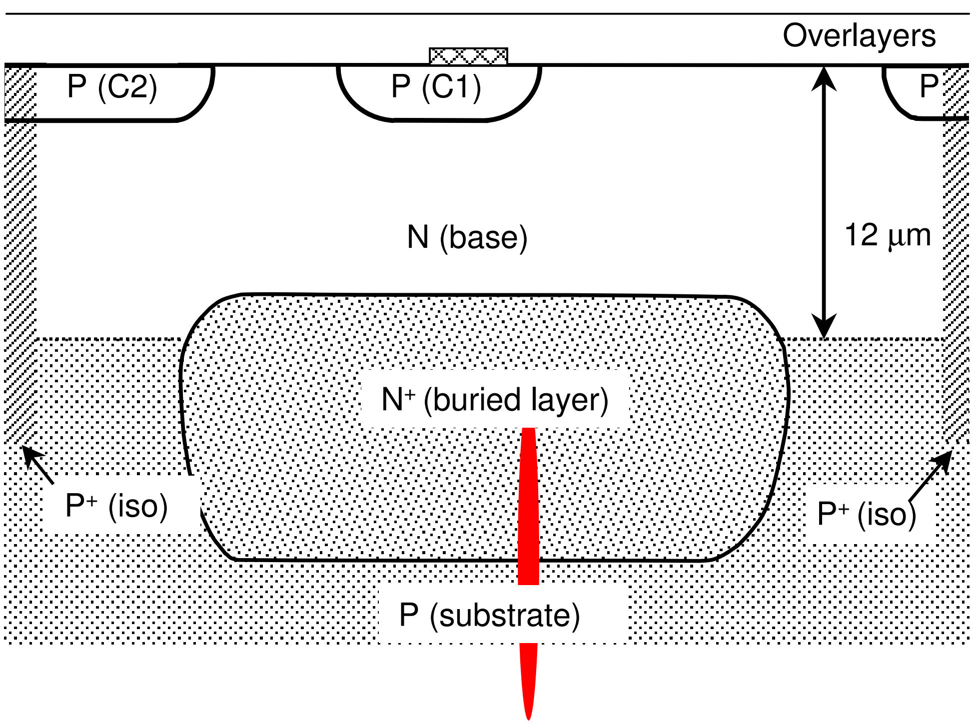

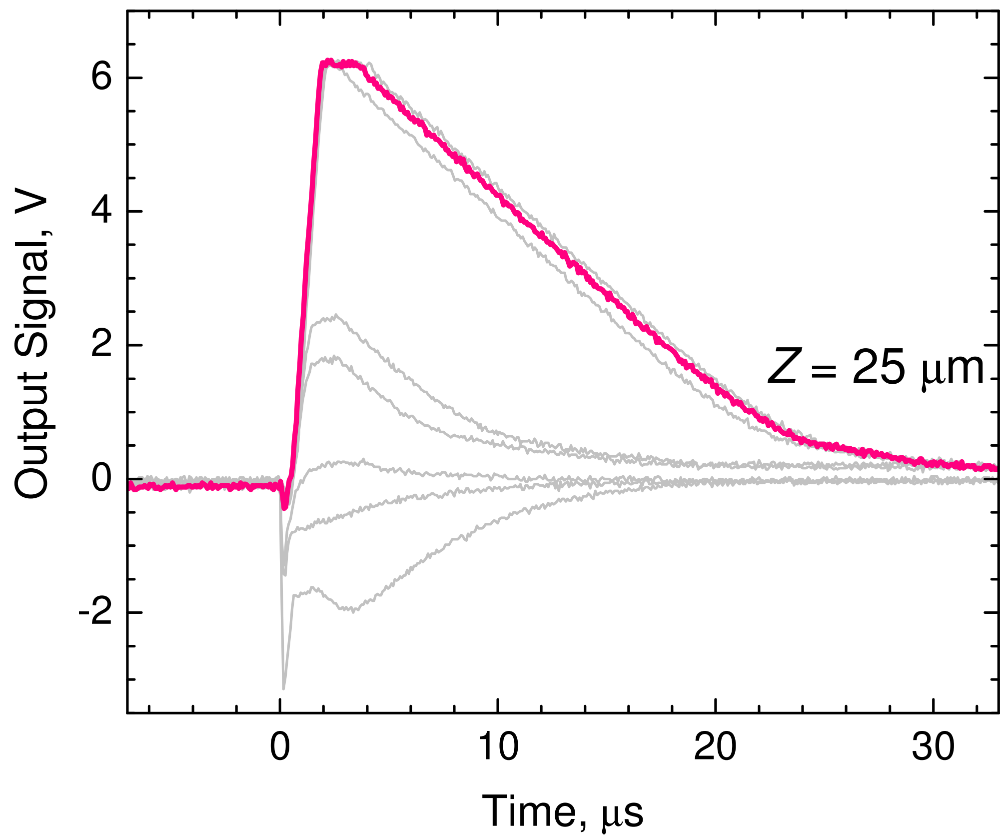

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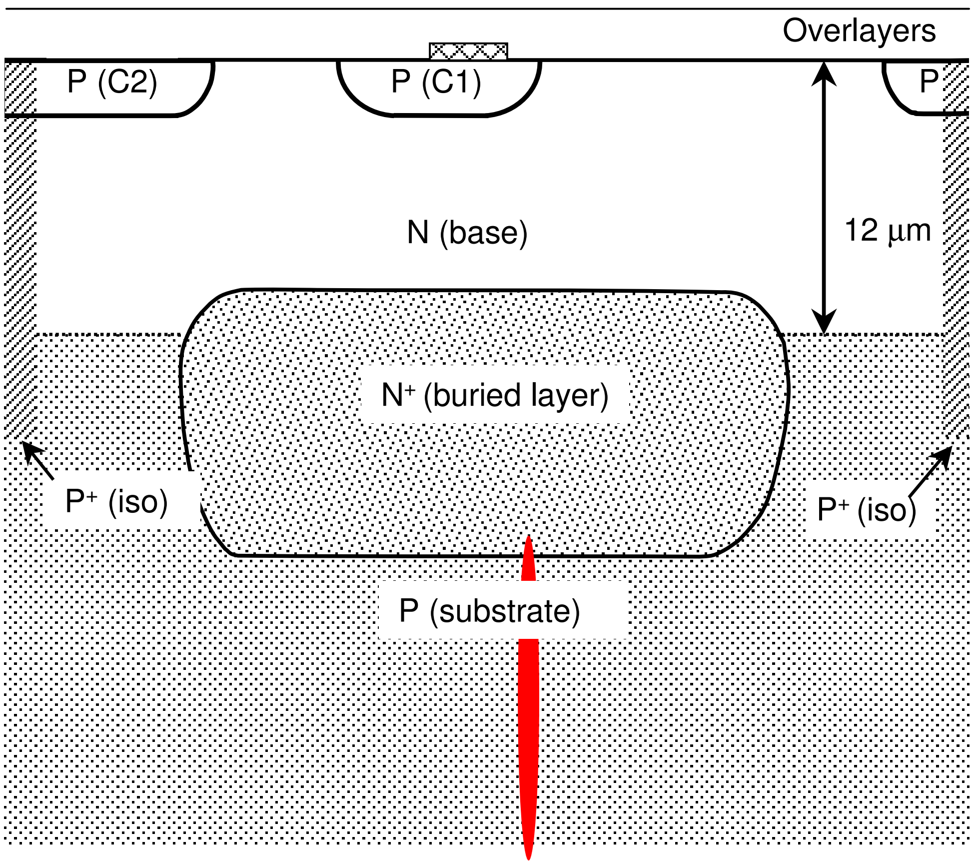

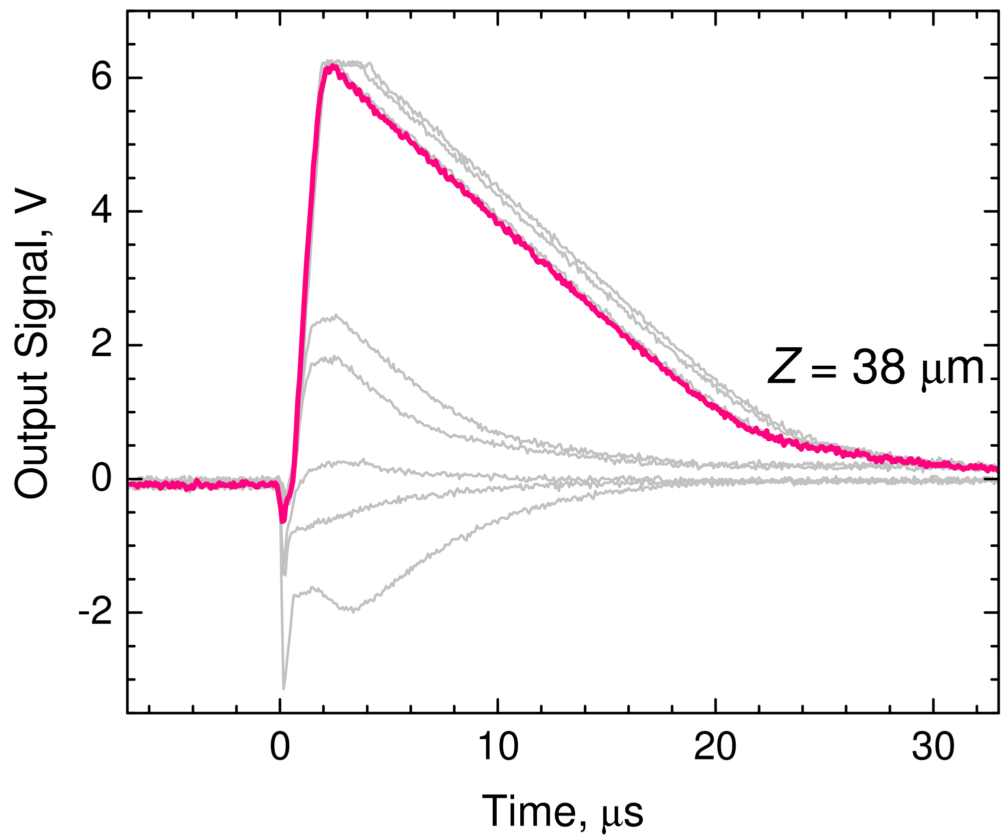

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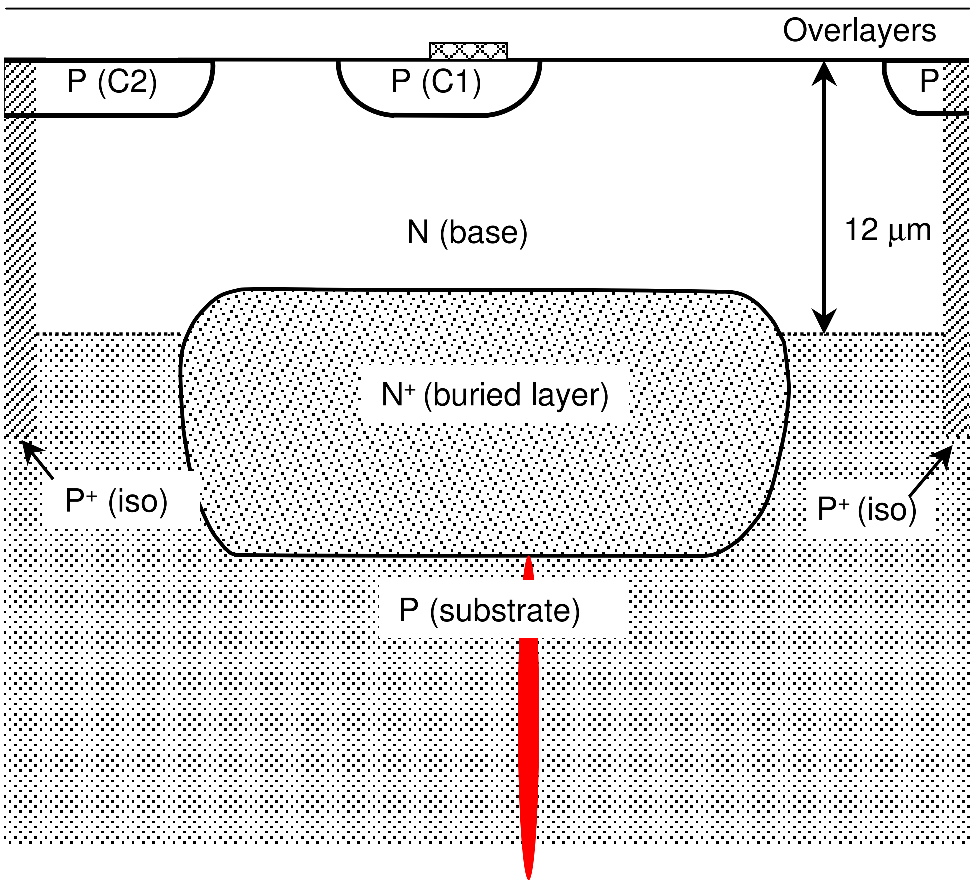

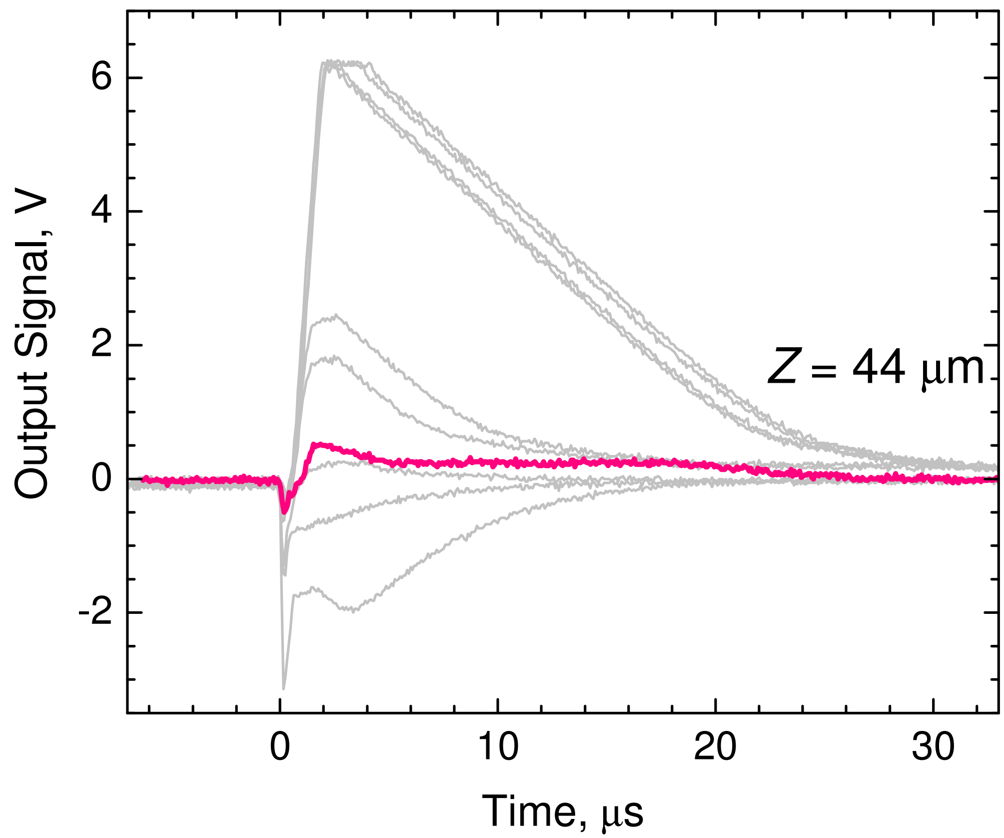

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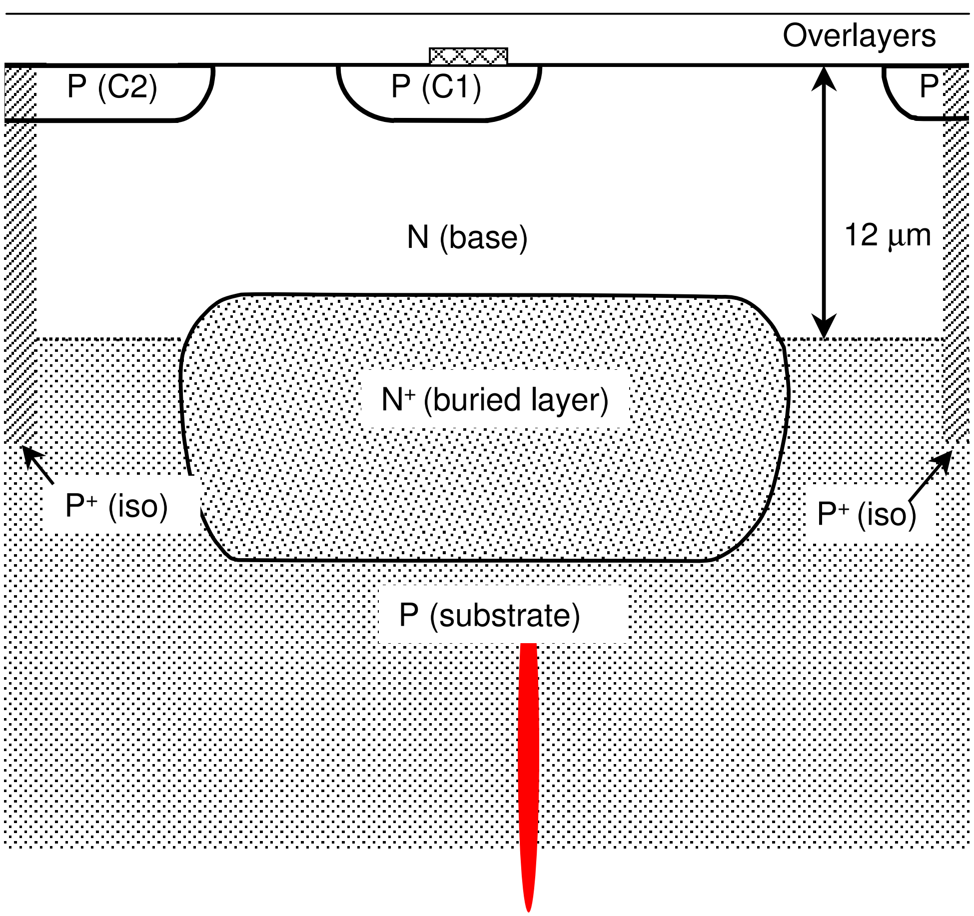

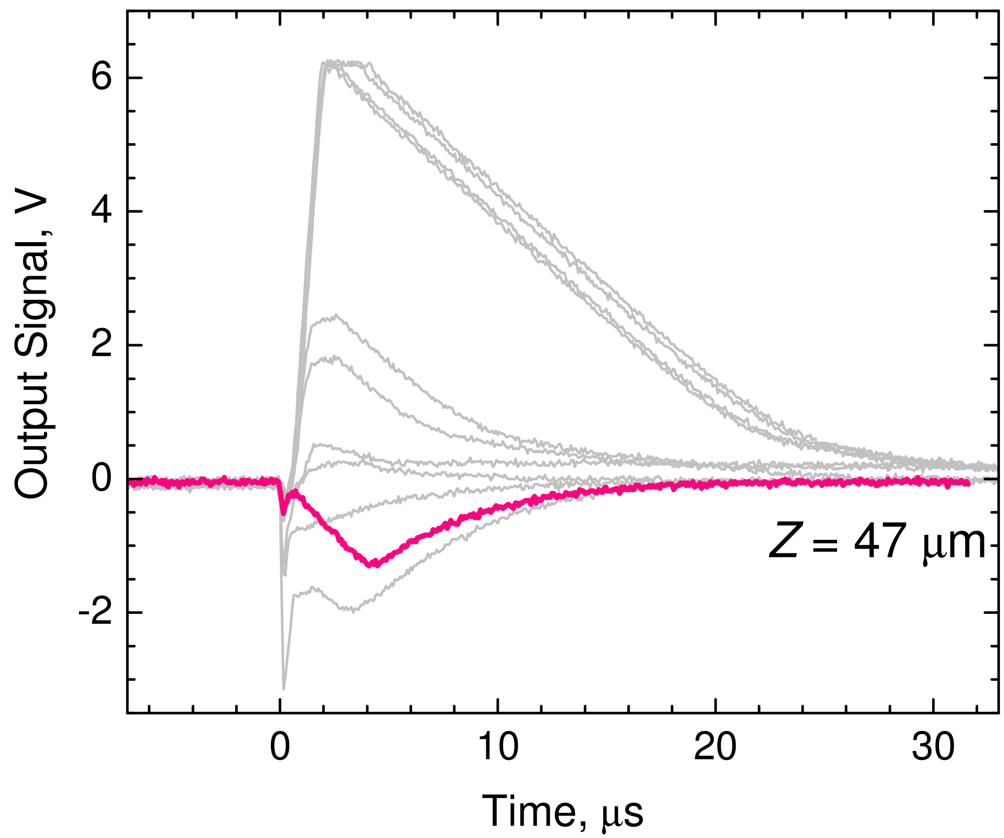

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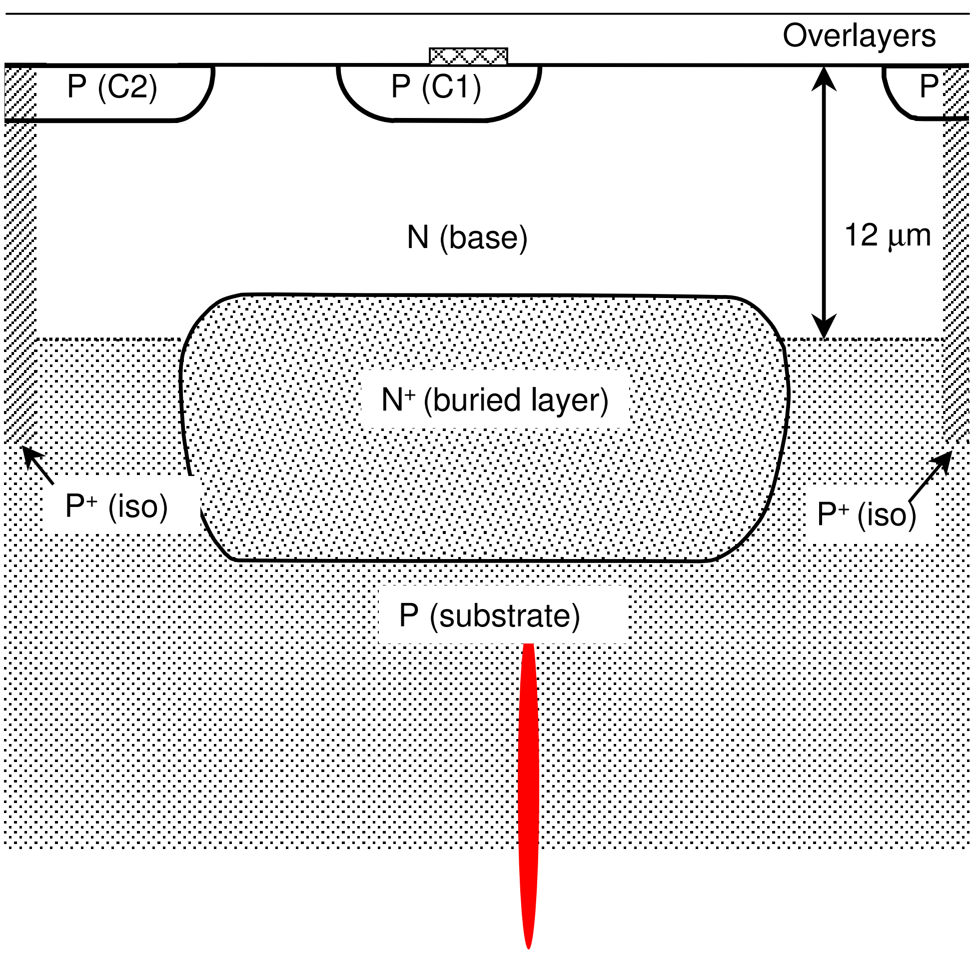
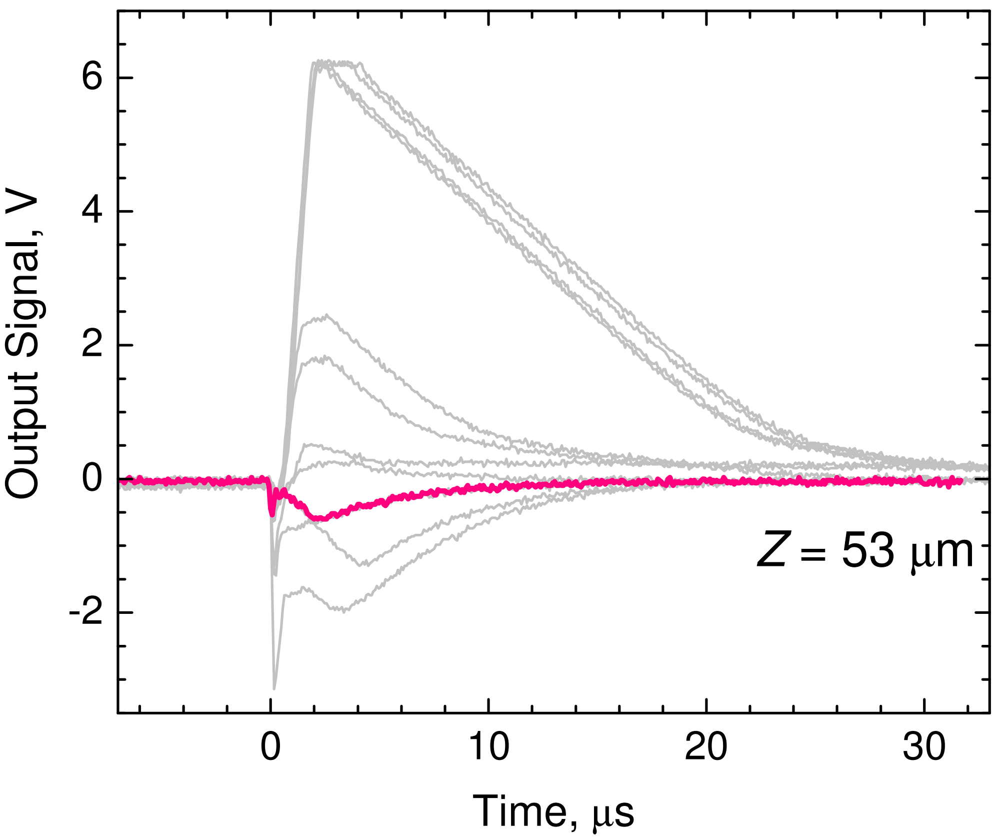
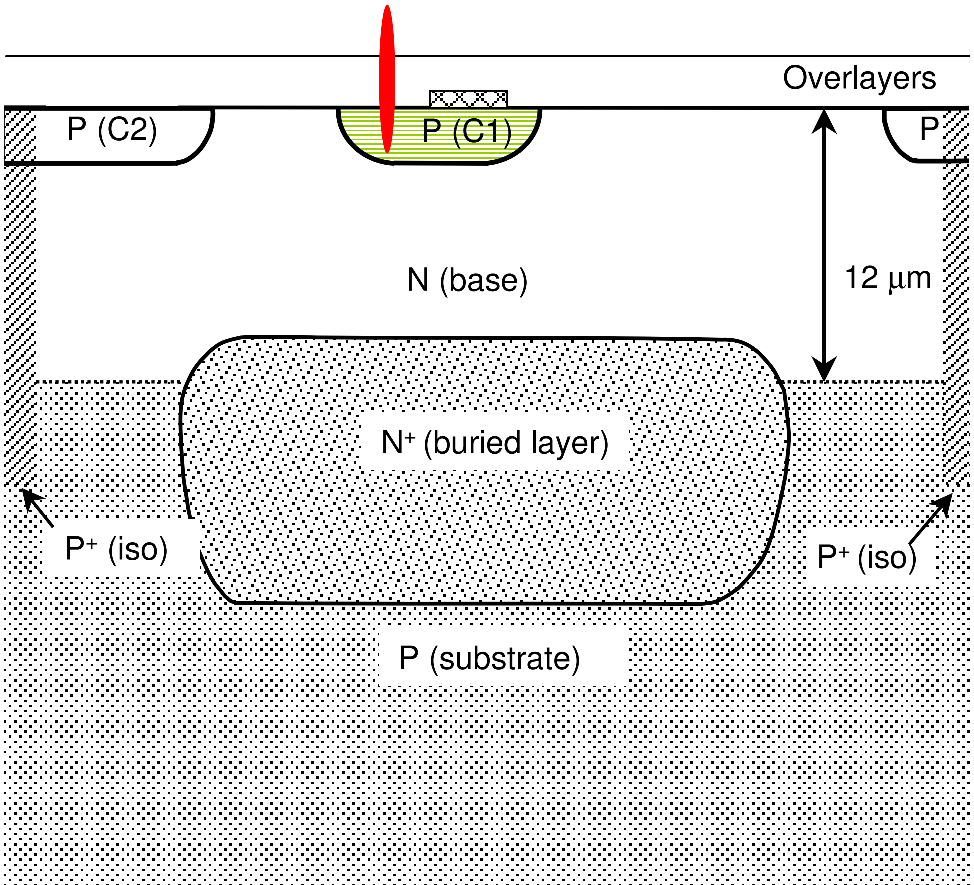
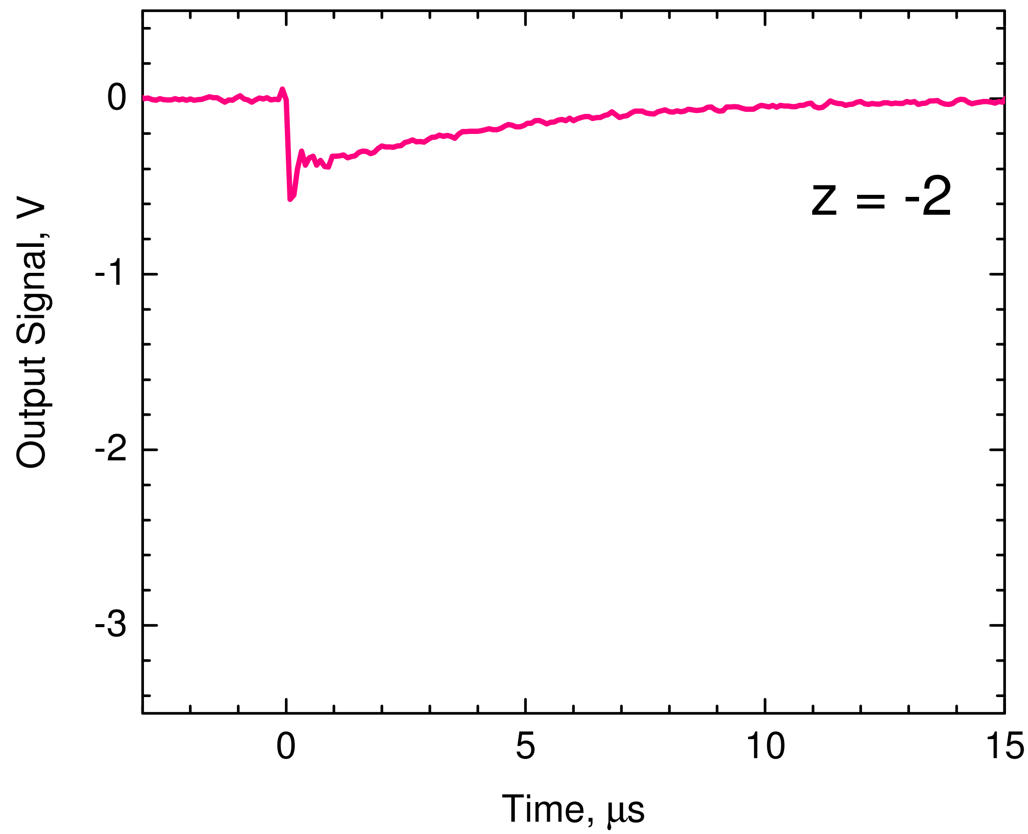




"Z" Dependence: LM124 Q20 TPA
Low Power Measurements





"Z" Dependence: LM124 Q20 TPA: Low Power

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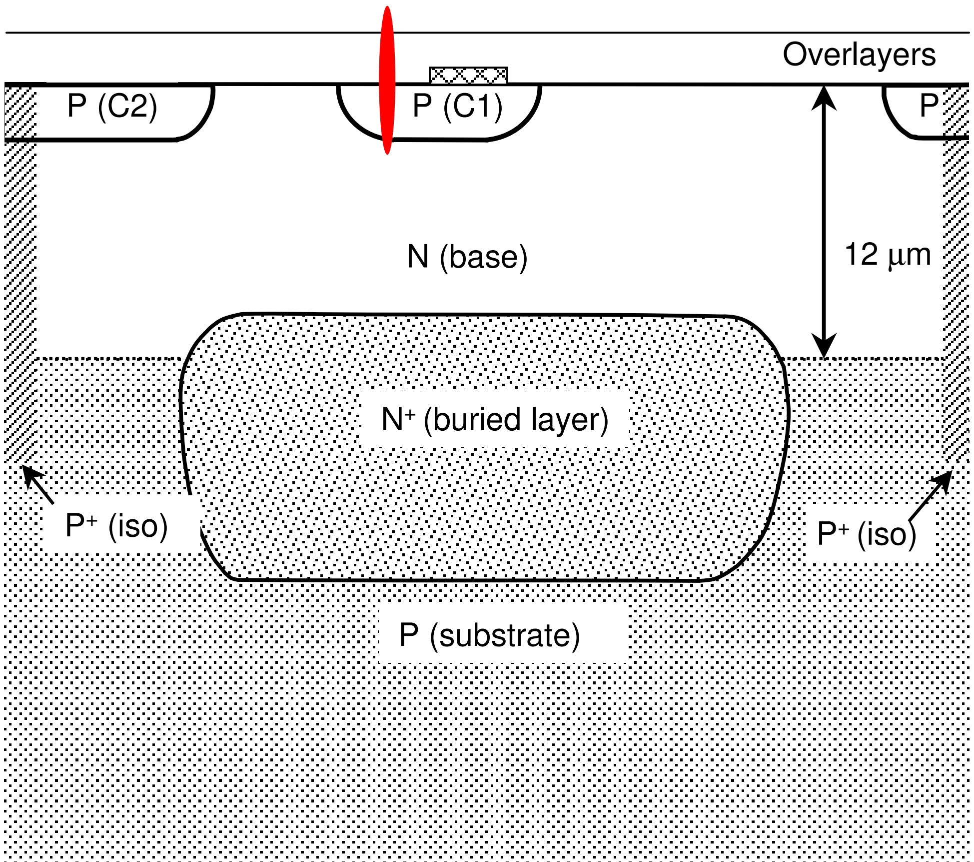

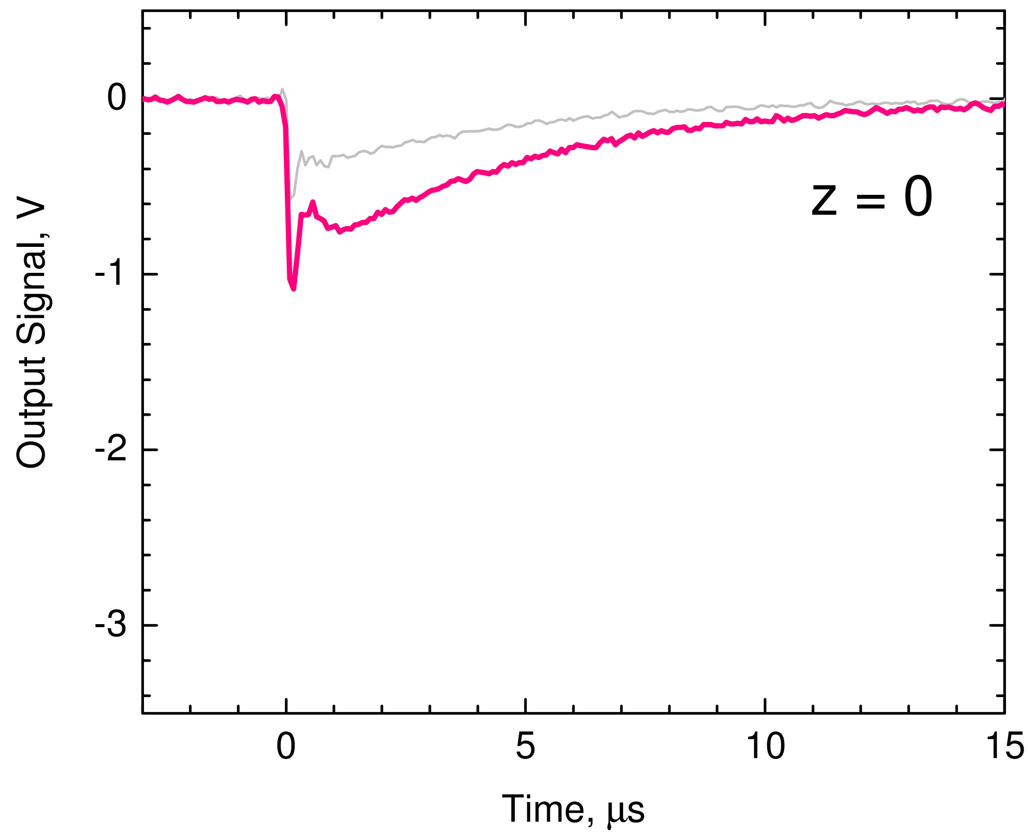

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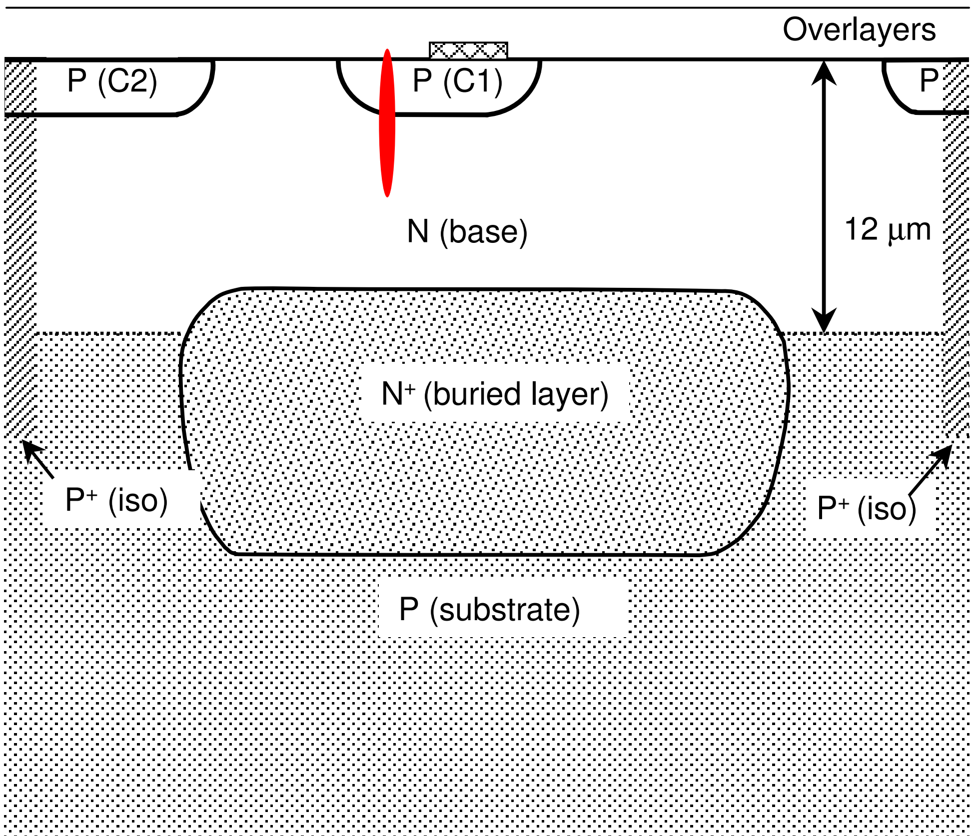

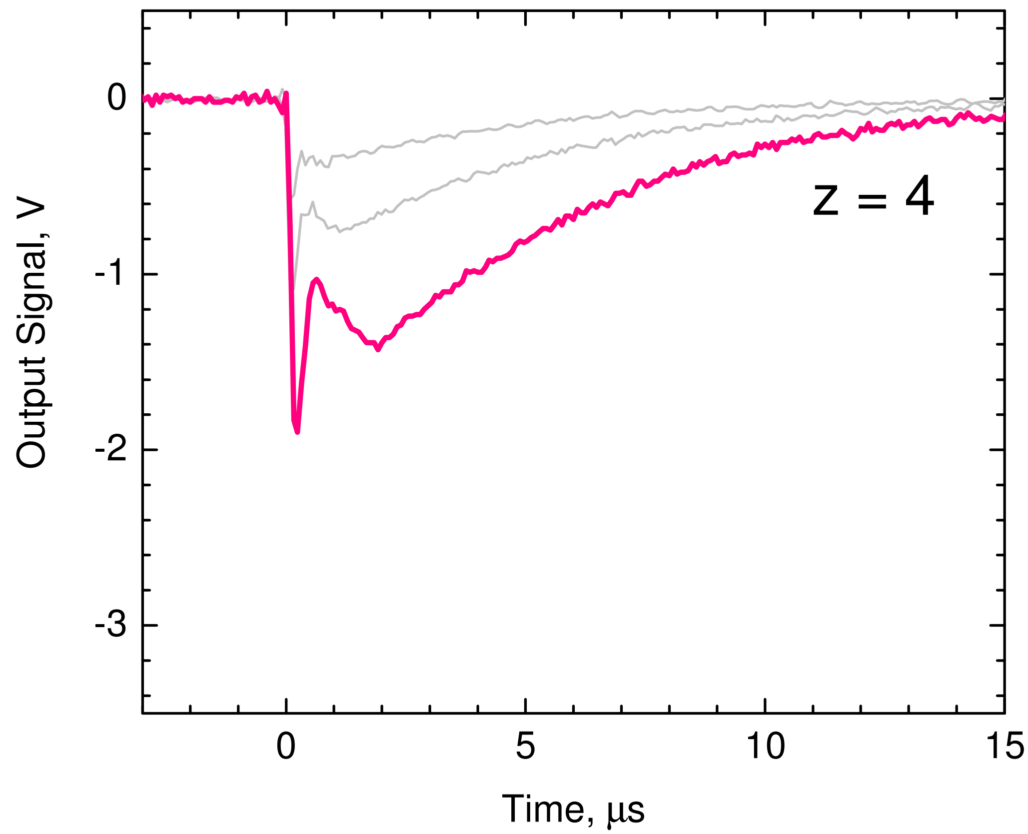

"Z" Dependence: LM124 Q20 TPA: Low Power

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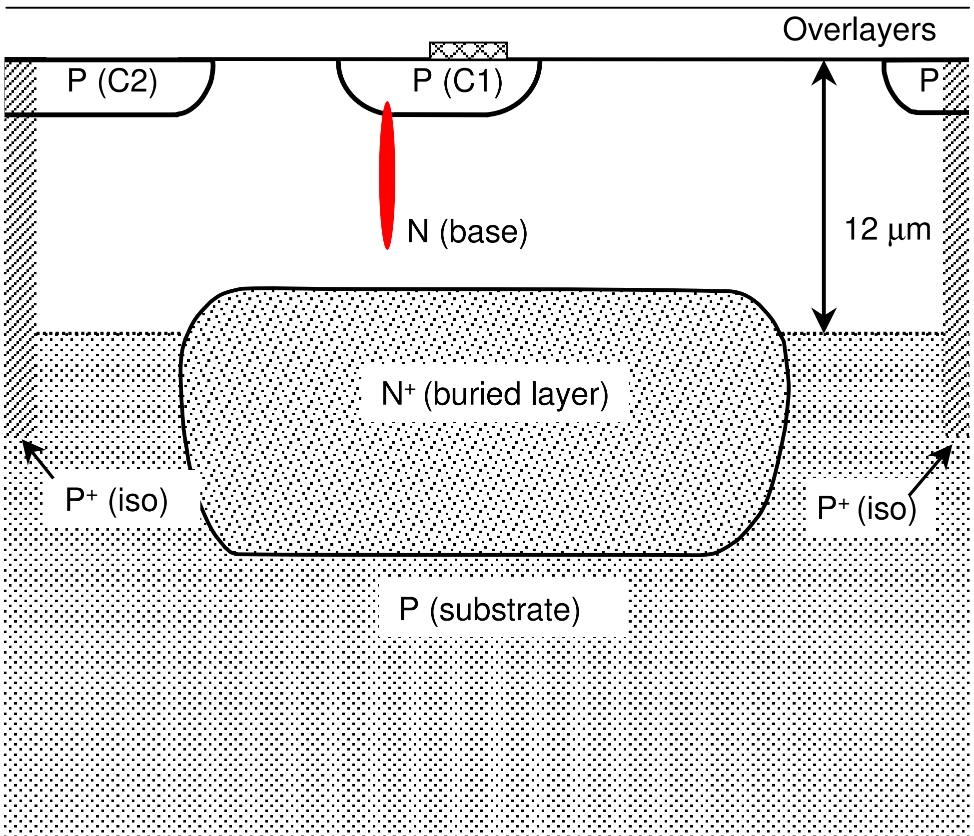
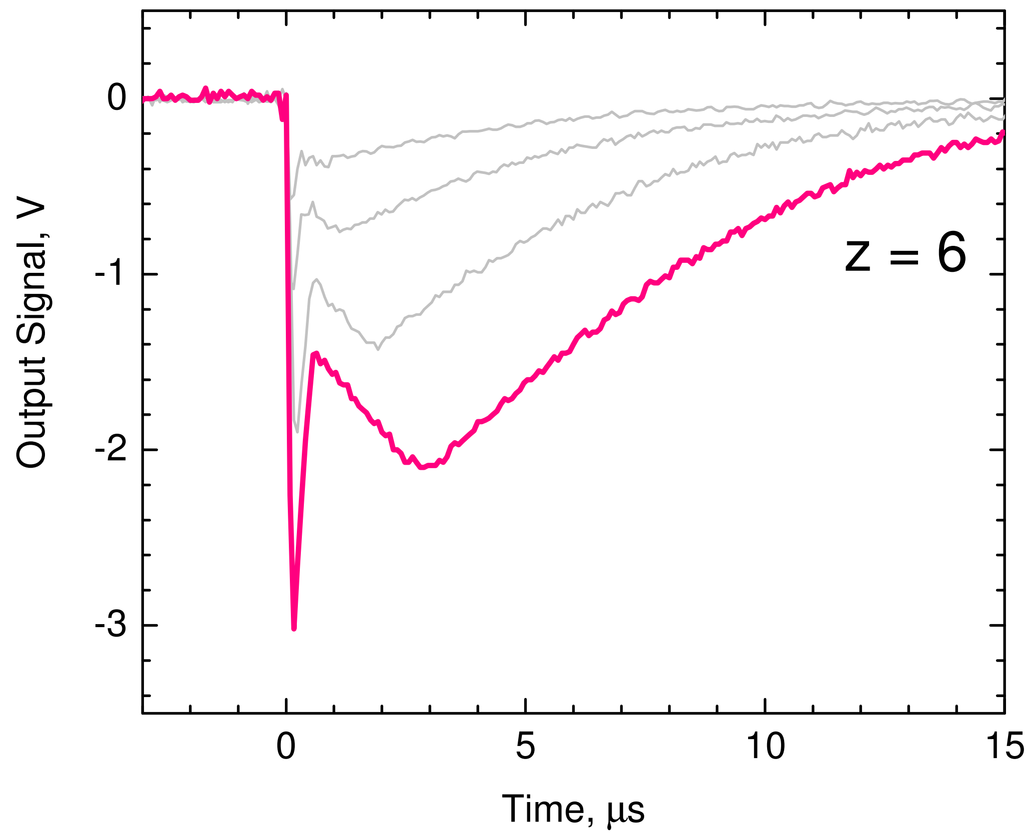
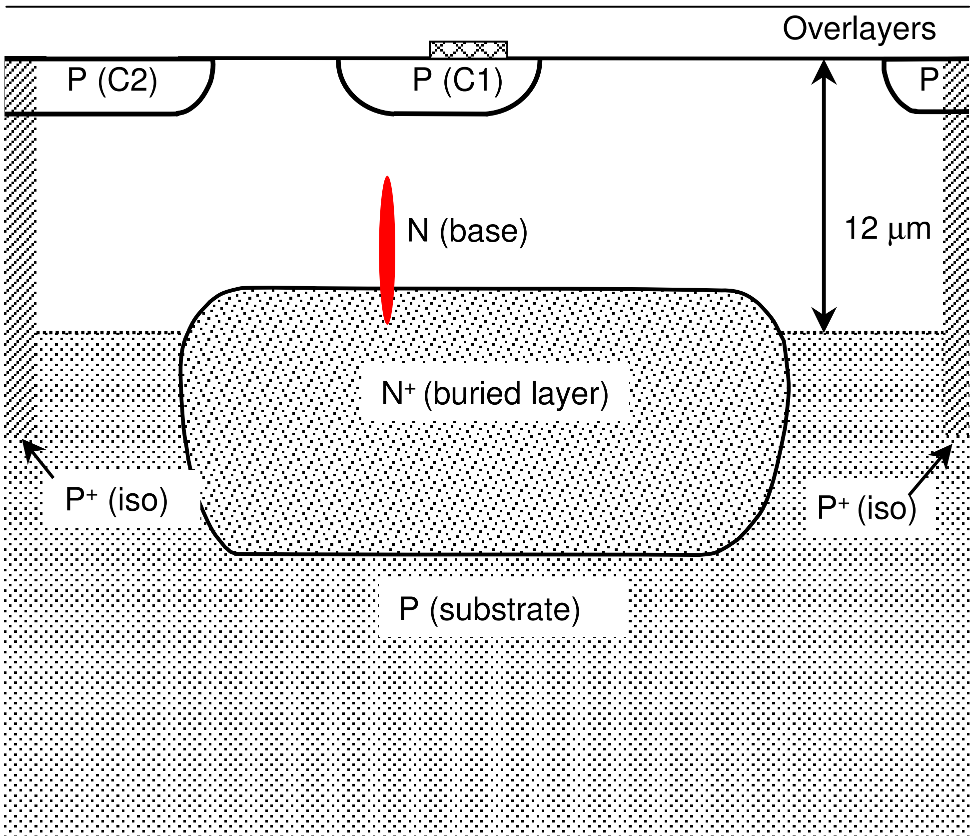
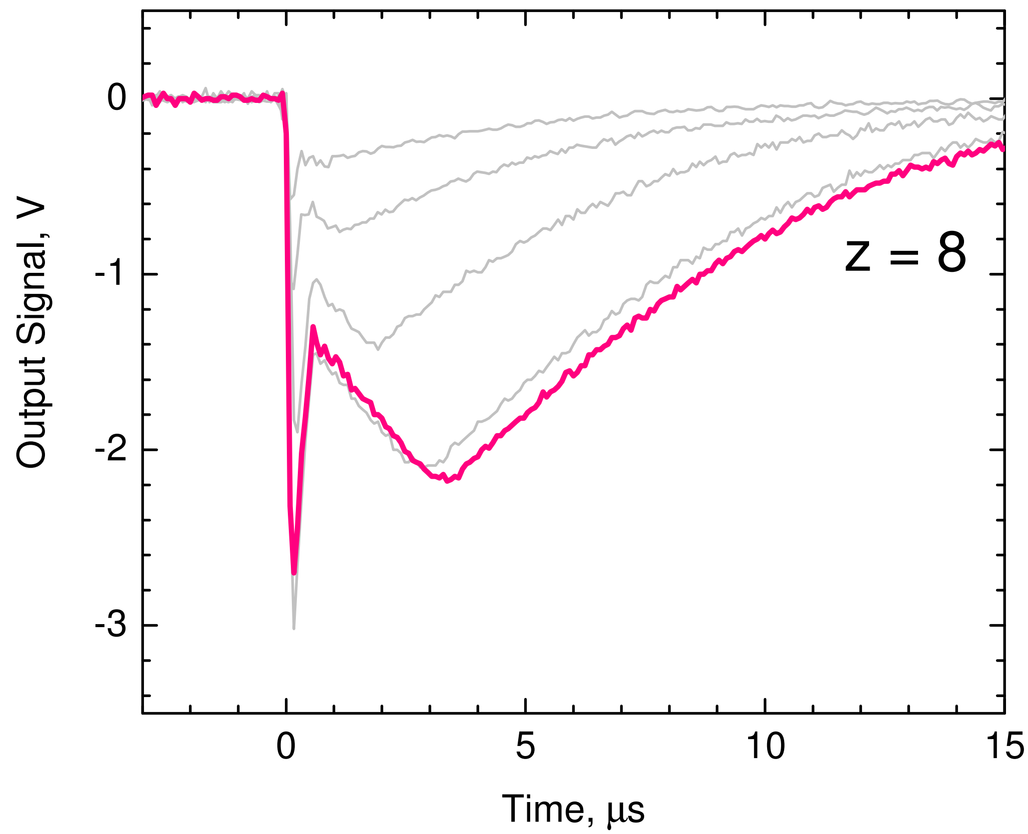




"Z" Dependence: LM124 Q20 TPA: Low Power

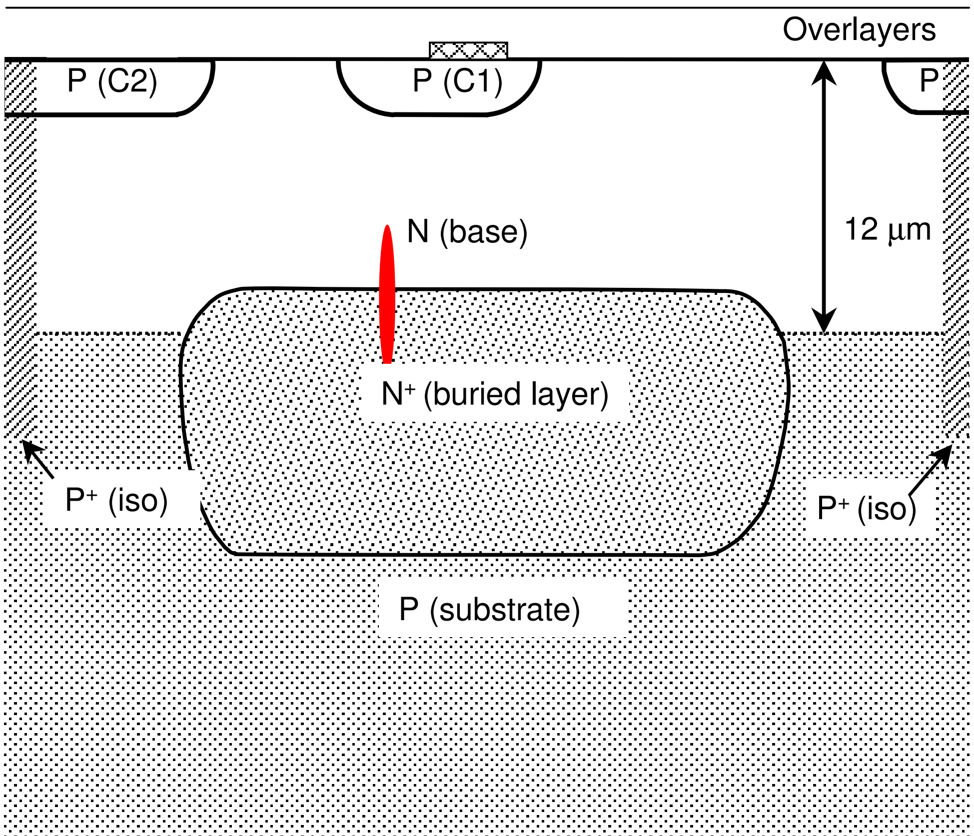
(Inverting Configuration; gain of 20)

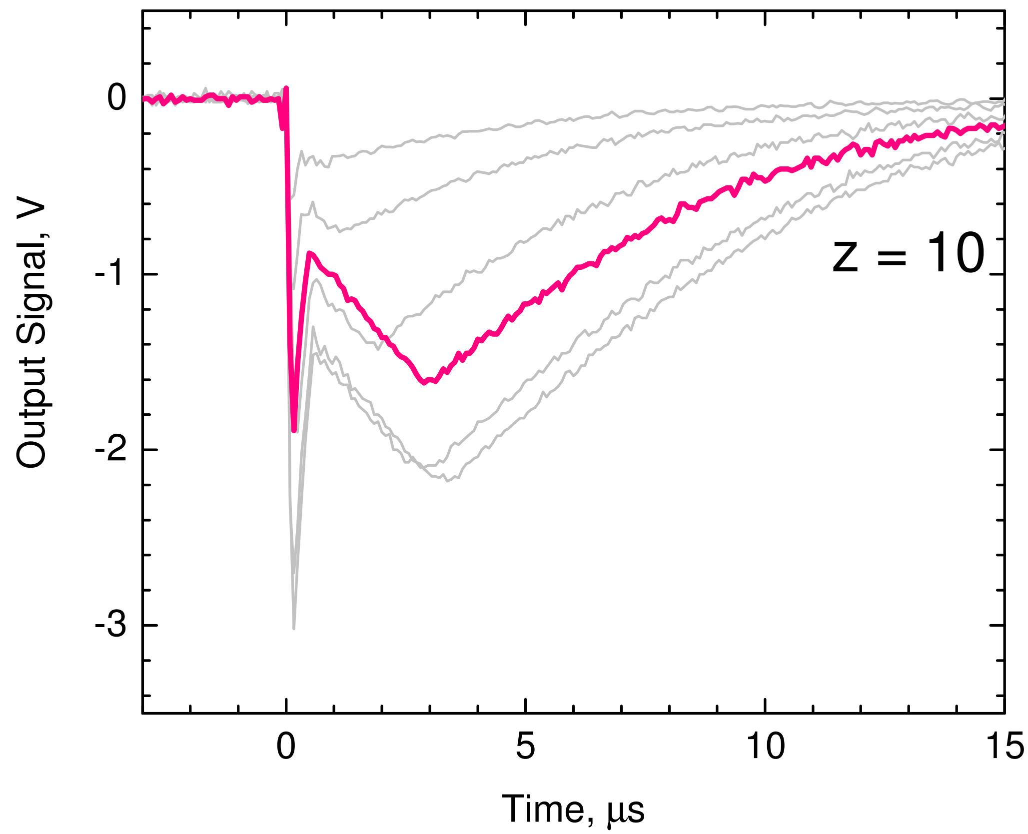




"Z" Dependence: LM124 Q20 TPA: Low Power

(Inverting Configuration; gain of 20)





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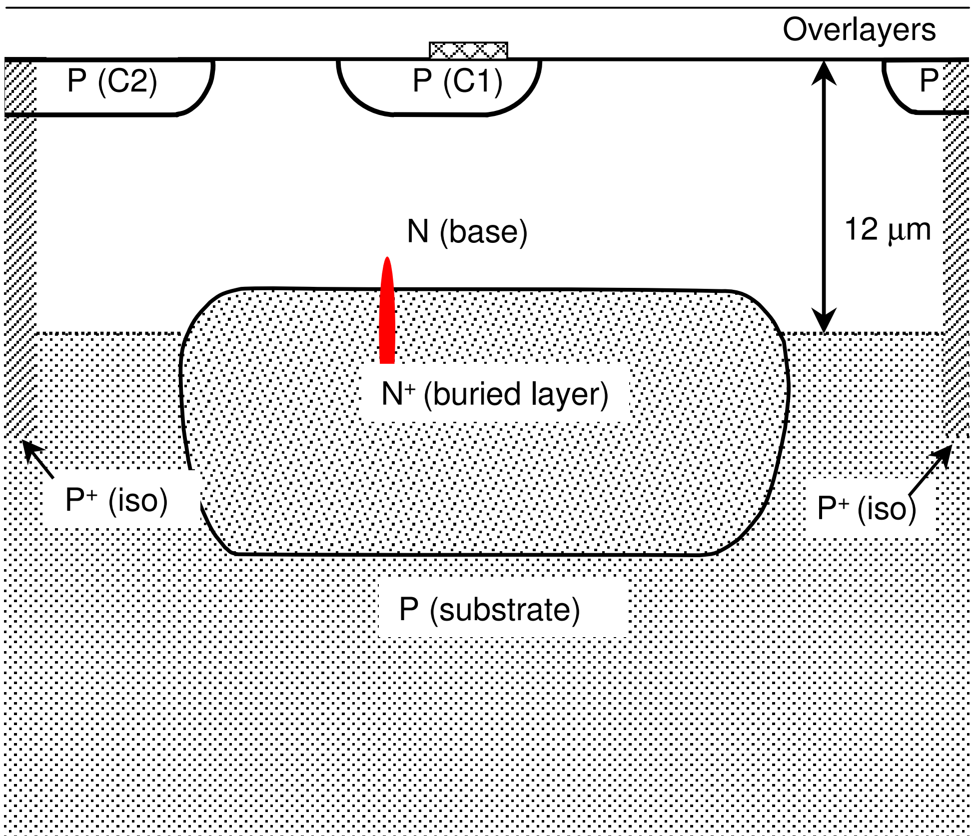
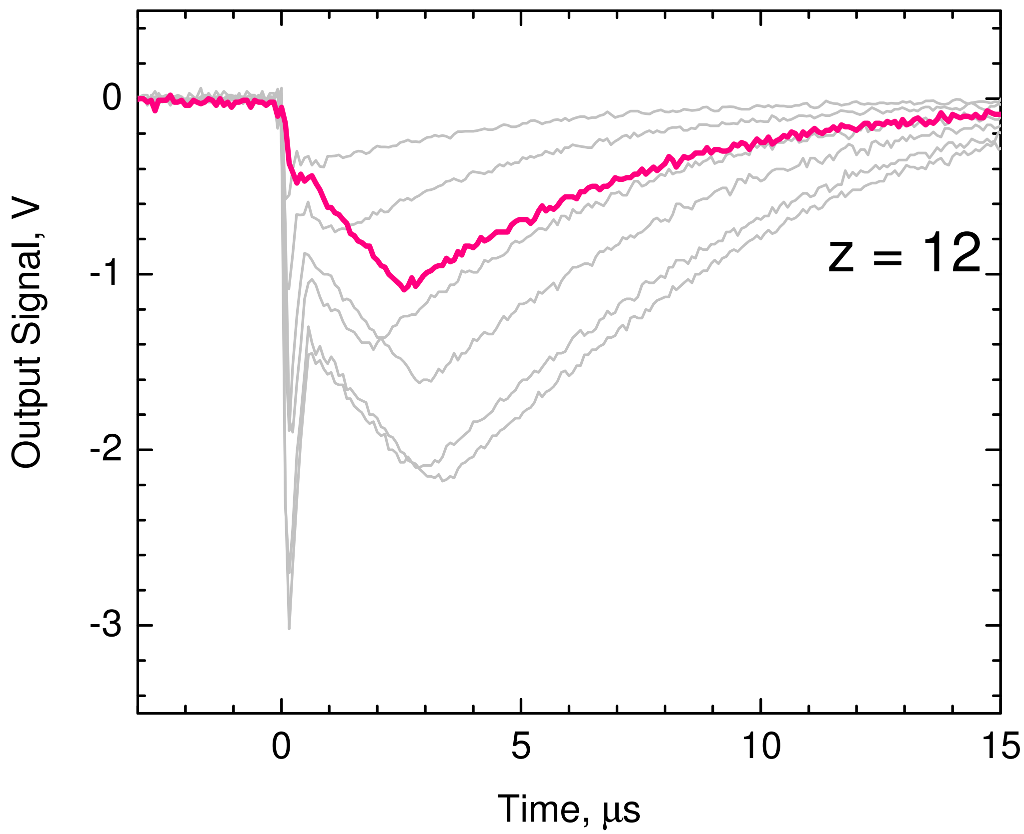
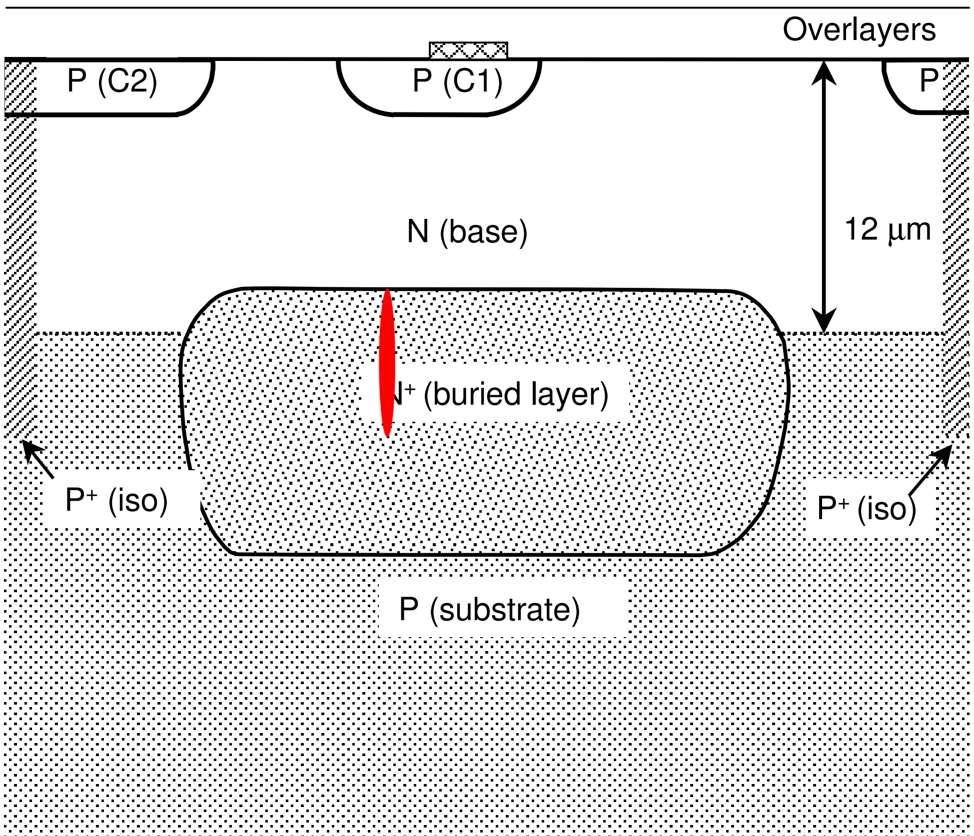
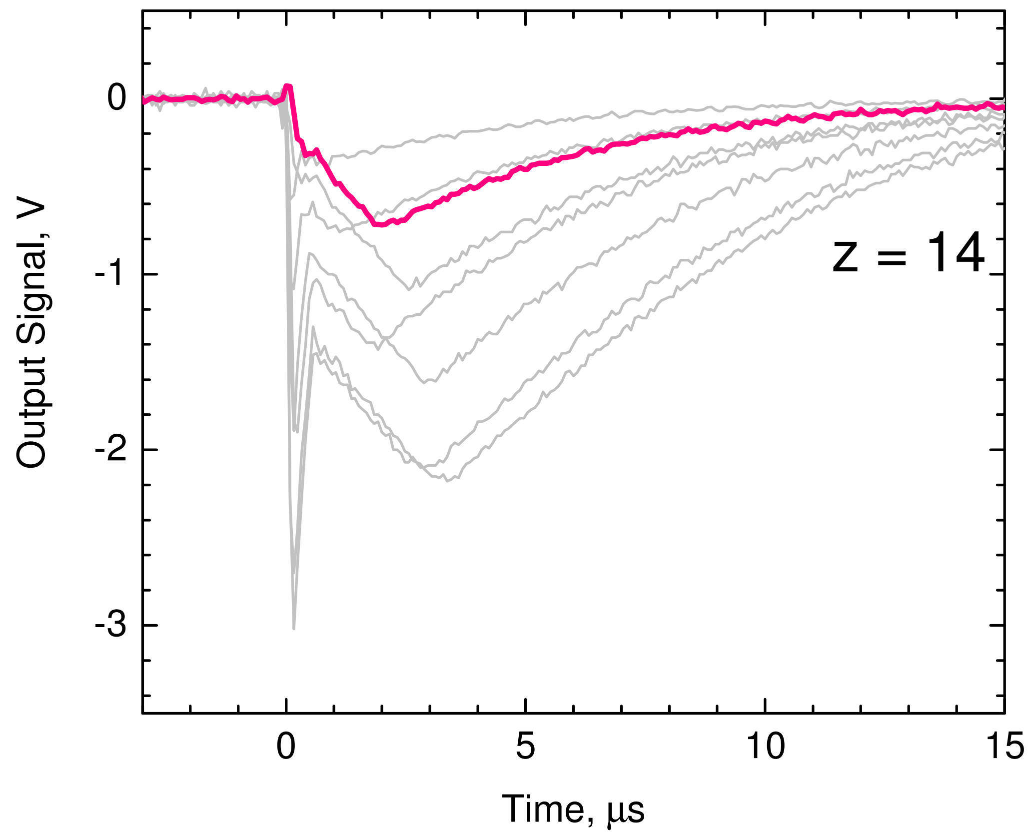




"Z" Dependence: LM124 Q20 TPA: Low Power

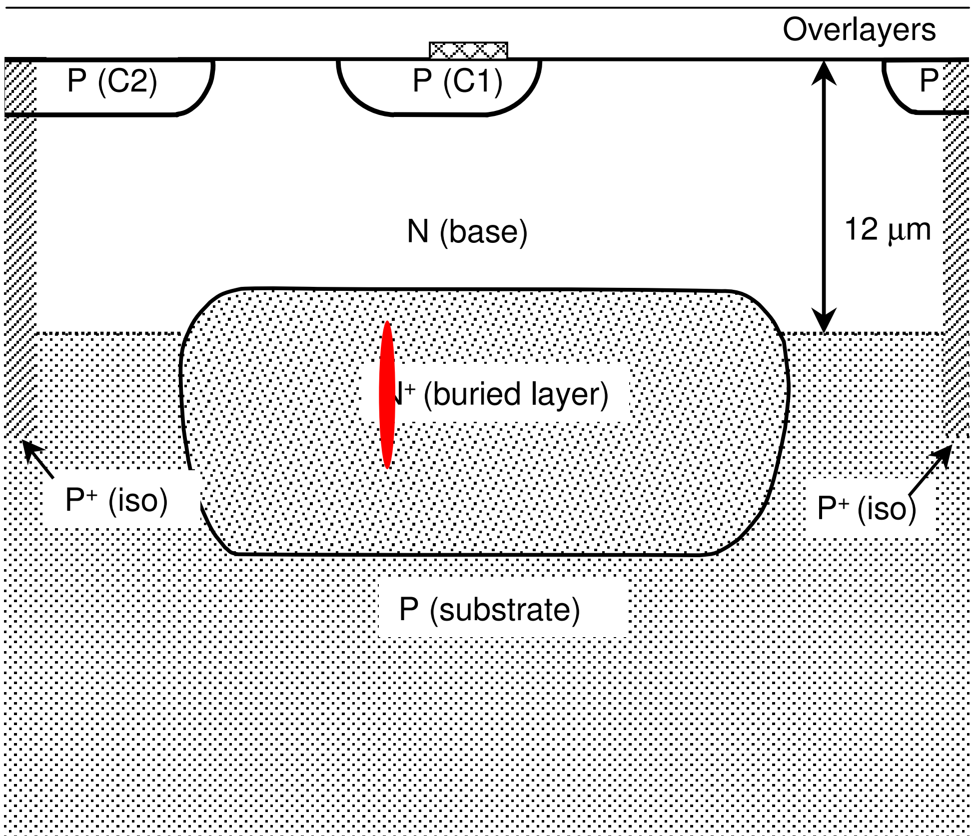
(Inverting Configuration; gain of 20)

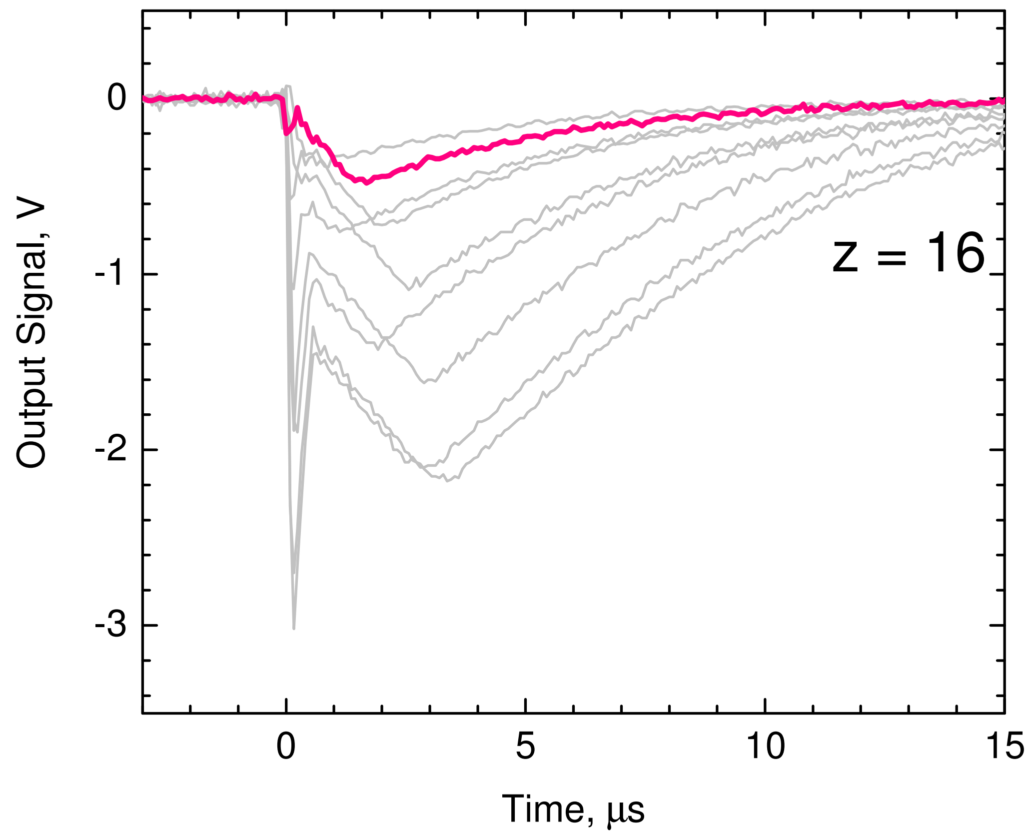




“Z” Dependence: LM124 Q20 TPA: Low Power

(Inverting Configuration; gain of 20)





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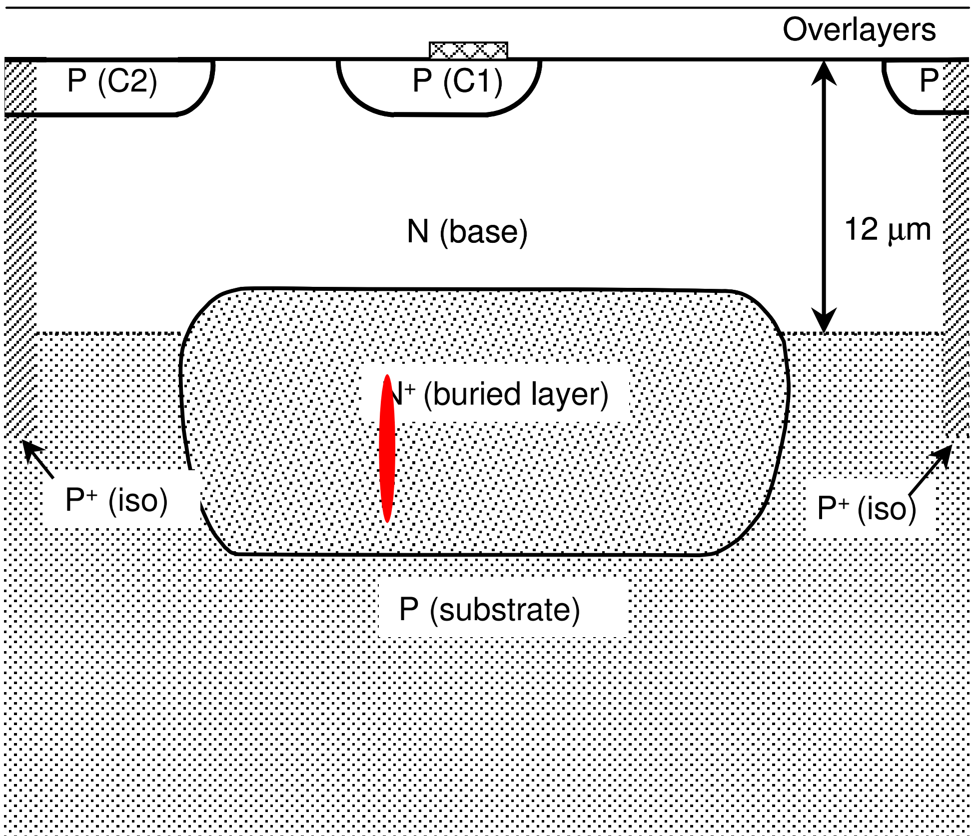
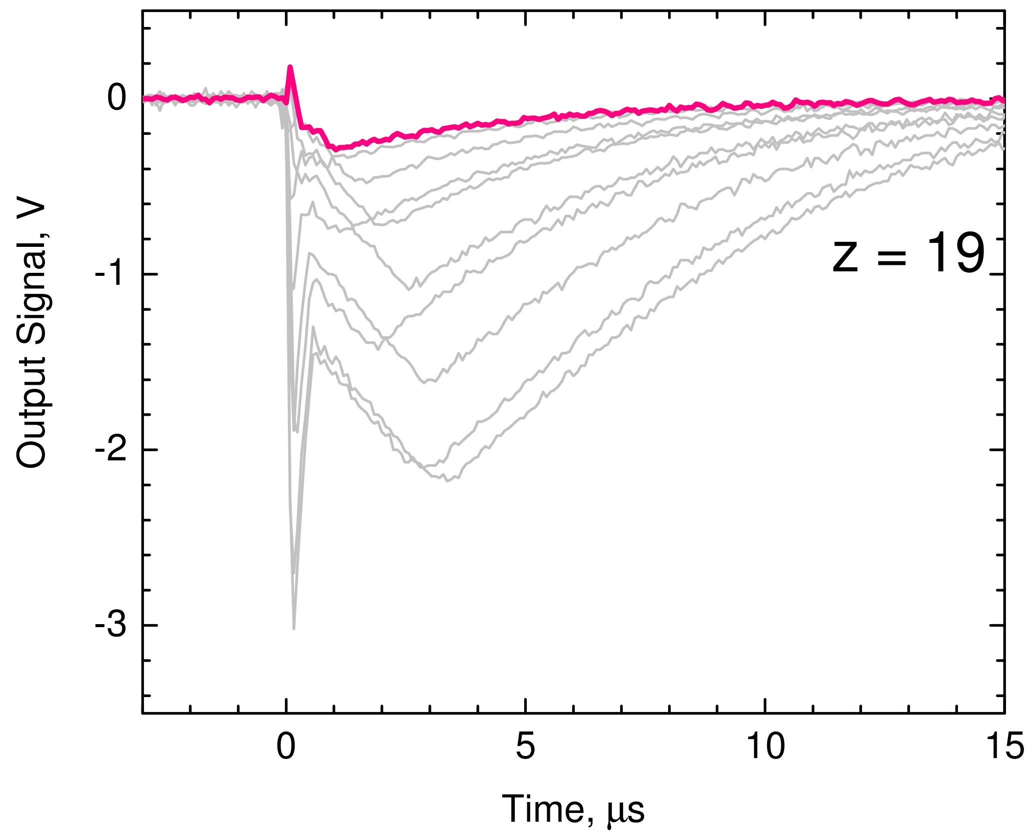
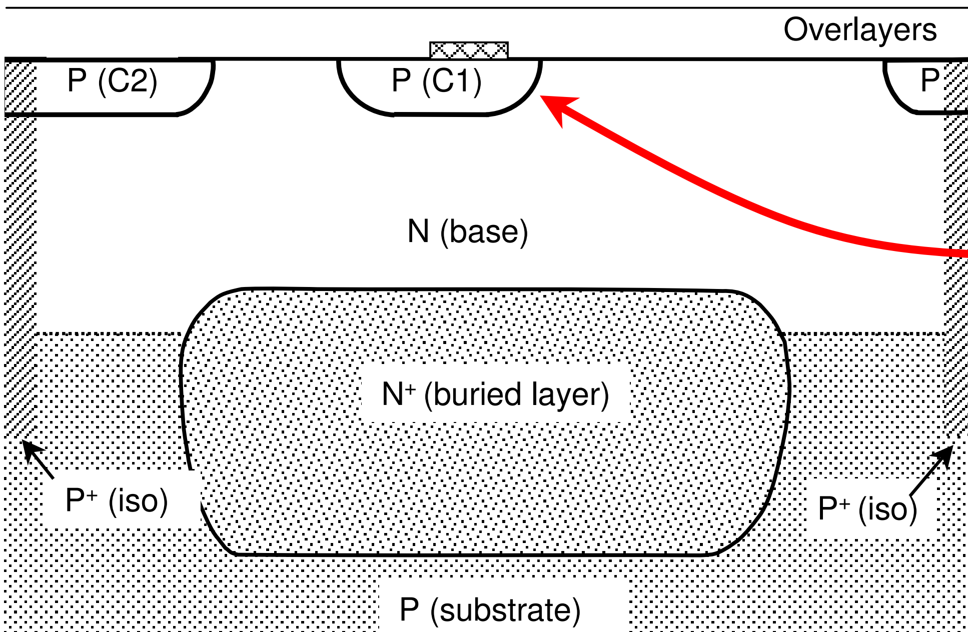
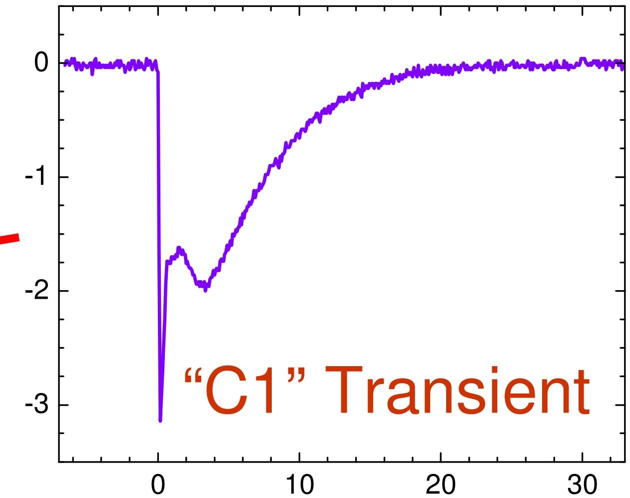
(Inverting Configuration; gain of 20)

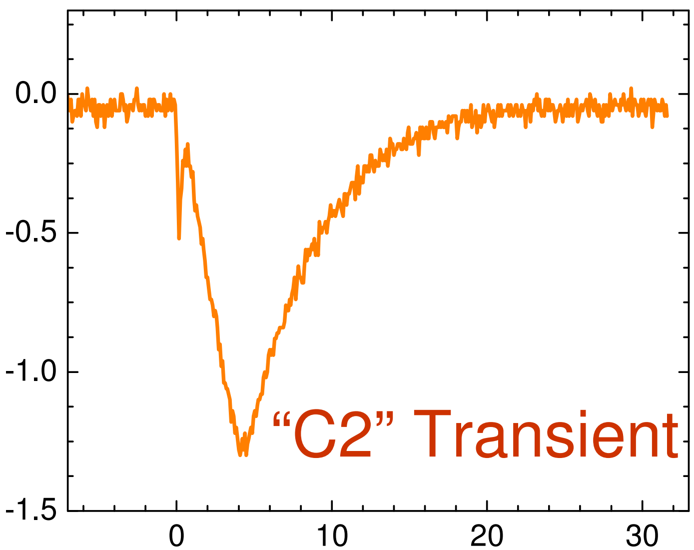


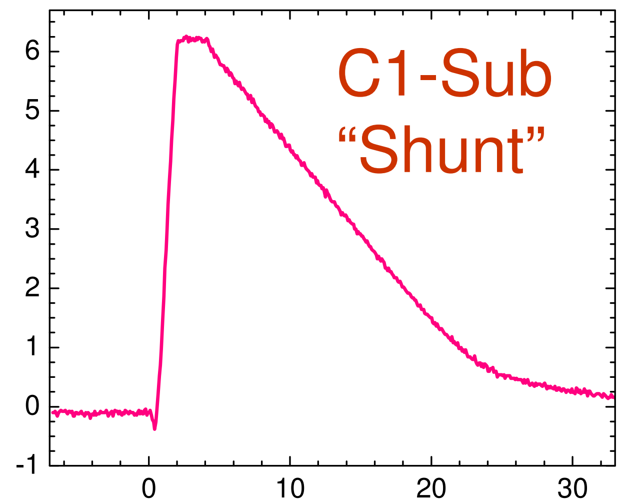


LM124 Q20 TPA SET: “Z” Dependence









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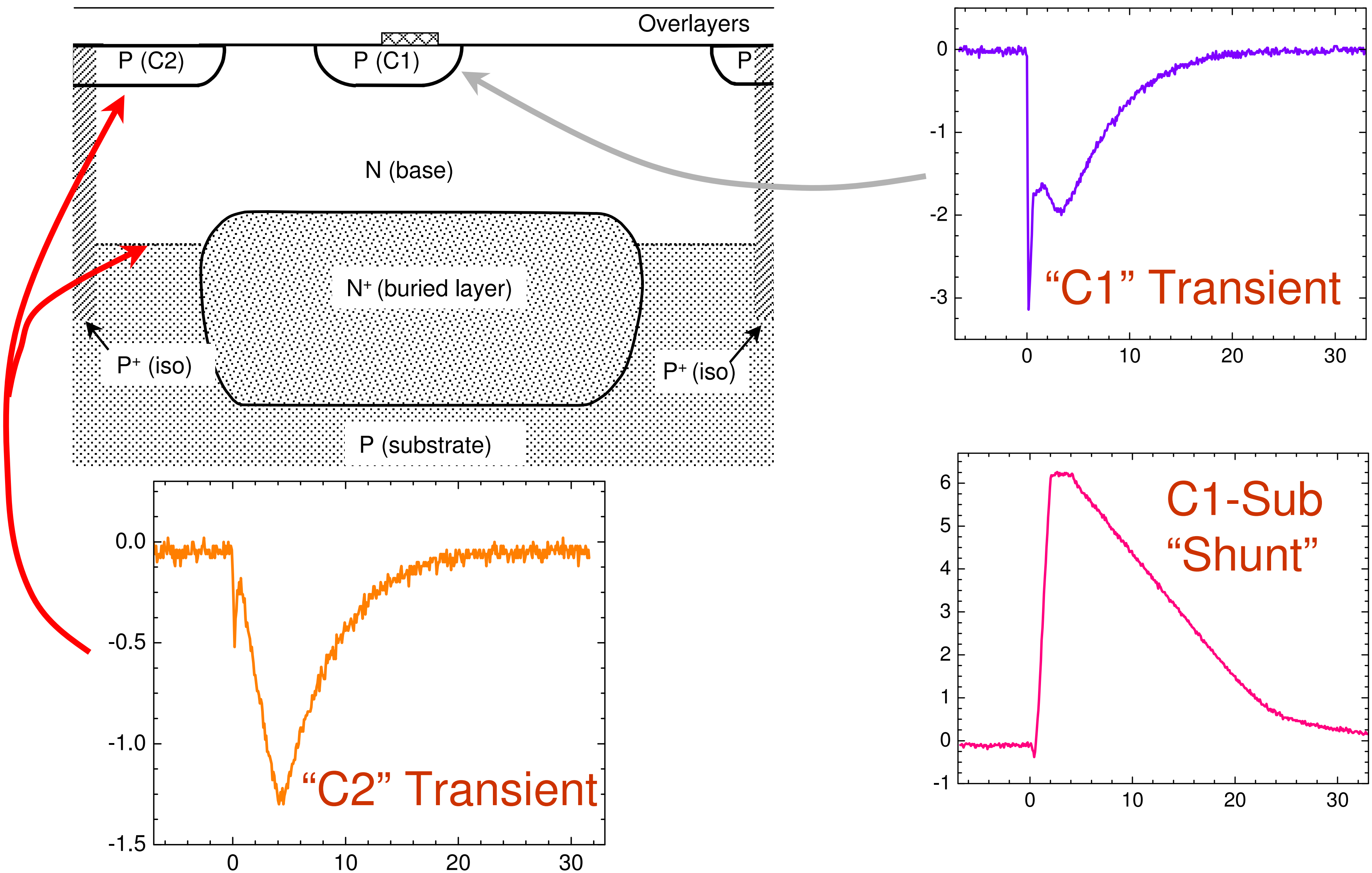
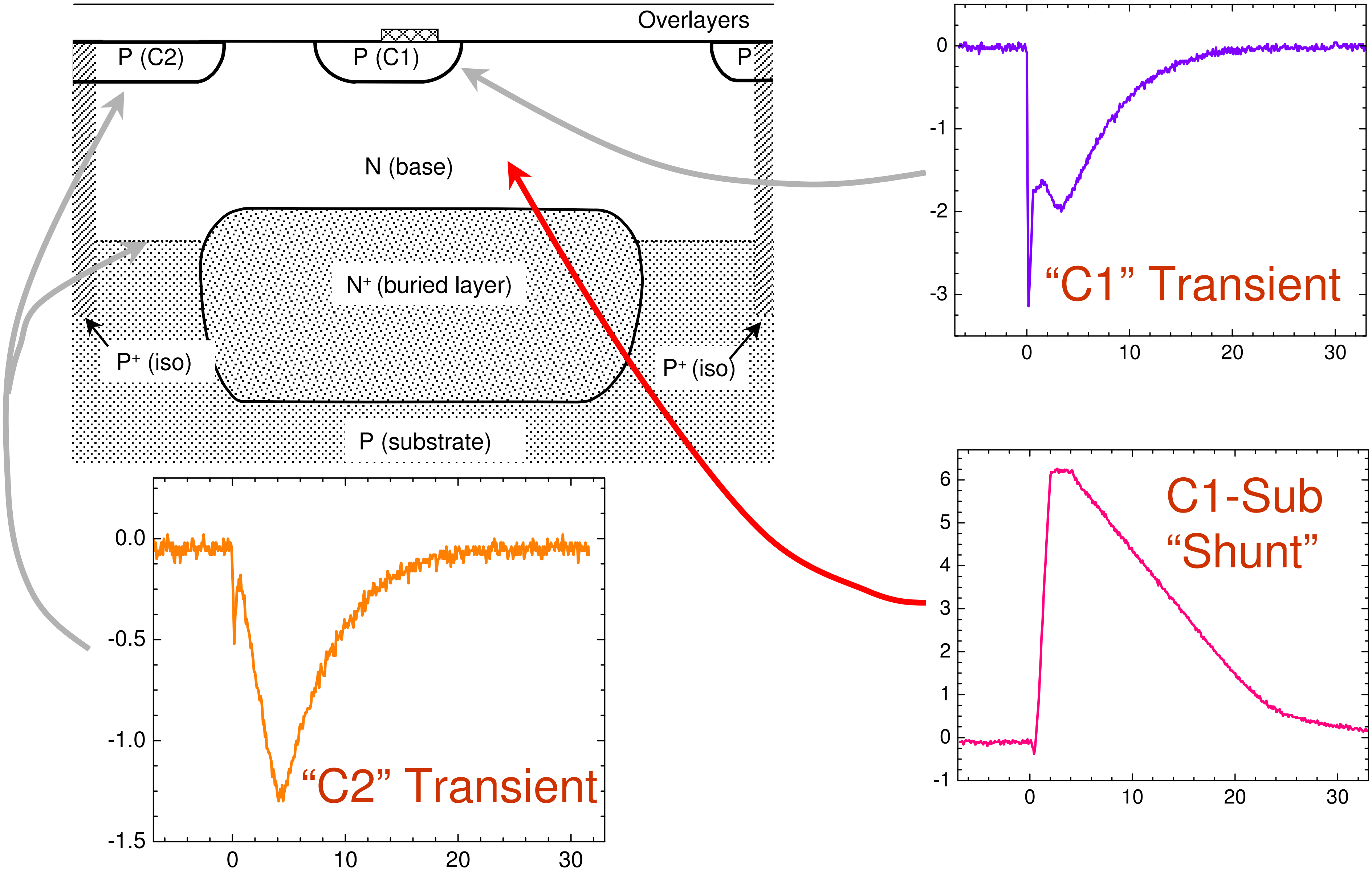
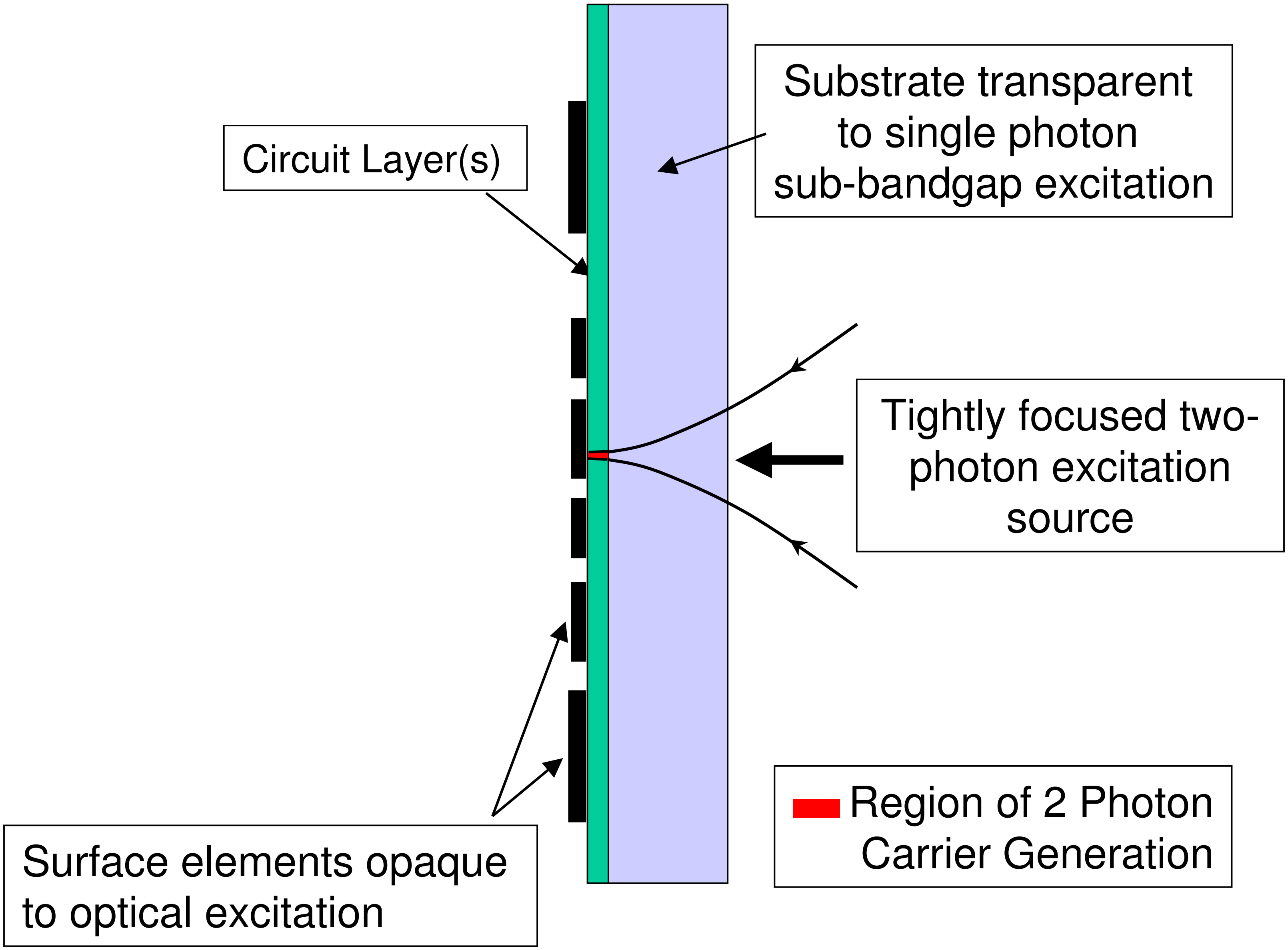
LM124 Q20 TPA SET: “Z” Dependence



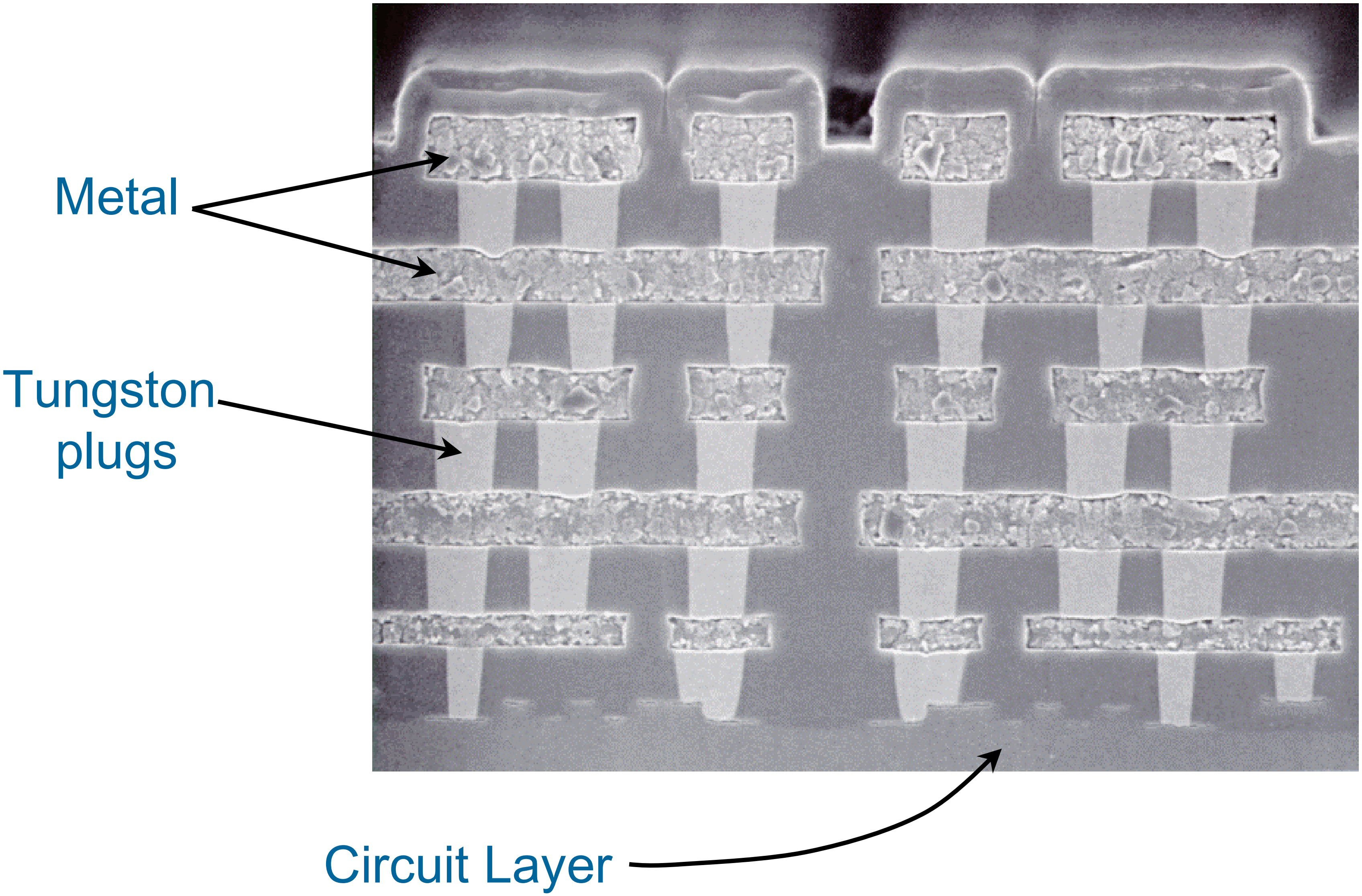
LM124 Q20 TPA SET: “Z” Dependence



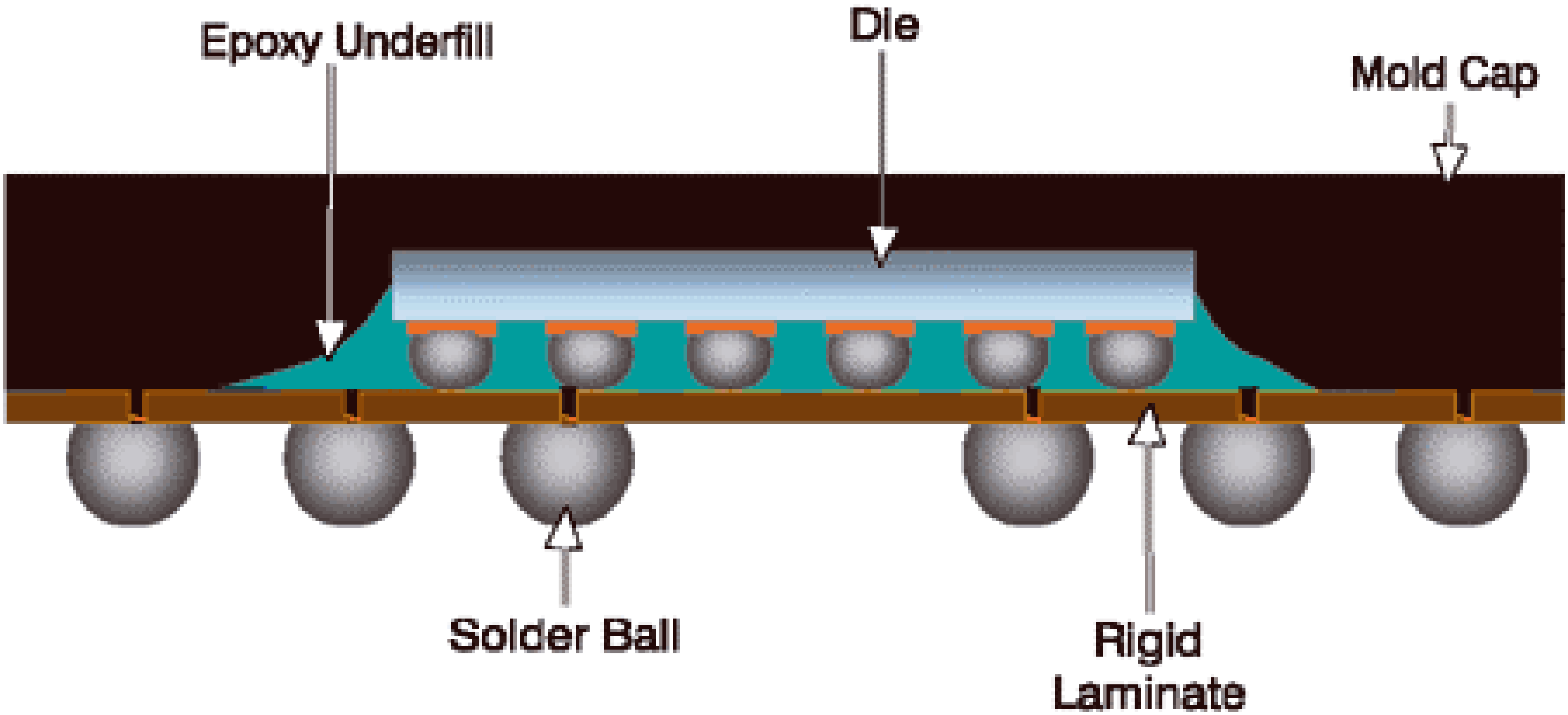
Backside "Through-Wafer" TPA Illumination



Cross Section of Modern Device

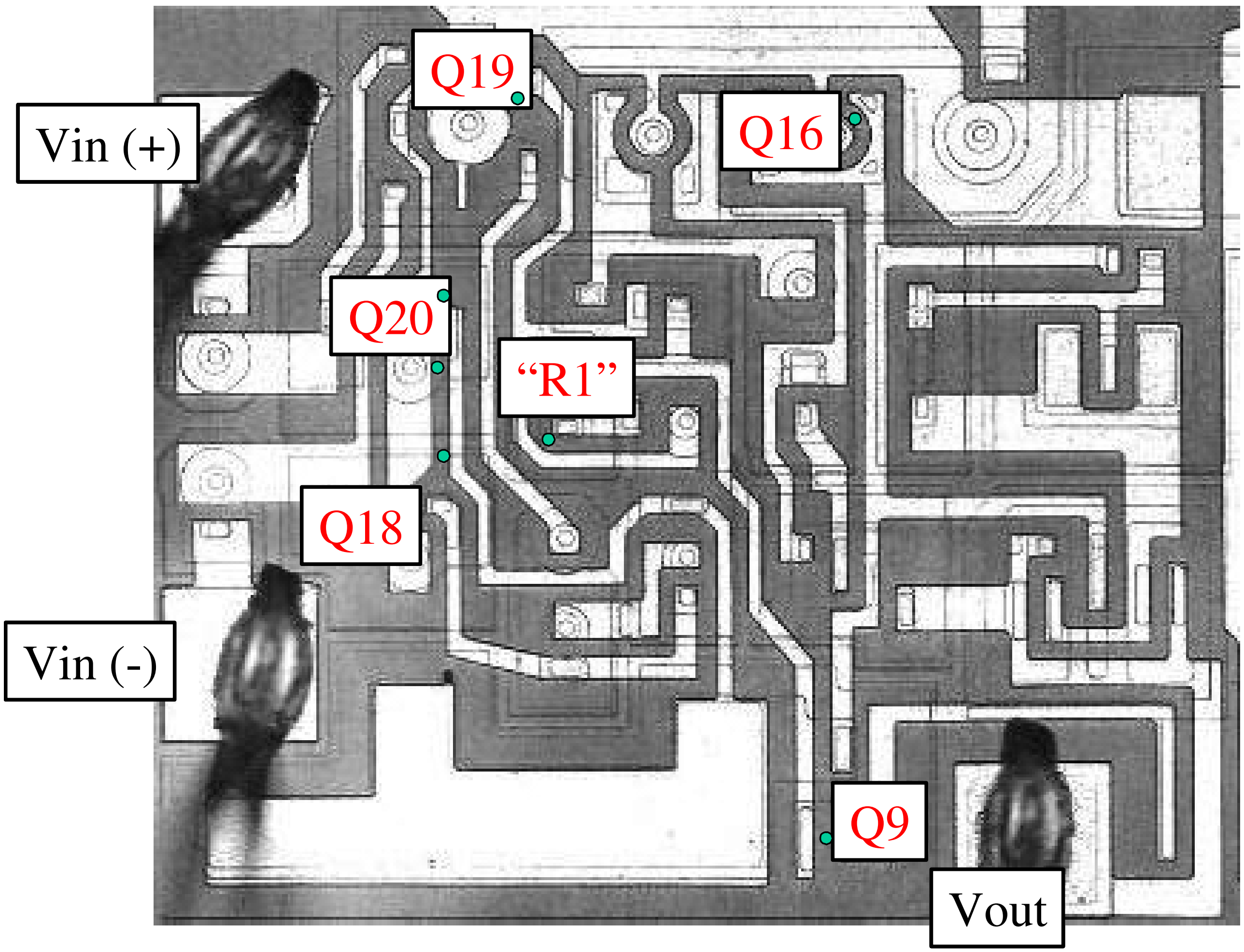


Schematic Flip Chip Cross Section



Backside "Through-Wafer" TPA Illumination

LM124 Operational Amplifier



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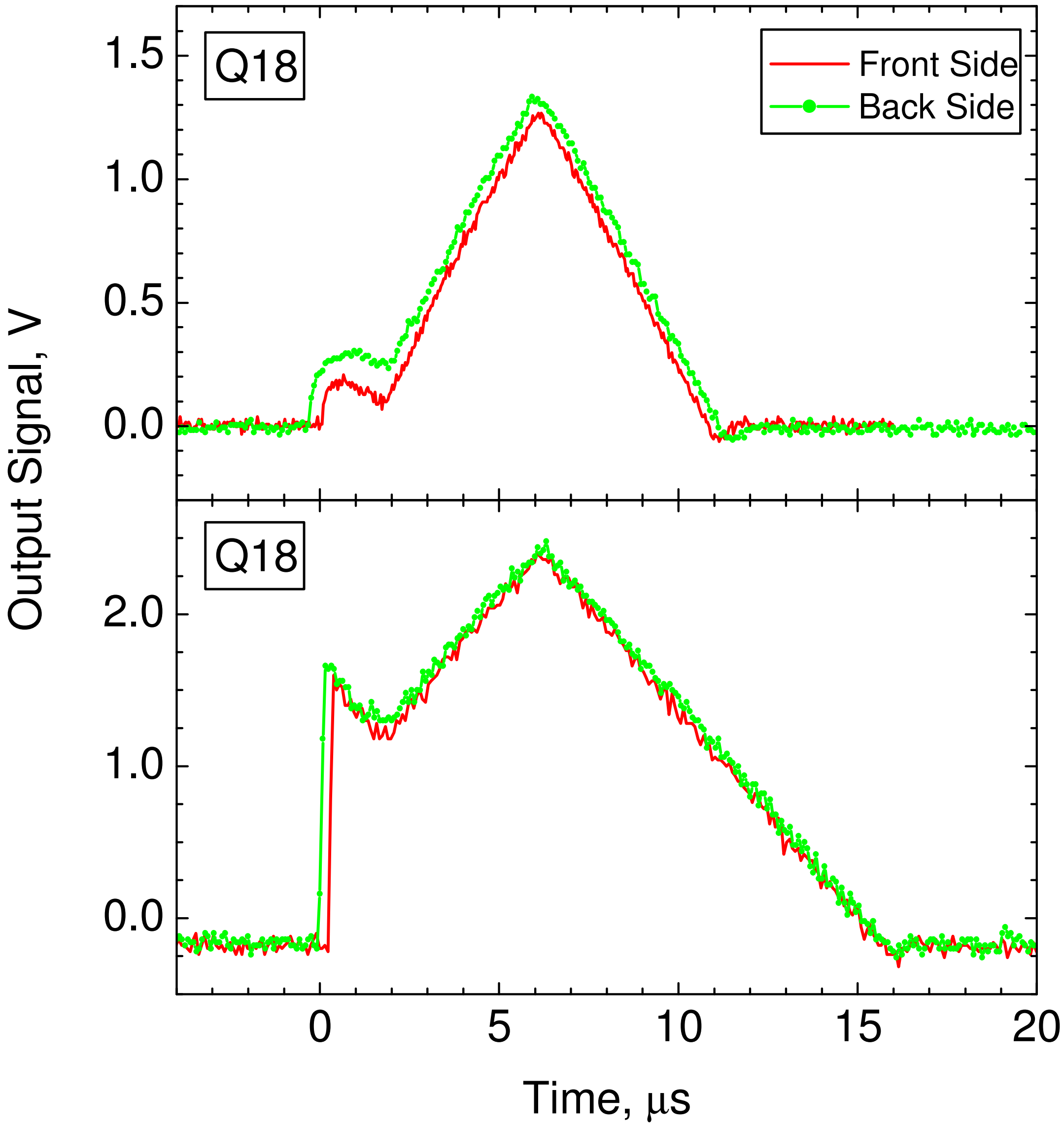
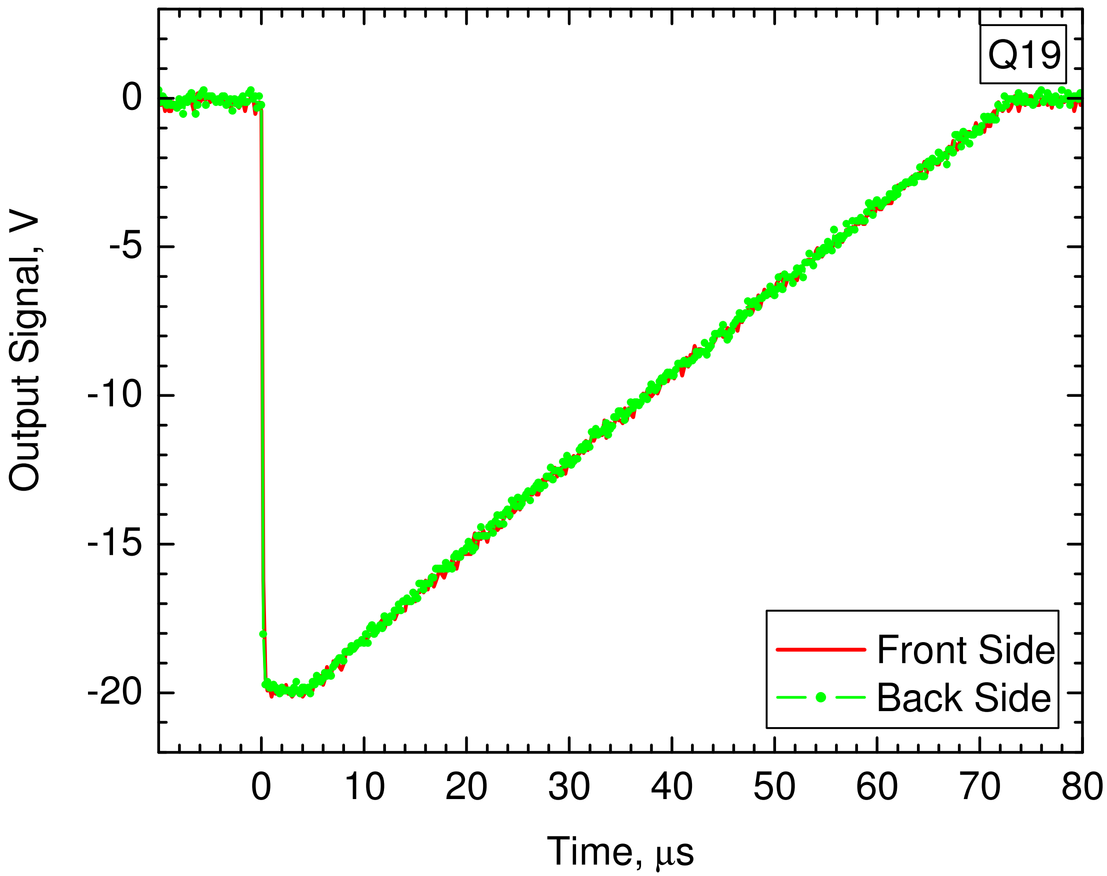
Backside “Through-Wafer” TPA Illumination
LM124 Operational Amplifier



Backside "Through-Wafer" TPA Illumination

LM124 Operational Amplifier



Backside "Through-Wafer" TPA Illumination
SEU in Flip Chip SRAM

- Issues
  - through-wafer imaging
    - InGaAs FPA
  - highly-doped substrate
    - linear loss from free-carrier absorption
    - attenuates IR beam
    - attenuates illumination light
    - wafer *thinned* to minimize absorption
- *Results*: SEUs successfully injected in SRAM by TPA at well characterized locations

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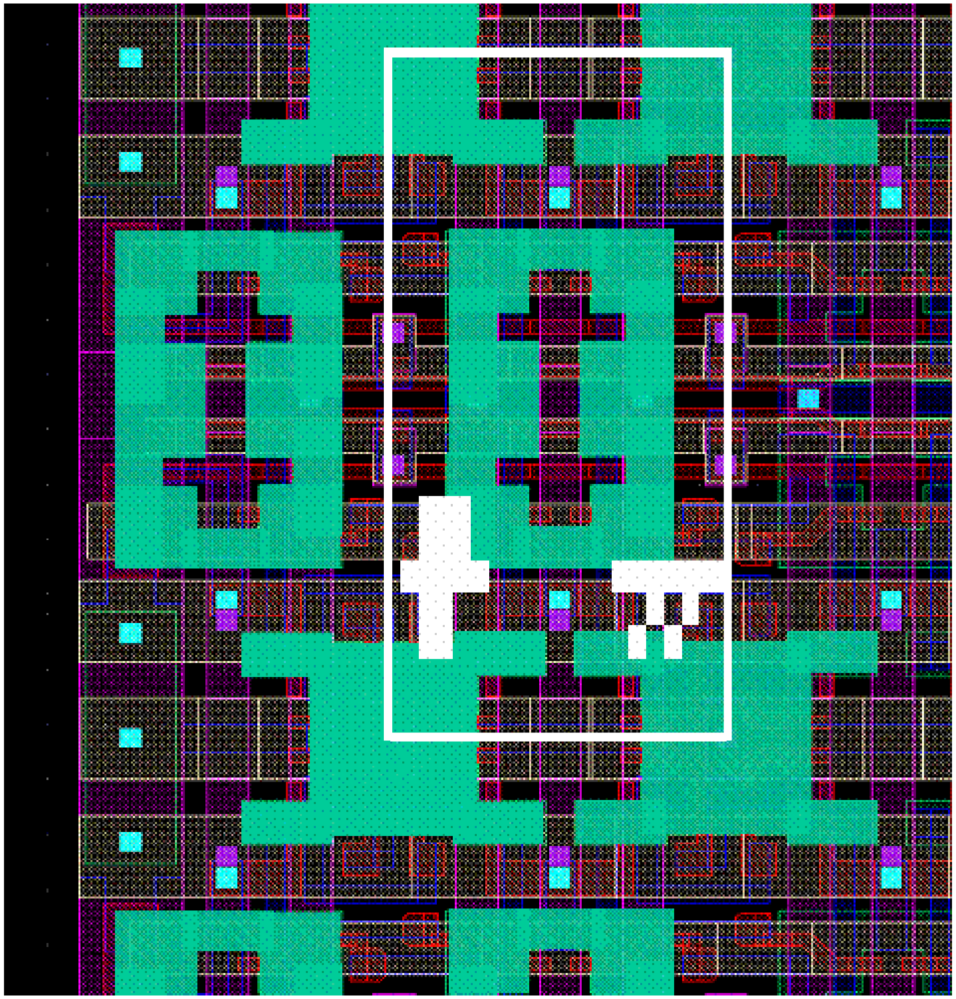
Backside "Through-Wafer" TPA Illumination
SEU in Flip Chip SRAM Test Structure

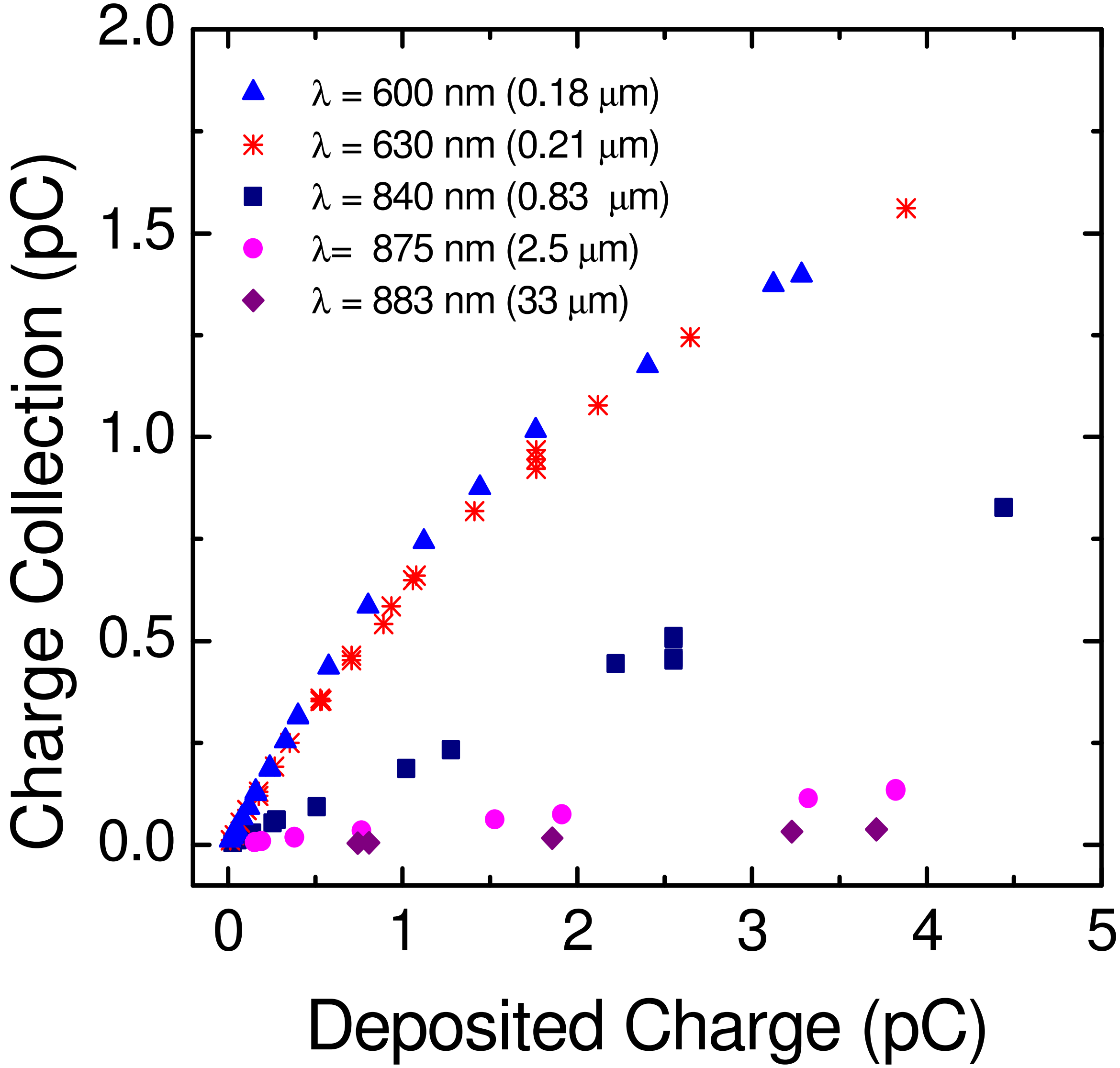
2D SEU Map



Conclusions

- The two-photon absorption method represents a novel approach to SEE evaluation with unique capabilities not exhibited by other techniques
- The present work demonstrates the utility of the nonlinear-optical TPA approach as a method for injecting carriers into the active regions of devices using both top-side and through-wafer, backside irradiation
- The use of backside irradiation eliminates interference from the metallization layers, and circumvents many of the issues associated with testing flip-chip-mounted parts
- The first experimental demonstrations of the through-wafer, backside, two-photon-induced single-event effects technique are presented

Time-Integrated Charge Collection in a GaAs HBT Device



$V_{ce} = 1.1$ V
$V_{be} = 1.0$ V