Radiation hardness of cadmium telluride solar cells in proton therapy beam mode

Shinhaeng Cho[1], Sang Hee Ahn[2], Ju Young Song[1]
1Chonnam National University Hospital, Department of Radiation Oncology, Jeollanam-do, South Korea
2National Cancer Center, Proton Therapy Center, Goyang, South Korea

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INTRODUCTION

We evaluated the durability of cadmium telluride (CdTe) solar cells upon proton beam irradiation as well as the possibility of achieving a dosimeter usable in proton beam therapy by applying 100 MeV of pencil beam scanning (PBS) irradiation. Specifically, a 100 MeV proton PBS beam was applied at irradiation doses of 0, 10^{12}, 10^{13}, 10^{14}, and 10^{15} cm^{-2}. In particular, the conversion efficiency, which is the main factor, was approximately 70% of that of the reference cell even at a high fluence of 1×10^{14} cm^{-2}. In addition, we observed the projected range of the hydrogen atoms based on the PBS beam energy using the Tool for Particle Simulation software and assessed the amount of fluence accumulated in a CdTe cell.

PROTON BEAM IRRADIATION

Fig 1 (a) shows the universal nozzle (UN) of a proton therapy system (230 MeV, IBA Proton Therapy System-Proteus 235, Belgium) at the National Cancer Center (NCC) of Korea. For this study, a 100 MeV proton PBS beam was irradiated at doses of 0, 10^{12}, 10^{13}, 10^{14}, and 10^{15} cm^{-2}. The CdTe devices, which were mounted on a homemade phantom composed of polymethyl methacrylate, were placed on PPS of a proton system in the direction of the glass substrate, which was also the direction of the PBS beam.

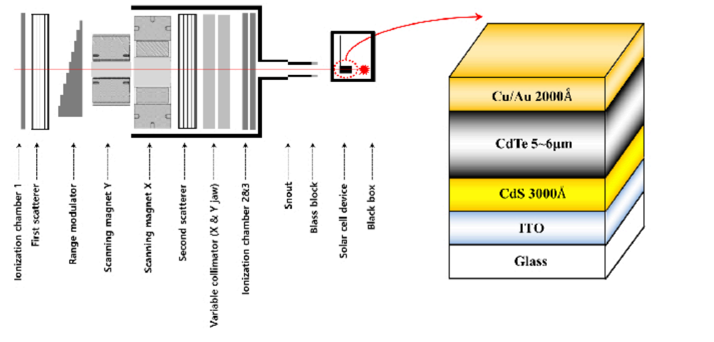
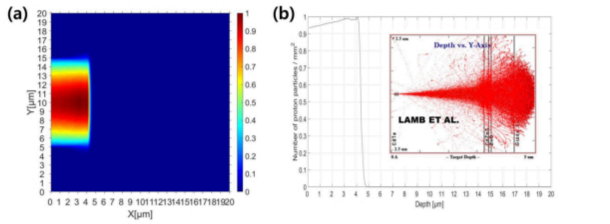


Fig. 1 Schematic diagram for (a) IBA proton Universal Nozzle and (b) CdTe solar cell

TOOL FOR PARTICLE SIMULATION

Fig 2. TOPAS simulation results. (a) Dose distribution and (b) fluence curves of hydrogen atoms in CdTe cells exposed to a 0.5 MeV PBS with a 1.5 cm diameter.



- Proton Energy 0.5 MeV
- Proton Beam Size : 10 um
- Proton Beam Shape : Circle

- 3250-nm CdTe (ICRU-346; 5.85 g.cm−3)
- 150-nm CdZnS (1:1:1 ratio; 4.46 g.cm−3)
- 100-nm ZnO (1:1 ratio; 5.61 g.cm−3)
- 800-nm AZO (2:50:50 ratio; 5.61 g.cm−3)
- 100-μm boro-silicate glass (2.60 g.cm−3)

RESULTS

Fig 3. Remaining factors, showing the degradation according to fluence. (a) V_{oc}, (b) J_{sc}, (c) *FF*, and (d) η in CdTe solar cells irradiated with a 100 MeV PBS beam

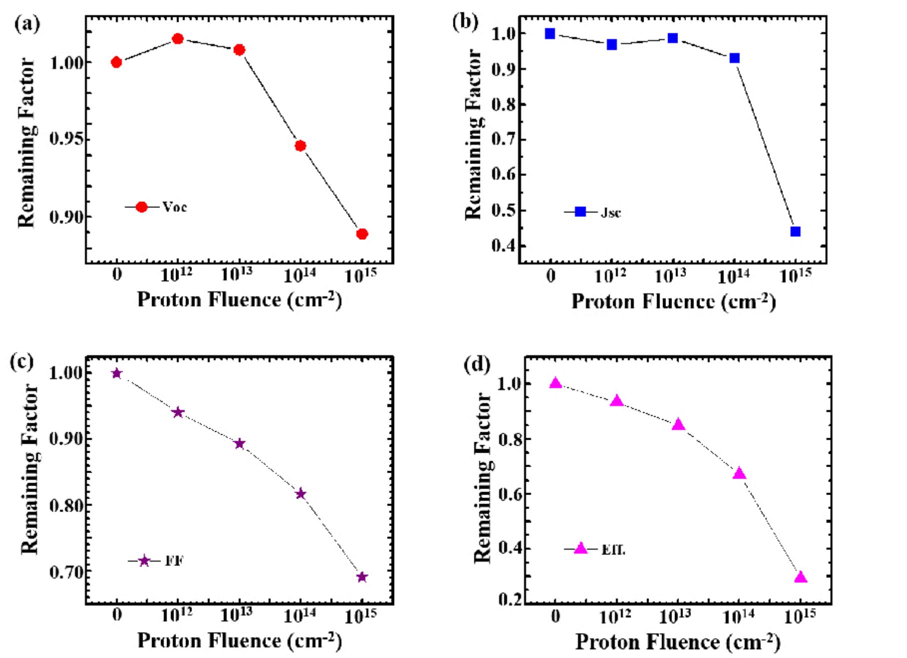
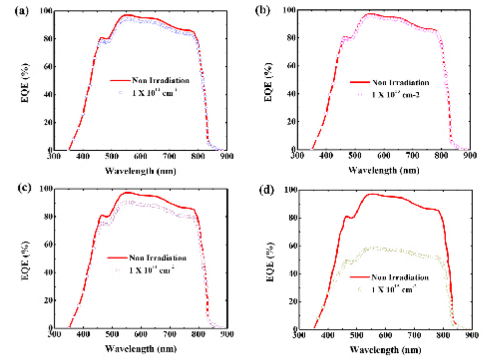


Table 1. Main parameters of photovoltaic cells at various fluences (including no irradiation) from 1×10^{12} to 1×10^{15} cm^{-2} averaged over three samples for each fluence.

Dose (cm^{-2})	Voc (mV)		Jsc (mA/cm^2)		FF (%)		η (%)		$\eta_{dif.}$ [a] (%)
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
Ref.	760	759	22.2	22.1	64.3	64.4	12.0	12.0	0
$1x10^{12}$	760	772	22.6	21.9	64.7	60.8	12.3	11.5	-0.8
$1x10^{13}$	755	761	21.2	20.9	64.4	57.5	11.9	10.1	-1.8
$1x10^{14}$	780	738	22.4	20.8	65.4	53.4	12.5	8.4	-4.1
$1x10^{15}$	757	673	21.4	9.4	61.4	42.4	11.6	3.4	-8.2

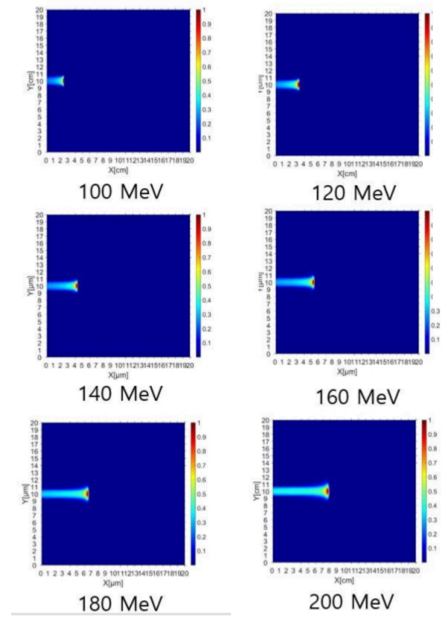
[a] indicates the difference in conversion efficiency before and after irradiation. [b] indicates the standard deviation for the performance parameters for all 15 samples before proton irradiation (3ea for each dose).

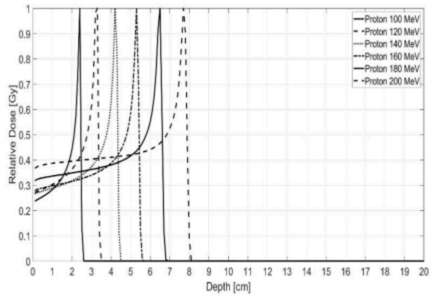


- Proton Energy : 100 MeV
- Proton Beam Size : 1.5 cm
- Proton Beam Shape : Pencil Beam Scanning (Circle)
- Fluence : 10^{12}, 10^{13}, 10^{14}, 10^{15} cm^{-2}
- Num particles : 10E+07

Fig 4. EQE spectra of CdTe cells with various proton doses. The EQE was measured after irradiation with a PBS beam at fluences of (a) 1×10^{12} cm^{-2}, (b) 1×10^{13} cm^{-2}, (c) 1×10^{14} cm^{-2}, and (d) 1×10^{15} cm^{-2} and compared with that of a non-irradiated CdTe cell.

Fig 5. TOPAS-based simulation results. Proton dose distributions according to layer depth obtained by the trajectories of PBS proton beams with energies of (a) 100, (b) 120, (c) 140, (d) 160, (e) 180, and (f) 200 MeV.

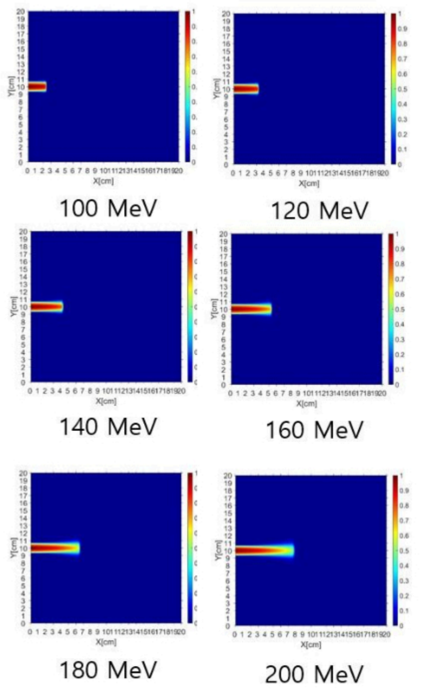


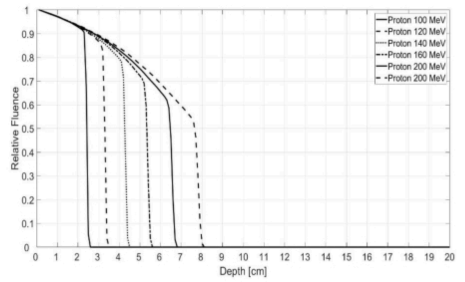


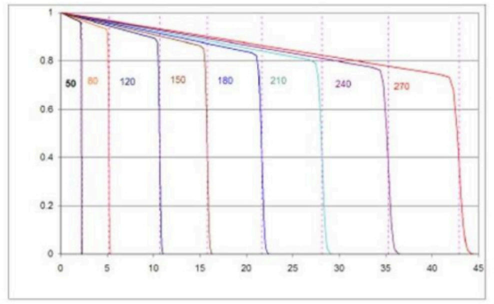
- **Bragg peak point in CdTe :**

1) Proton 100 MeV: 2.3 cm
2) Proton 120 MeV: 3.2 cm
3) Proton 140 MeV: 4.1 cm
4) Proton 160 MeV: 5.2 cm
5) Proton 180 MeV: 6.4 cm
6) Proton 200 MeV: 7.6 cm

Fig 6. Dose distributions of accumulated protons. Dose distributions obtained using PBS proton beams of the same fluence and energies of (a) 100, (b) 120, (c) 140, (d) 160, (e) 180, and (f) 200 MeV.







Decrease of Fluence of Primary Protons in Dependence of Energy in MeV and Depth Z in Water

CONCLUSIONS

We investigated the effects of radiation by a proton therapy beam on CdTe-based solar cells by irradiating a proton PBS beam with 100 MeV of energy. As a result, V_{oc}, J_{sc}, and *FF*, which are the main parameters of the solar cell, were approximately 89%, 44%, and 69%, respectively, of the corresponding value for the reference cell (without irradiation) at the highest dose of 1×10^{15} cm^{-2}. In particular, η was reduced to approximately 30% of its reference value owing to the combined effects of the parameters. The CdTe cell recorded an efficiency rate of approximately 70% even at a high fluence of 1×10^{14} cm^{-2}, confirming the durability of CdTe solar cells for space missions and their future application as dosimetry sensors. Likewise, a TOPAS-based simulation showed that the proton fluence curves accumulated in a CdTe cell when irradiated with a 100–200 MeV proton beam. Based on the Bragg peak characteristics of protons, we assessed the relatively high proton fluence at low energies compared to that at high energies. The high probability of incurring more radiation damage after low-energy irradiation was also addressed. This work serves as a preliminary study for the application of thin-film CdTe-based solar cells in proton therapy beam mode and is expected to provide valuable reference material for studies on thin-film solar cell proton dosimetry sensors. To improve the performance of the CdTe cell, we have studied a $CdCl_2$ treatment method using Freon gas, and aim to apply it to CdTe cell fabrication. Studies are being conducted to achieve reproducible performance, while reducing the thickness of CdS and CdTe. To increase the durability, a new surface treatment method in CdTe/metal interface is also being studied.

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CONTACT INFORMATION

Corresponding Author : Shinhaeng Cho E-mail : cho.ilmm80@gmail.com