OPTICALLY ENHANCED C-SI SOLAR CELLS FOR EPHEMERAL SPACE APPLICATIONS

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ABSTRACT: The market of small-scale space satellites has been growing significantly. Concepts as CubeSats, based on open-hardware platforms became a standard, opening new opportunities for small companies such as technological start-ups. However, prototypes' associated costs are still an obstacle, mainly due to their power systems. Historically photovoltaic technology was elected as one of the most reliable solutions to power satellites. Multijunction solar cells based on III-V groups elements are the most efficient photovoltaic devices, enabling high energy densities. Reason why they became the standard for spatial applications. Nevertheless, the associated cost of such devices is a hindrance for short-term satellites' missions. For such applications, the use of more cost-effective technologies as crystalline silicon solar cells should be considered even if their efficiencies are lower. Moreover, the use of advanced light trapping concepts could further enhance the conversion efficiency while reducing solar cell's thickness and mass. A very effective way to improve light capture in crystalline silicon is surface texturization. Silicon technology has the potential to deliver 70% of energy per unit of area of the best III-V solar cells while reducing the cost by two to three orders of magnitude.
Keywords: space, cost reduction, silicon solar cell, light trapping

1 INTRODUCTION

Since the beginning of the space era, photovoltaic (PV) systems were one of the technologies of choice to power satellites. As main advantages of PV one can point the abundance of solar resource outside the atmosphere and the scalability of the technology, that allows adapting the power installed to the missions' requirements. Moreover, when discussing circum-terrestrial satellites, PV has gained ground relatively to the use of nuclear fission systems due to its safety, especially after the reentry into the atmosphere and subsequent crash of the Cosmos 954 satellite in 1978 [1].

Although, the first PV powered satellites were based on crystalline silicon technologies, due to their high efficiency, reliability in space environment and lower weight per watt produced, III-V groups' solar cells have become the dominant power technology in space applications [2].

Recently the interest in small-scale satellites has increased very significantly. Favoured by the standardization provided by the CubeSat Program [3], that opened the way to important cost reductions, the number of nanosatellite launches has exploded in the last years. Until now more than 1700 nanosatellites were launched, and it is expected that a total of 750 are launched during this year [4].

Small-size satellites such as CubeSats offer a low-priced means to develop small scientific projects or provide a proof-of-concept before large-scale prototype production [5]. This opens new opportunities for small research labs and companies such as technological start-ups.

However, the associated costs of these devices are still a hindrance to their widespread use, mainly due to the price of the power systems, mostly based on III-V solar cells.

We argue that since most of the small-size satellites are programmed for short-term missions, the use of more cost-effective photovoltaic technologies, even if less efficient such as crystalline silicon, should be considered. As is well known crystalline solar cells suffer higher degradation in space environment than the III-V solar cells, however for the life cycle of the targeted applications is less relevant.

As a mean to enable the promotion of these lower cost photovoltaic devices, advanced light trapping concepts could be applied to increase the conversion efficiency.

2 ANALISYS

Enhancing the optical performance of crystalline silicon solar cells by introducing light trapping nano structures allows to reach high conversion efficiencies while significantly reducing the cell's thickness and thus its mass [6]. For instance, reducing the thickness from the industry standard of 180μm to few tenths of μm, allows mass reductions around 80% approaching the weight/watt values of the III-V group tandem solar cells.

Due its simplicity and potential cost-efficiency, metal assisted chemical etching (MACE) techniques are being more and more considered by silicon solar cells' industrials as an effective method to improve light capture and solar cell efficiency. In this scope, we have recently presented the characterization of a maskless MACE procedure based on the use of a solution of hydrogen peroxide (H_2O_2), hydrofluoric acid (HF), and silver nitrate ($AgNO_3$). The results of the process characterization were presented elsewhere [7, 8, 9].

The surface texturizations obtained with the MACE method showed a strong reduction of the spectral reflectance in the range 350-1100 nm.

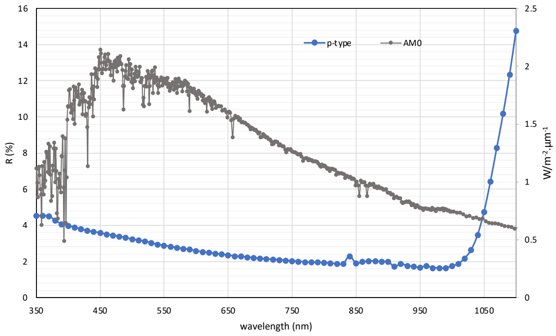

Figure 1: Reflectance curve for a p-type wafer and AM0 spectrum [10] in the range 350-1100 nm.

As shown in Figure 1, for an uncoated p-type silicon wafer the reflectance is under 4% for most of the analyzed range, leading to an effective reflectivity (eq.1) of 2.9%.

$$R_{\mathrm{eff}} = \frac{\sum_\lambda R_\lambda n_\lambda}{\sum_\lambda n_\lambda} \qquad (1)$$

R_λ and n_λ are respectively the reflectance measured and the number of photons in the AM0 [10] for the wavelength λ.

Such low reflective surfaces are suitable for thinner devices as they promote high gains of photocurrent generation rates. Finite-Difference Time-Domain (FDTD) electro-magnetic simulations based on Maxwell equations were performed showing that the obtained texturizations have by itself the potential to increase the generation rate by a factor of two for 40 µm thick cells [11]. This gain could be further improved by considering optimization strategies like back reflectors.

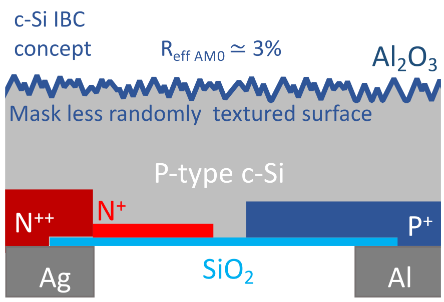

Figure 2: Concept diagram of an interdigitated solar cell. The mass reduction

An example of a solar cell structure that could benefit from this optical enhancement is the interdigitated back contact configuration (Figure 2), which is particularly adequate for MACE texturizations since both contacts and junctions are located at the back surface.

Nonetheless, the potential mass reduction resulting from the use of thinner devices' concepts is not an effective advantage for CubeSat applications as for instance, considering an 1U CubeSat configuration (10×10×10cm^3) the difference between silicon solar cells weights of 180 µm and 40 µm is about 2 grams. As Table I, classification of satellites' systems based on their mass shows, CubeSats mainly identified as Pico, Nano, and Micro satellites have their masses ranging from 1-100 kg.

Table I: Classification of satellites according to mass [5]

	Mass (kg)
Large satellite	> 1000
Small satellite	500-1000
Mini satellite	100-500
Micro satellite	10-100
Nano satellite	1-10
Pico satellite	< 1

In terms of energy conversion, the III-V groups tandem solar cells typically used in space industry have a maximum efficiency 32 % [12], while silicon solar cells have demonstrated efficiencies ranging from 22% to 26% [13] for terrestrial STC. Considering these figures, optically enhanced crystalline silicon solar cells could assure around 70% of the energy per area unit when compared to the III-V groups solar cells. In this way the use of silicon solar cells implies larger cells areas to suppress the same energy payload. On the other hand, replacing III-V tandem solar cells by crystalline silicon ones allows a cost reduction of the satellites energy production system by two to three orders of magnitude [14], having a major impact in the CubeSat overall cost.

4 CONCLUSIONS

The use of CubeSat satellites and other small low-orbit devices for short-term missions is becoming more frequent. Reducing the production costs of these devices can further generalize their access and thus accelerate their deployment.

Optically enhanced c-Si solar cells have the potential to reduce the cost of the satellites power production systems in two to three orders of magnitude for space applications when compared to III-V solar cells, while assuring 70% of the energy yield.

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