Response of solar cells to heavy ions at energies close to 10 AMeV at GANIL

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SOLAR CELL

Silicon - Solar Cells (Earth Solar Panels)

Germanium - Solar Cells (Space Applications)

Michele Sguazzin  
GANIL Colloque Conference 2021  
September 28, 2021
SOLAR CELL for ions detection

- 1979 Siegert  
  First heavy ions detection at energies about 1 AMeV

CHARGE COLLECTION PROCESS IN SOLAR CELLS IS VERY DIFFERENT

Field-funneling effect

SOLAR CELL for ions detection

Main Advantages:

1) **Energy (1-2%) and time (few ns) resolution**
SOLAR CELL for ions detection

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2) Better radiation resistance
SOLAR CELL for ions detection

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1) Energy (1-2%) and time (few ns) resolution

2) Better radiation resistance

3) Flexible geometry, very robust

4) Extremely cost-efficient (5 €)
SOLAR CELL for ions detection

Solar Cells appear a very interesting alternative to Silicons detector for Heavy ions at energies between 1 and 10 AMeV.

But...

NECTAR Project:
Solar Cells as heavy ions detectors at energies $E > 1$ AMeV in UHV!

high capacitance ($4\cdot10^{\,nF/cm^2}$, 1000 times larger than Si detector), increasing with Solar Cells surface

NO TEST HAS BEEN EVER PERFORMED!!
**First irradiation experiment with Heavy ions above 1 AMeV!**

CIME cyclotron was used to accelerate beams of:
- $^{84}Kr$ at 7, 10 AMeV
- $^{129}Xe$ at 10,13 AMeV

**First results:**

1. Best performance: company Solar Made, 10x10 mm$^2$, $\sigma(E)/E=1.5\%$ (RMS) and 3.6 ns (FWHM).
2. Stable behavior during irradiation with 100 to few $10^3$ pps for a minute.

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New irradiation experiment (E809) :
March 2021
CIME cyclotron was used to accelerate beams of:

- \(^{84}Kr\) at 5, 10, 15 AMeV
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**E809 experiment (March 2021)**
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CIME cyclotron was used to accelerate beams of:
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HF signal

Solar Cell

C strippe

~100 pps

Charge-state selection using Dipole D11!
CIME cyclotron was used to accelerate beams of:
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E809 experiment (March 2021)
CIME cyclotron was used to accelerate beams of:
• $^{84}$Kr at 5, 10, 15 AMeV

MAIN IMPROVEMENTS

• Better intensity control
• Better alignment with respect to the incoming beam
1. Energy ($\sigma(E)/E$) and Time (FWHM) resolution

E809 experiment (March 2021) – Final RESULTS

$^{84}Kr$ beam

Si - 10x10 $mm^2$

Ge - 20x20 $mm^2$

Si Detector

Ge - 20x20 $mm^2$
E809 experiment (March 2021) – Final RESULTS

1. Energy ($\sigma(E)/E$) and Time (FWHM) resolution

$^{84}Kr$ beam

- Si - 10x10 $mm^2$
- Ge - 20x20 $mm^2$
- Si Detector

$\sim 1.1\%$

$E$ is the energy in AMeV, and $\sigma(E)$ is the resolution in $E$. The plot shows the energy resolution for different detector sizes.
**E809 experiment (March 2021) – Final RESULTS**

1. **Energy ($\sigma(E)/E$) and Time (FWHM) resolution**

   - **Si - 10x10 mm$^2$**
   - **Ge - 20x20 mm$^2$**
   - **Si Detector**

   **84$^\text{Kr}$ beam**

   **Energy Resolution**

   **Time Resolution**

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E809 experiment (March 2021) – Final RESULTS

1. Energy ($\sigma(E)/E$) and Time (FWHM) resolution

Energy Resolution

- Si - 10x10 $mm^2$
- Ge - 20x20 $mm^2$
- Si Detector

$^{84}Kr$ beam

Very important results for NECTAR project (large detection arrays)!
2. Characterization of solar cells linearity

![Graph showing the characterization of solar cells linearity. The graph plots ADC (channel) versus energy (AMeV). Two different detector types are compared: Si - 10x10 mm$^2$ and Si Detector. The graph highlights the linearity of the detectors across the energy range.]
2. Characterization of solar cells linearity

E809 experiment (March 2021) – Final RESULTS

Unexpected but very interesting!

Where does it come from?

Si Detector

Si - 10x10 mm²
PRELIMINARY RESULTS

3. Simulation

1) $^{84}$Kr 5 AMeV
2) $^{84}$Kr 10 AMeV
3) $^{84}$Kr 15 AMeV

ATLAS Silvaco code

CHARGE COLLECTION PROCESS IN SOLAR CELLS
E809 experiment (March 2021) - RESULTS

PRELIMINARY RESULTS

3. Simulation

1) $^{84}$Kr 5 AMeV
2) $^{84}$Kr 10 AMeV
3) $^{84}$Kr 15 AMeV

SOLAR CELLS SIGNAL IS REPRODUCED but there are still many free parameters

COLLECTION PROCESS IS RESPONSIBLE OF SOLAR CELLS NO-LINEARITY

Results:

- SOLAR CELLS SIGNAL IS REPRODUCED but there are still many free parameters.
- COLLECTION PROCESS IS RESPONSIBLE OF SOLAR CELLS NO-LINEARITY.

Graph:

- Red circles represent Si -10x10 mm$^2$
- Black circles represent Simulation

Graph shows the relationship between Amplitude (mV) and Energy (AMeV) for different simulations and experimental data points.
E809 experiment (March 2021) – Final RESULTS

4 - Irradiation

- Silicon Detector

- 10x10 mm² - Silicon Solar Cell

\[ \sim 12 \cdot 10^6 \frac{p}{cm^2} \]

\[ \sim 32 \cdot 10^6 \frac{p}{cm^2} \]

84 \( Kr \) beam at 15 AMeV

before irradiation

\[ \sim 12 \cdot 10^6 p/cm^2 \]

\[ \sim 32 \cdot 10^6 p/cm^2 \]
Solar Cells remain an interesting alternative to Silicon Detectors still for heavy ions beams at energies > 1 AMeV!!

Main Results:

1) **20x20 Ge substrate (Azurspace)** the best performances in Energy ($\sigma(E)/E = 1.1\%$ RMS) and Time Resolution (2.6 ns)

2) The Response of Solar Cells have been characterized up to 15 AMeV for $^{84}\text{Kr}$:
   - **Simulation are able to reproduce Solar Cells signal**

3) **Long Irradiation Test**: Better behaviour of Solar Cells respect to Silicon Detector (for time response)
   - **VERY IMPORTANT FOR USE IN UHV!**

SOLAR CELLS ARE WELL SUITED FOR NECTAR project but also for experiments with heavy ions

FUTURE PROSPECTIVES

- Xe & Kr beams
- U beam
- Confirm experimentally our predictions
- Digitize Solar Cells signal
- Preamplifier system: Final optimization stage
  - explore Solar Cells possibilities as beam like residues detectors
Thank you for your work
Thank you for your attention ...

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Backup Slides
E809 experiment (March 2021) - RESULTS

PRELIMINARY RESULTS

SOLAR CELLS Interaction

CURRENT (A)

TRANSIENT TIME (s)

84-Kr (5 AMeV)

84-Kr (15 AMeV)

POTENTIAL DISTORTION

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E809 experiment (March 2021) - RESULTS

PRELIMINARY RESULTS

SOLAR CELLS Interaction

84-Kr (5 AMeV)

84-Kr (15 AMeV)

200 µm

CURRENT (A)

TRANSIENT TIME (s)

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3. Simulation

- 1) 84-Kr 3 AMeV
- 2) 84-Kr 5 AMeV
- 3) 84-Kr 7 AMeV
- 4) 84-Kr 10 AMeV
- 5) 84-Kr 15 AMeV

ATLAS Silvaco code

PRELIMINARY RESULTS
4 – Irradiation

- Silicon Detector
  - Before irradiation: \( \sim 7.885 \times 10^6 \text{ p/cm}^2 \)
  - After irradiation: \( \sim 32 \times 10^6 \text{ p/cm}^2 \)

- 10x10 mm\(^2\) - Silicon Solar Cell

\[ \text{84} \  \text{Kr beam at 15 AMeV} \]

\[ \sim 7.885 \times 10^6 \text{ p/cm}^2 \quad \text{before irradiation} \]

\[ \sim 32 \times 10^6 \text{ p/cm}^2 \]
Solar Cells: Ge 20x20 mm² $\rightarrow$ rate 5 KHz

Amplitude Spectra as function of real time

- Fast Amplitude decrease

~5h40 of irradiation
Amplitude & Time Spectra before and after the irradiation

Solar Cells: Ge 20x20 mm² ----> rate 5 KHz

Measurements realized at low rate ~ 50 Hz
Solar Cells: Ge 20x20 mm$^2$ ----> rate 5 KHz

Time constant, no spread in the distribution

Time Spectra as function of real time

Entries: 4.1428668e+07
Mean x: 1.036e+04
Mean y: 2714
Std Dev x: 5979
Std Dev y: 105.3

Time (s) ~5h40 of irradiation
Cells 10x10 Si Amplitude

Energy (AMeV)

Amplitude (mV)
Solar Cells

20x20 mm²
Solar Cells

10x10 mm²
Solar Cells

2 columns coupled

definition zone (1 mm)

Inner hole
SOLAR CELL

- One or more p-n junction, different composition and substrate types

- **Low resistivity silicon of high impurity concentration** (0.1-100 Ω · cm) which has a significant impact on the cell properties:
  - a narrow depletion region (below 1 μm)
  - a huge capacitance C (tens of nF/cm)

Worst device for the detection of light charged particles............