Electric field measurement in LGAD and update in RASER

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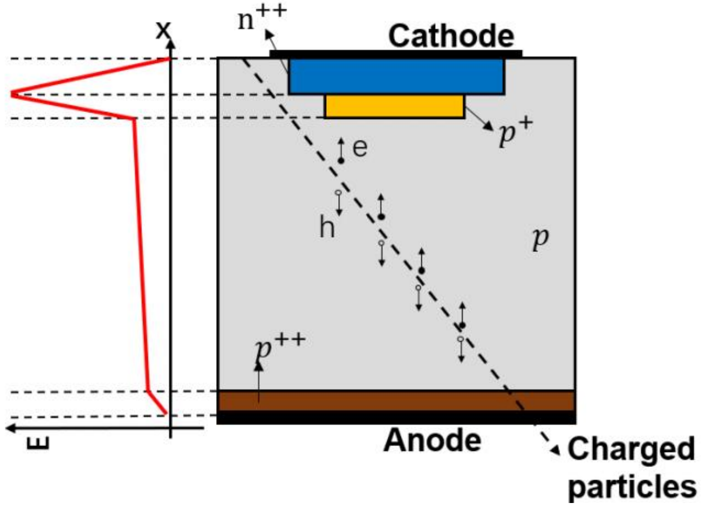
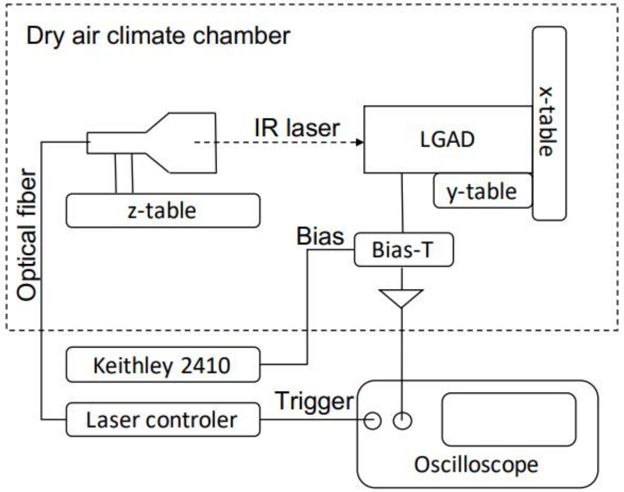
Outline

- Electric field measurement in Si LGAD
- Irradiation simulation for Si strip and SiC planar detector
- Summary and Plan

Si LGAD and experimental set-up



Sketch of Si LGAD



Layout of edge-TCT set-up

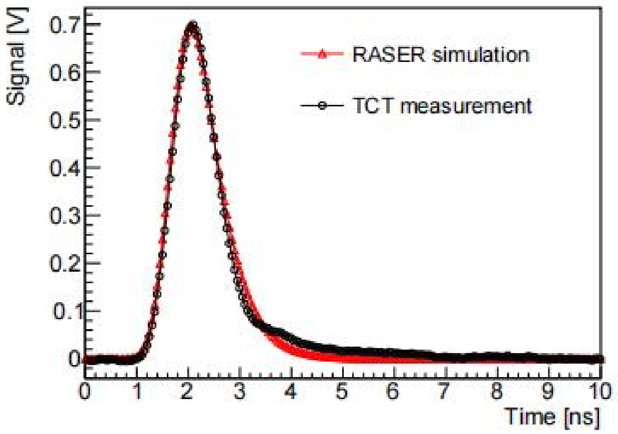
- LGAD Tpye3.2 fabricated by HPK
- Key parameters in RASER: 1.3×1.3 mm² size, 50 μm thick
  p bulk doping 1.0×10^{12} cm^{-3}
  p+ doping 2.0×10^{16} cm^{-16}

RASER simulation

Based on 41st RD50 Edge-TCT simulation of LGADs

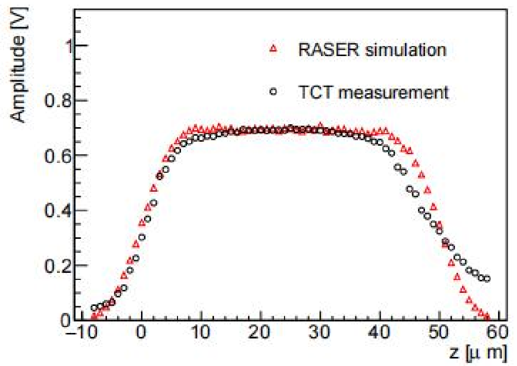
- Optimise multiplication

$$M = \frac{\exp\left[\int_0^{d_{gain}} (\alpha_{\rm n} - \alpha_{\rm p})\,{\rm d}x\right]}{1 - \int_0^{d_{gain}} \alpha_{\rm p} \exp\left[\int_0^{x} (\alpha_{\rm n} - \alpha_{\rm p})\,{\rm d}x\right] {\rm d}x}$$

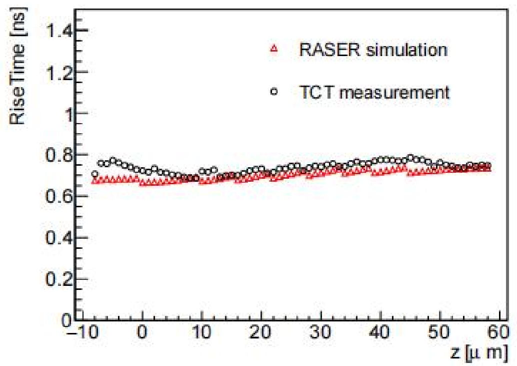


(b) Edge-TCT waveform of LGAD.

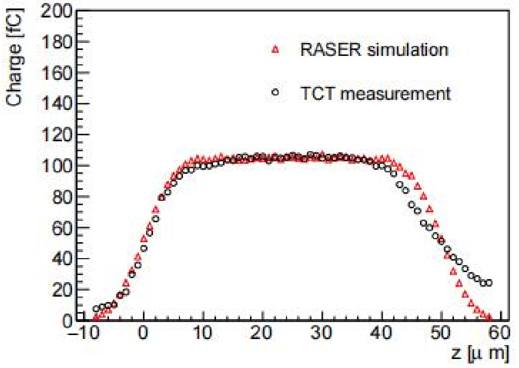
Effective signal!



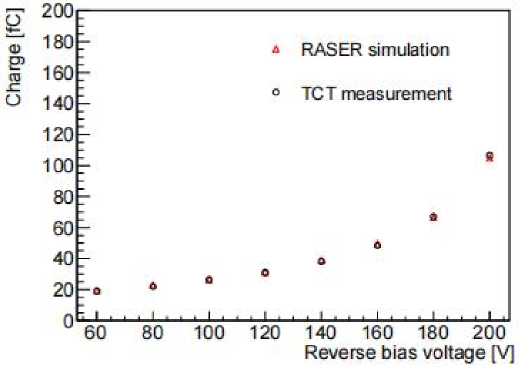
(a) Amplitude-z relation.



(b) Rise time-z relation.



(c) Charge collection-z relation.



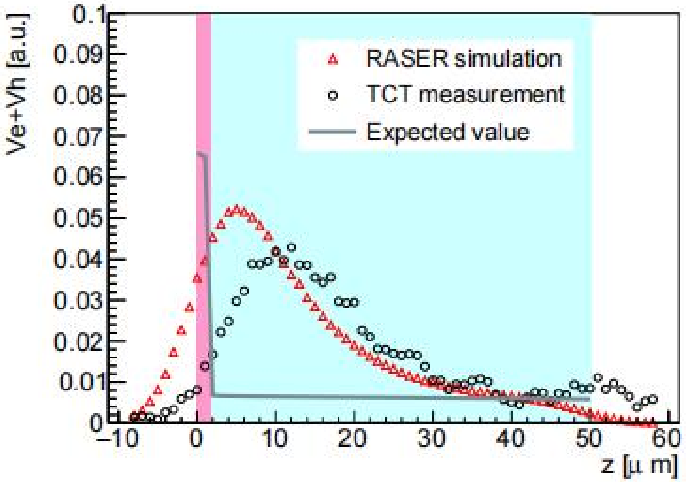
(d) Charge collection-Bias voltage relation.

Field measurement: velocity profile

- Main trend method
  for electric field measurement
- Use instant signal
  near the laser injection time
- Original and gain signal mixed...

$$v_e(t) + v_h(t) = \mu_e[E(z_e)]E(z_e) + \mu_h[E(z_h)]E(z_h)$$
$$\approx \{\mu_e[E(z_0)] + \mu_h[E(z_0)]\}E(z_0).$$

$$i_q(z; t \to t_0) = \sum_q q\vec{v}_q \nabla U_w \approx \frac{ne}{d}(\mu_e + \mu_h)E(z)$$



(a) Velocity profile of LGAD.

Not as expected
with certain laser

Field measurement: diffusion profile

https://arxiv.org/abs/2302.10020

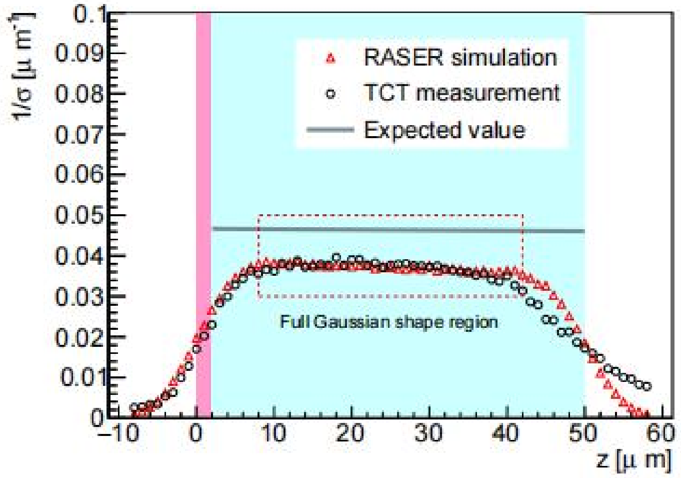
- Use the expand of carrier cluster
- Utilize information of field intensity along carrier path
- Novally designed for LGAD!

$$N = N_0 * \frac{1}{\sqrt{2\pi\sigma_D^2}} \exp[-\frac{(z-\mu E t)^2}{2\sigma_D^2}]$$

$$N(z,t) = \frac{1}{\sqrt{2\pi\tau^2}} \exp(-\frac{t^2}{2\tau^2}) \; * \; \frac{\sum N}{\sqrt{2\pi\sigma^2}} \exp[-\frac{(z-z_0-\mu E t)^2}{2\sigma^2}],$$

$$\frac{\mathrm{d}\sigma^2}{\mathrm{d}t} = \frac{k_B T}{q}\mu + 2\sigma^2 \frac{\mathrm{d}(\mu E)}{\mathrm{d}z}.$$

$$\sigma^2 = \frac{(\mu_e E_e)^2}{(\mu_i E_i)^2}\left[\int_{z_i}^{z_e} \frac{k_B T}{q} \frac{\mathrm{d}z}{E} \frac{(\mu_i E_i)^2}{(\mu E)^2} + \sigma_0^2\right], \quad \left.\frac{\mathrm{d}i_q}{\mathrm{d}t}\right|_{max} = \frac{k_2 \sum N}{\sqrt{\tau^2 v_e^2 + \sigma^2}},$$

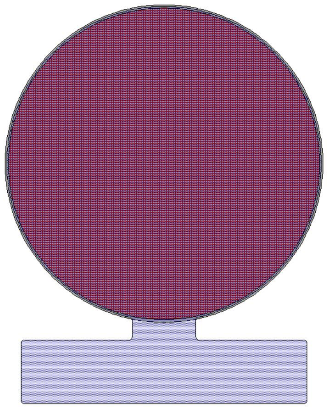


(b) Diffusion profile of LGAD. The dashed box represents a preferred range that excludes the effect of the non-Gaussian shape of the carrier cluster.

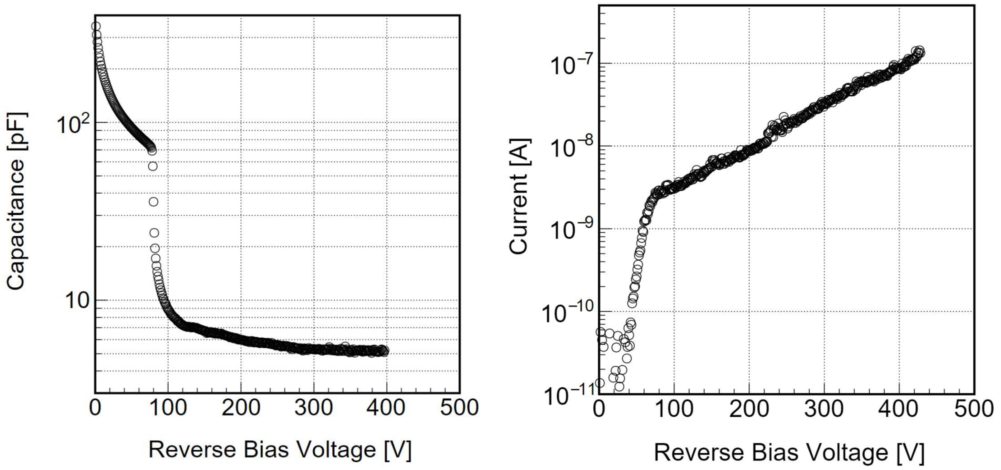
Same trend & close value

SICAR SiC+LGAD

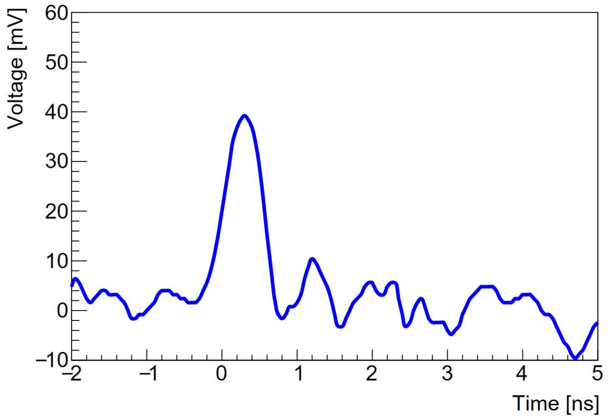
Details in **[Charge Collection of SICAR]**



Sketch of SICAR



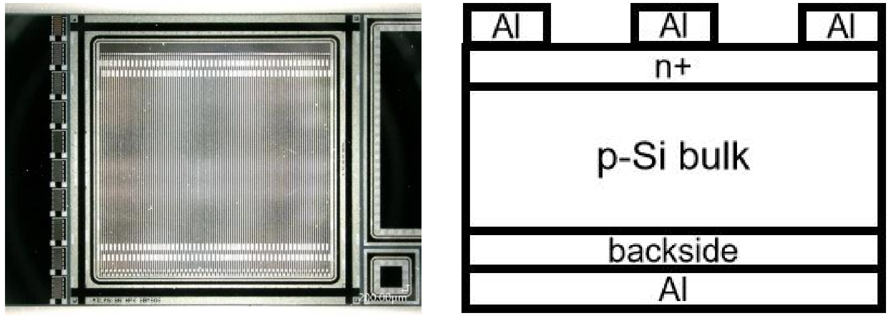
CV&IV curve of SICAR



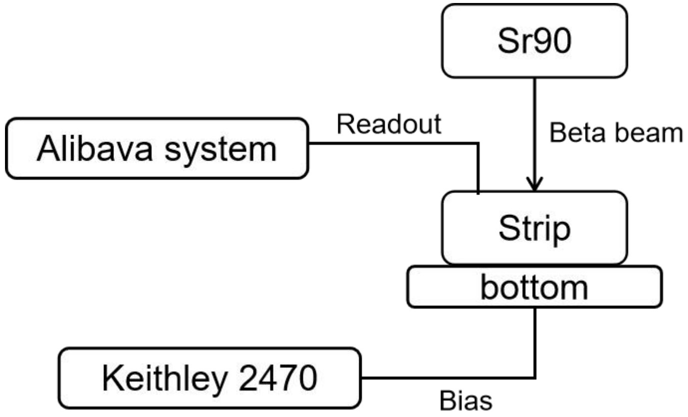
Waveform of beta test

- SICAR(SiC with gain layer) fabricated by RASER Team, using the facilities at Institute of Semiconductors, Chinese Academy of Sciences
- CV curve shows the depletion of gain layer, dark current ~10^{-7}A
- 20mV trigger for beta test(^{90}Sr), rise time ~0.5ns

Si strip detector and experimental set-up



Si strip detector



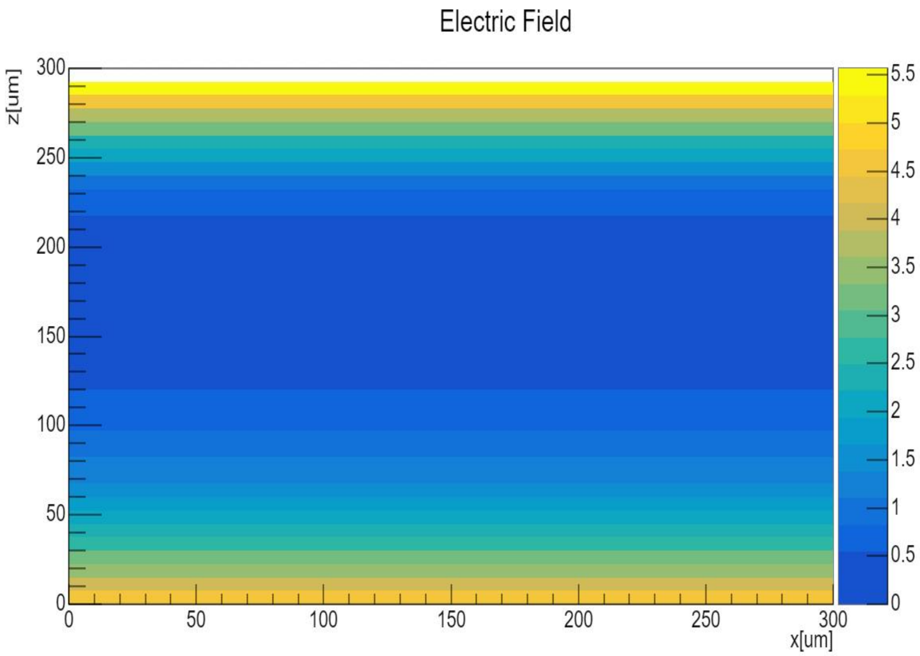
Layout of beta test set-up

- ITk mini sensor
- Alibava system classic for electrical readout

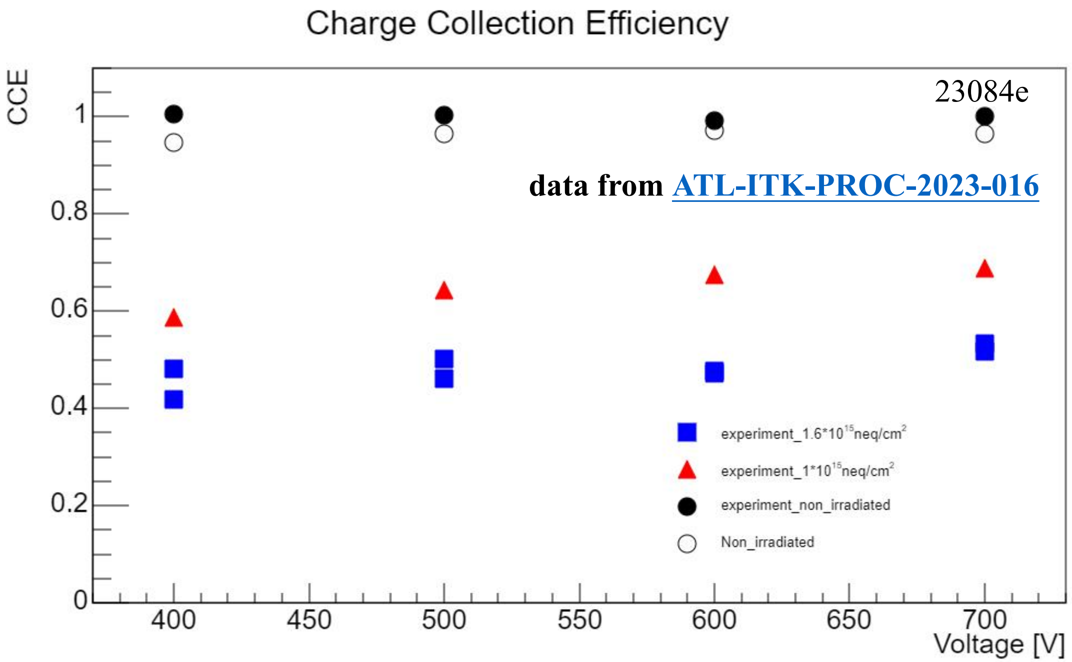
  → charge information

ITk mini sensor		
n+	$1.0*10^{19}cm^{-3}$	1 um
p	$3.2*10^{12}\ cm^{-3}$	300 um
backside	$1.0*10^{15}cm^{-3}$	5 um

Charge collection of Si strip



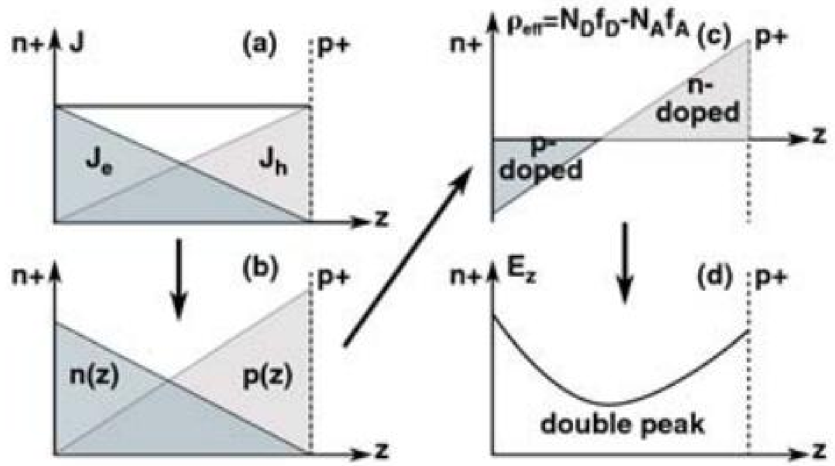
Electric field from RASER



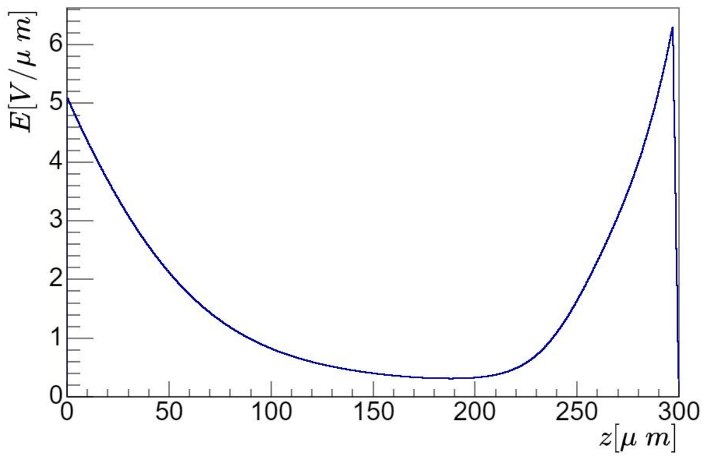
Charge colletion before/after irradiation at 20°C

- 2D field solved in RASER by DEVSIM
- Charge collection simulation of non-irradiated detector shows good agreement with experiment.
- Charge collection decrease to ~50% with irradiation of 1.6×10^{15} neq/cm^2

Irradiation in RASER



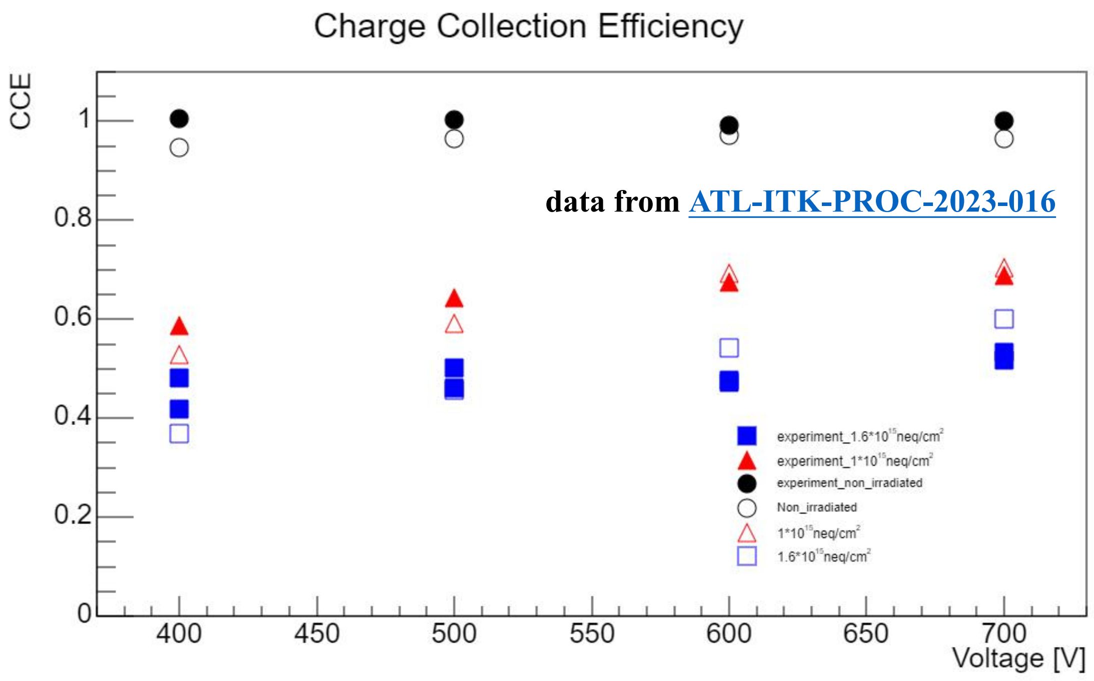
Double peak electric field in irradiated Si detectors



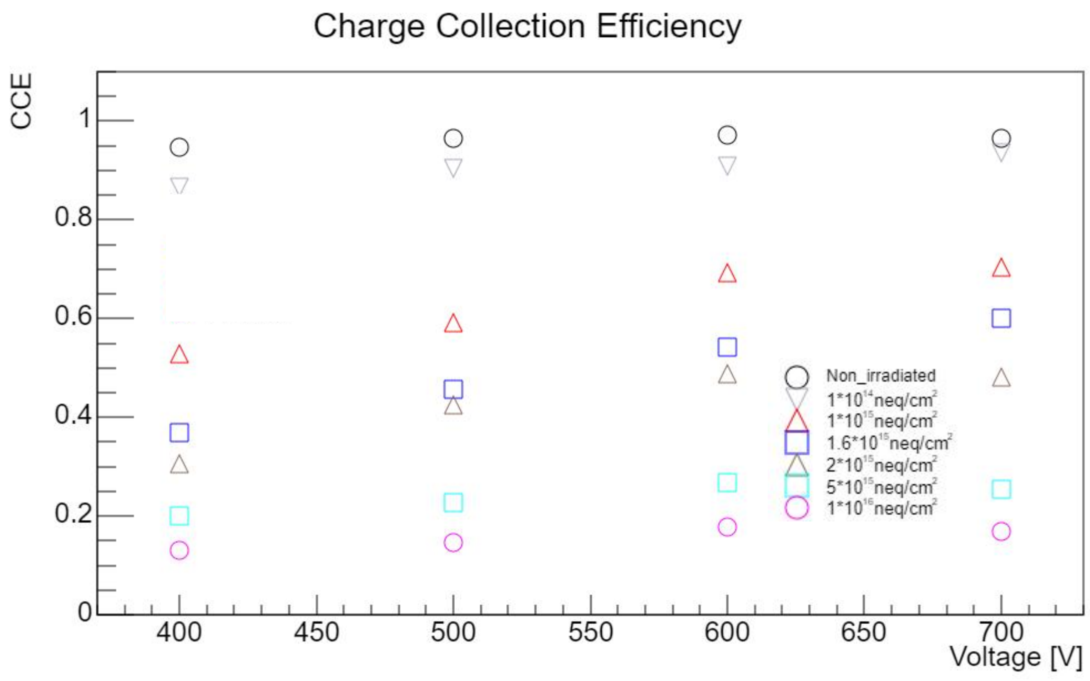
Electric field from RASER

- Free carriers generated from leakage current and trapped by deep level defects, changing the electric field distribution
- Total effective space charge negative at n+ contact and positive at p+ contact, causing double peak electric field
- Carriers trapped by deep level defects, signal depressed

Irradiation in RASER



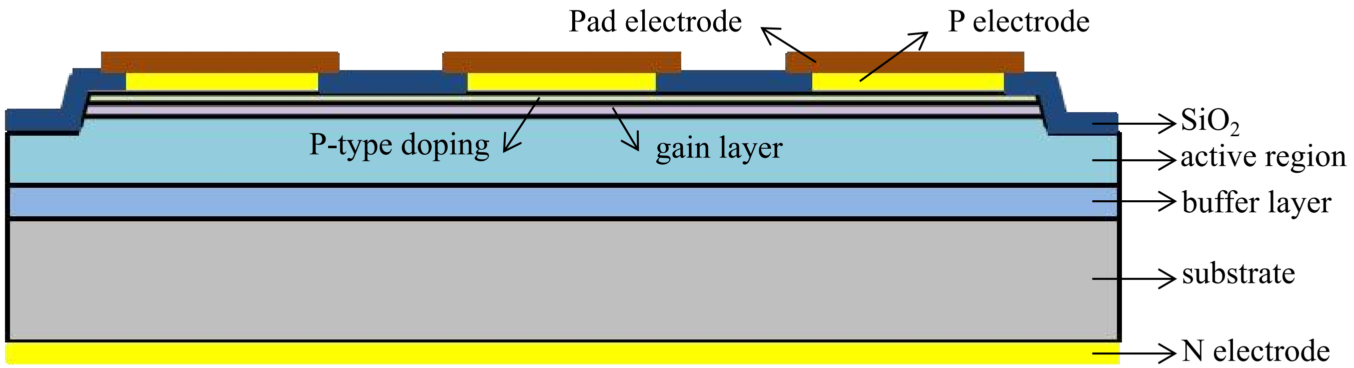
Simulated charge colletion before/after irradiation at -20℃



Charge collection prediction for other irradiation dose

- Considering double peak and trapping time, charge collection simulation is closed to data at irradiation dose of 1.0×10^{15} neq/cm^2 and 1.6×10^{15} neq/cm^2

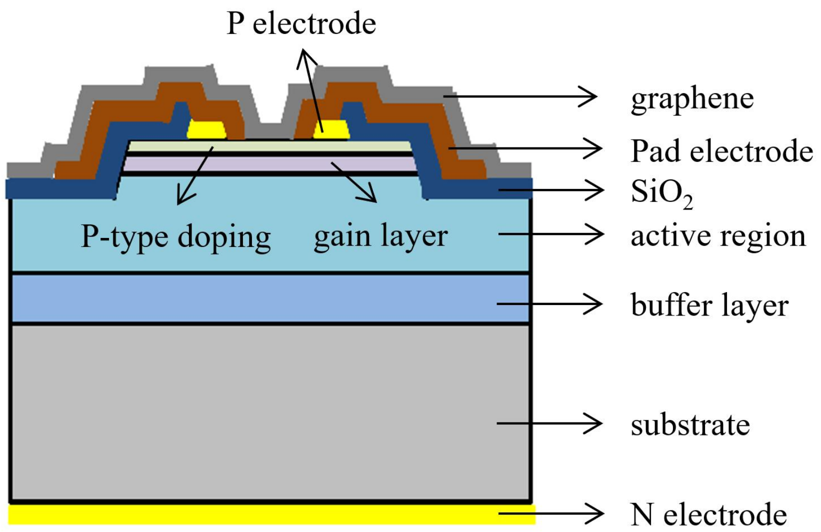
SICAR strip



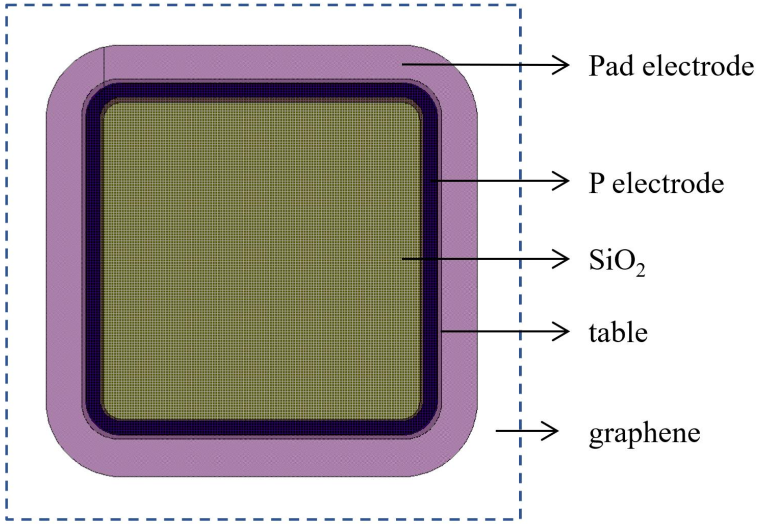
SICAR strip stucture

- SICAR strip is possible based on previous Si strip study
- Epitaxy wafer same as SICAR, electrodes will be fabricated soon. SiC strip(without gain layer) will also be fabricated.
- 1D spatial information

Circular SICAR with graphene



Cross section of circular SICAR with graphene

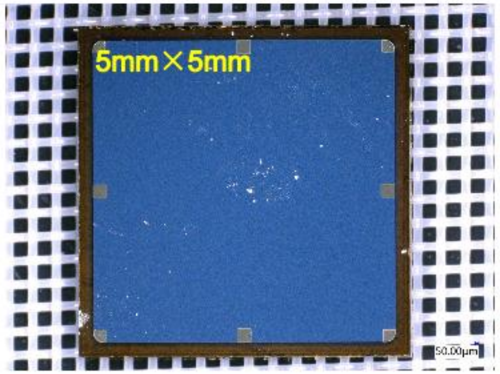


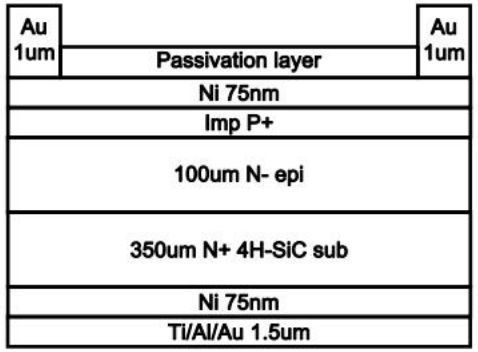
Top view of circular SICAR with graphene

- SICAR with circular electrodes avoid the metal effect, graphene will help carriers movement.
- Circular SICAR without graphene fabricated, behaves bad on IV&CV.
- Circular SiC will be produced for comparison.

SiC planar detector

Slides from 42nd RD50 [Irradiation effect of SiC]

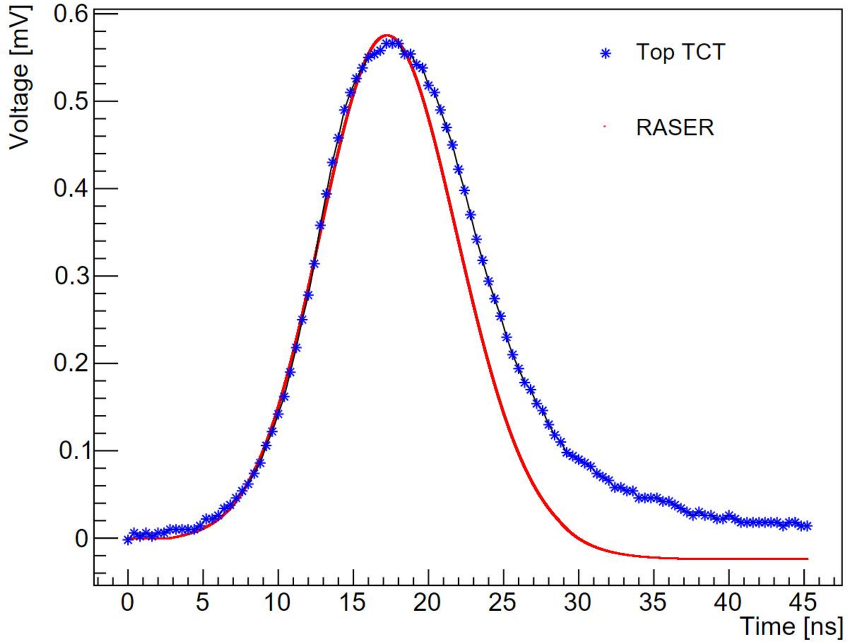




SiC planar detector

$$I_{e,h}(t) = A e_0 N_{e,h} \exp\left(-\frac{t}{\tau_{\mathrm{eff},e,h}}\right) \vec{v}_{e,h}(t) \cdot \vec{E}_w$$

contribution from trapping time

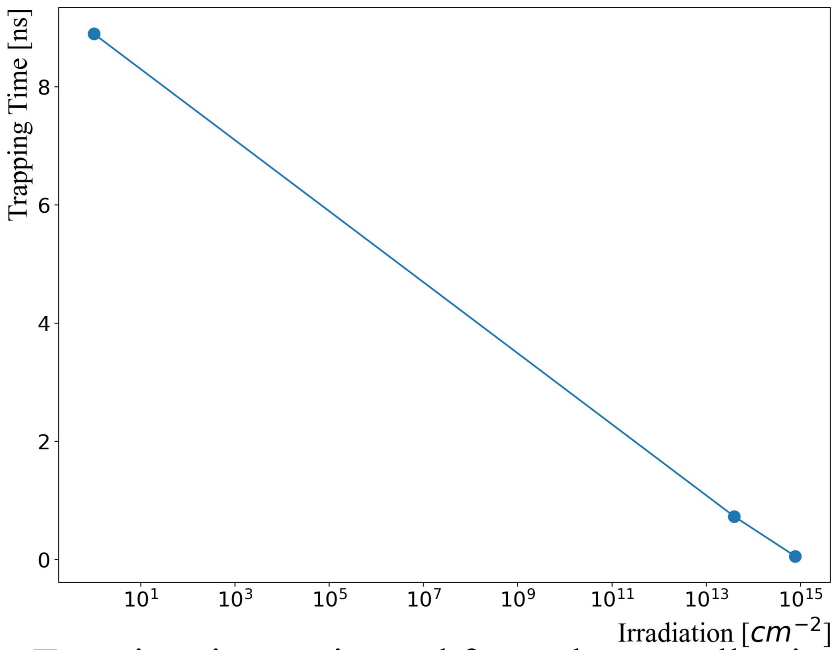


Waveform and RASER simulation

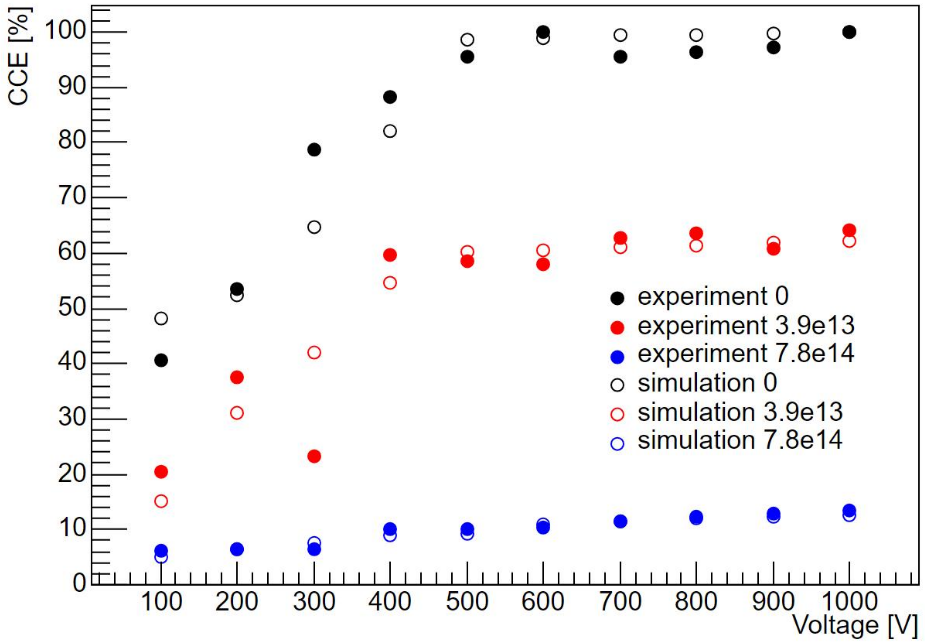
- SiC planar detector fabricated from Nanjing University.
- Considering contribution from trapping time, waveform from RASER simulation is close to data.

SiC irradiation

Slides from 42nd RD50 [Irradiation effect of SiC]



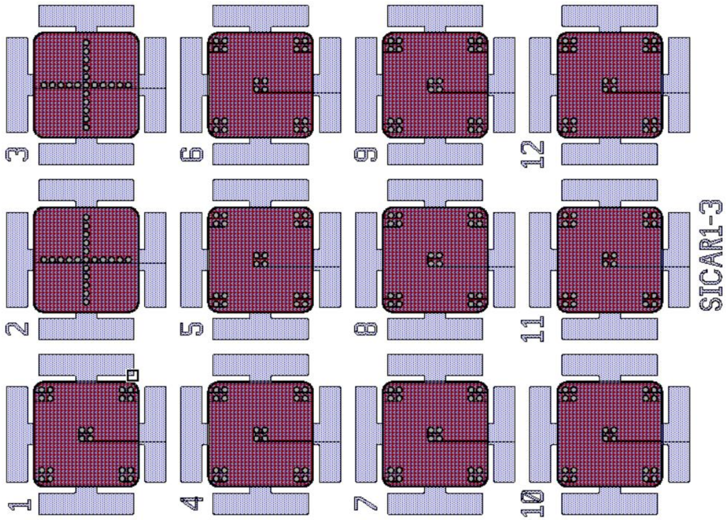
Trapping time estimated from charge collection



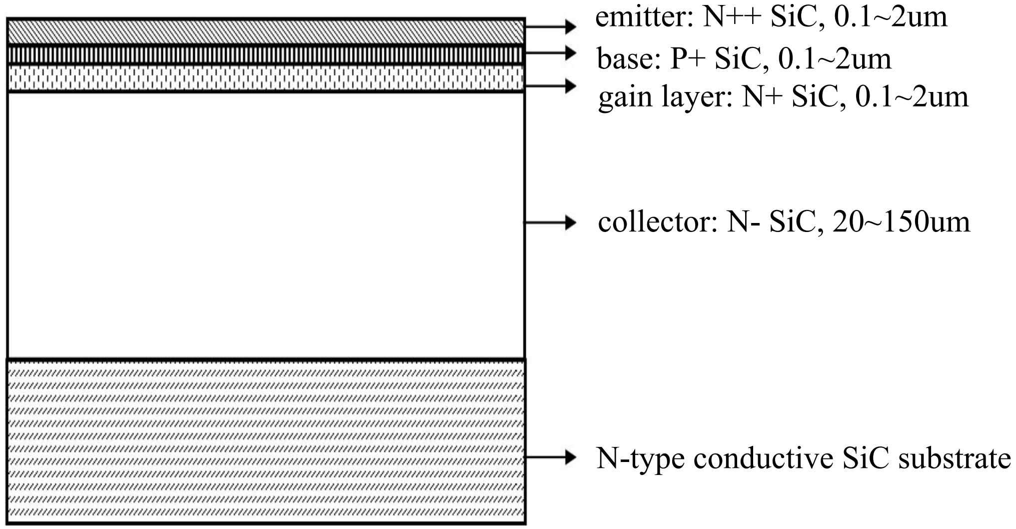
Charge collection before/after irradiation

- Trapping time and log(irradiation dose) show good linear distribution.
- Charge collection curve simulated in RASER is consistent with experiment. 100% is set at 1000V of non-irradiated case.

SICAR pixel and BJT



Layout of SICAR array



Sketch of SICAR BJT integrated sensor

- Based on the SICAR array we have now, pixel study is possible.
- 2D spatial information
- AC-coupled SICAR pixel will be designed, in order to get better spatial resolution.

- Pre-amp and main amplifier induce noise
- Integrating BJT with SICAR, noise will be depressed and timing resolution will be improved.

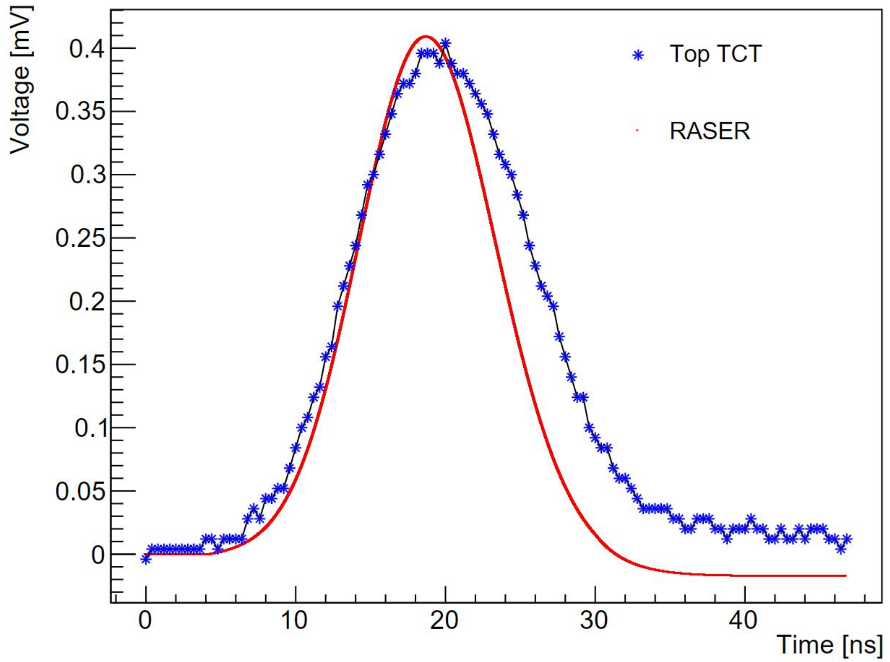
Summary and Plan

- Propose diffusion profile method for electric field in Si LGAD
- Simulate Si strip and SiC planar detector and irradiation effect

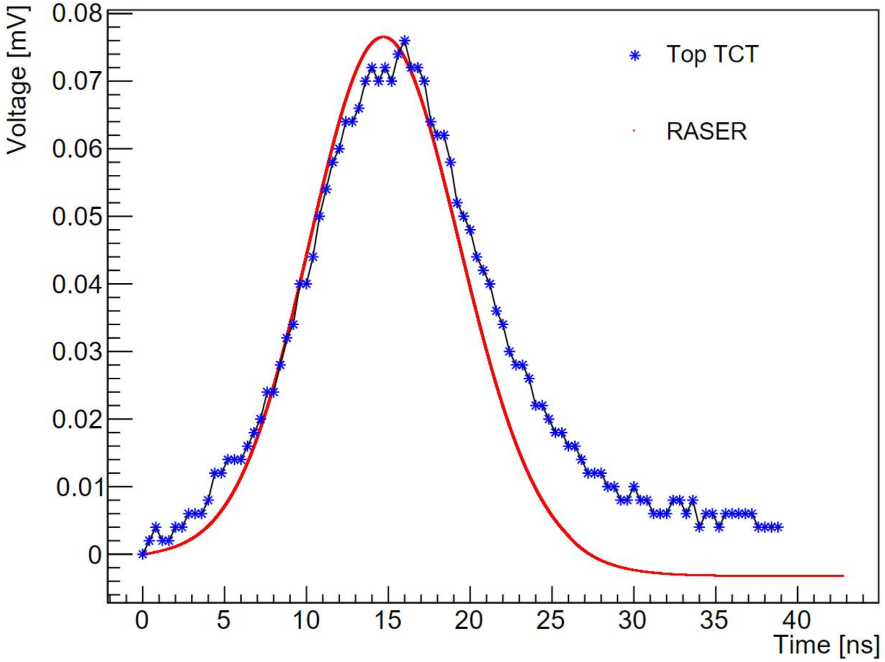
- [ ] Electric field and irradiation of SICAR
- [ ] Development in SICAR strip and pixel
- [ ] More structure: circular SICAR with graphene, SICAR BJT...

Thanks for your attention.

Back-up



Wavefrom after 3.9e13 irradiation



Wavefrom after 7.8e14 irradiation

Back-up

Strip irradiation

- The proportion of accumulated electrons in defects：
  - $f_t = \frac{n_t}{N_t - n_t} = \frac{c_n n + e_p}{c_n n + e_n + c_p p + e_p}$
- The generation rate of accumulated charge carriers in deep level defects：
  - $G_n = N_t f_t e_n \quad G_p = N_t(1 - f_t)e_p$
- Carrier concentration in deep level defects：
  - $n(x) = p(x) = \frac{J}{e<v_{th}>}$
- Effective space charge concentration：
  - $N_{eff} = N_{sh} + (1 - f_t)N_{DD} - f_t N_{DA}$
- Capture time of electrons and holes：
  - $\frac{1}{\tau_{eff,e}} = \sum_{defects} c_n(1 - f_t)N_t$
  - $\frac{1}{\tau_{eff,h}} = \sum_{defects} c_p f_t N_t$

Type	Energ[eV]	$g_{int}[cm^{-1}]$	$\sigma_e[cm^2]$	$\sigma_h[cm^2]$
Acceptor	$E_c - 0.42$	0.48	1e-15	1e-14
Acceptor	$E_c - 0.46$	0.18	7e-15	7e-14
Donor	$E_v + 0.36$	0.05	3.23e-13	3.23e-14
Donor	$E_v - 0.48$	0.64	4.1e-15	1.9e-16