Laser Processes for Contact Optimization in c-Si Solar Cells

C. Molpeceres^{*1}, D. Muñoz¹, I. Sánchez¹, M. Morales¹, M. Colina², I. Martín², P. Ortega², C. Voz², R. Alcubilla²

¹Centro Láser UPM, Universidad Politécnica de Madrid, Campus Sur UPM, Ctra. De Valencia Km. 7.3, 28031. Madrid, Spain,

²Departament d'Enginyeria Electrònica, Universitat Politècnica de Catalunya UPC, C/Jordi Girona 1-3, Mòdul C4, 08034 Barcelona, Spain

* Corresponding author: carlos.molpeceres@upm.es

Abstract: Solid State Lasers (SSL) have been used in microelectronic and photovoltaic (PV) industry for decades but, currently, laser technology appears as a key enabling technology to improve efficiency and to reduce production costs in high efficiency solar cells fabrication. Moreover, the fact that the interaction between the laser radiation and the device is normally localized and restricted to a controlled volume makes SSL a tool of choice for the implementation of low temperature concepts in PV industry. Specifically, SSL are ideally suited to improve the electrical performance of the contacts further improving the efficiency of these devices. Advanced concepts based on standard laser firing or advanced laser doping techniques are optimal solutions for the back contact of a significant number of structures of growing interest in the c-Si PV industry, and a number of solutions has been proposed as well for emitter formation, to reduce the metallization optical losses or even to remove completely the contacts from the front part of the cell. In this work we present our more recent results of SSL applications for contact optimization in c-Si solar cell technology, including applications on low temperature processes demanding devices, like heterojunction solar cells.

OCIS codes: (140.3390) Laser materials processing; (140.3480) Lasers, diode-pumped

1. Introduction

SSL have become a fundamental tool in the photovoltaic (PV) industry, helping this technology to achieve two major goals: cost reduction and efficiency improvement. Among the present PV technologies, crystalline silicon (c-Si) maintains clear market supremacy. In these devices one of the key issues is to improve the quality of the contacts in the cell structure, and lasers are offering emerging solutions to address these challenges. Currently a number of them, conceptually intended to optimize the front contact, have been adapted or are under development. In particular laser ablation of dielectric layers, new laser-based metallization techniques and laser doping (LD) for selective emitter formation (in a number of different approaches) are the most promising techniques to improve the electrical quality of the front contacts of the new generation of high efficiency c-Si solar cells [1-2]. On the other hand, the interest of improving the passivation in the back contact has led to new successful uses of lasers in the PV industry. In particular the use of Laser-Fired Contact (LFC) techniques in Passivated Emitter and Rear Cell (PERC) devices, in which the laser is used to locally fire a metallic layer through a dielectric passivation layer to form the electrical contact with the silicon wafer [2], is becoming an industrial standard. Moreover, the use of advanced concepts for the rear contact formation based on local LD techniques offers very encouraging possibilities of further improving the electrical performance of the device by means of laser technology [3].

In this work we will discuss the application of local LD techniques, firstly for local emitter formation, discussing the influence of the laser irradiation parameters on the electrical quality of the generated diodes and, secondly, to produce locally-diffused back contacts with a reduced surface recombination velocity. This process is a good alternative to standard Laser-Fired contacts minimizing the damage induced in the material by the laser irradiation process. Applications in final devices, including heterojunction solar cells, are demonstrated in both cases.

2. Experimental and Results

2.1. Local Laser Doping (LD) processes for emitter formation

To assess the influence of laser parameters on local LD processes we have created n⁺ regions into p-type c-Si wafers, using a dry LD technique in which a stack of phosphorus-doped a-SiC_x:H films (deposited with a Plasma Enhanced Chemical Vapor Deposition reactor) is laser irradiated to produce locally doped n⁺ regions [4-5]. To irradiate the samples we have compared different commercial SSL at different wavelengths and irradiation conditions. To assess the characteristics of the diodes we prepared specific samples in which a matrix of emitters

was generated and electrically evaluated [6]. Additional measurements of doping profiles and sheet resistance measurements were used to confirm the validity of the electrical measurements.

Figure 1. TOF-SIMS doping profiles with IR and UV irradiation at different laser conditions. The interaction mechanisms in IR lead to a deeper doping profile and higher dopant concentration. On the other hand UV profiles remain close to the surface with enough dopant concentration to assure optimal electrical behavior [6].

Finally we fabricated final devices incorporating this punctual selective emitter concept in the rear side of the solar cell with optimized LFC on the front (see structure in Fig 2.) to demonstrate that a full laser solution for both contacts is possible (we call this concept DopLaCell, Doped by Laser Cell). The structure presented hereby offers a device concept extremely cost-effective and easy to fabricate with only three basic steps: film depositions, laser processing and metallization. Additionally, the distance between rear punctual emitters, or pitch, is identified as a key design parameter that strongly impacts on FF. The results for the shortest pitch demonstrate the feasibility of the concept with Voc and FF in the state of the art. The relatively low Jsc values are limiting conversion efficiencies of the fabricated devices. However, the optical origin of these losses, lack of texturization of the samples and a non-optimized metallization in the front of the cell, could be overcome without modifying the structure of these devices.

Fig. 2 Electrical figures for finished solar cells incorporating punctual emitters made by laser doping. The figure on the right shows J-V characteristics for different pitches between emitters.

2.1. Local Laser Doping (LD) processes for micro-ohmic contacts production in passivated rear cells

As other relevant example of the potential of local LD techniques, we present the production of locally-diffused ohmic micro-contacts, as an alternative to standard laser-fired techniques, irradiating with an IR SSL an Al₂O₃ layer previously to a final Al metallization [7-9]. We compare this approach to other two well known LFC strategies for the back contact of c-Si solar cells: evaporated Al LFC and Aluminum Foil LFC. Although good contacts are

obtained for the three approaches (with specific contact resistance values around $1 \text{ m}\Omega\text{cm}^2$), Al_2O_3 contacts obtained by LD led to lower surface recombination velocities, probably due to a reduced damage on the substrate and a more controlled p+ region formation. Finally we compared the three strategies applying them to heterojunction solar cells. The results in final device show as well the best results for the Al_2O_3 LD approach.

Fig. 3 Effective surface recombination velocity as a function of the laser treated area for the three laser contacting strategies. On the left a scheme of the Al_2O_3 LD based structure is depicted

4. Conclusions.

Laser LD techniques are optimal to improve the electrical quality of the contacts in advanced concepts of high efficiency solar cells. Local emitter formation with laser enables to produce structures in which a very low thermal input is needed. In addition the use of LD to create ohmic micro-contacts offers new possibilities to further improve the back contact electrical behavior minimizing the damage induced by laser irradiation in the material. In these approaches SSL appear as the ideal tools to be used in these processes, due to the fact that the range of wavelengths, pulse widths and repetition rates available together with the optical characteristics of the beams allow, by means of an appropriate process parameterization, to obtain optimized processes of outstanding electrical quality for a wide range of materials and cell structures.

5. Acknowledgements.

This work has been supported by the Spanish Ministry of Science and Innovation under projects AMIC ENE2010-21384-C04-02, TEC2011-26329 and INNDISOL IPT-420000-2010-6 (FEDER funded “Una manera de hacer Europa”).

6. References

- [1] Booth, H., “Laser Processing in Industrial Solar Module Manufacturing”. Journal of Laser Micro/Nanoengineering, 5(3), 183-191 (2010).
- [2] Colville, F., “Laser assisted selective emitters and the role of laser doping,” Photovoltaics International, 5, (2009).
- [3] Schneiderlöchner, E., Preu R., Lüderman R., Glunz SW. “Laser-fired rear contacts for crystalline silicon solar Cells,” Progress in Photovoltaics: Research and Applications 10, 29–34 (2002)
- [4] Orpella, A., Blanqué, S., Roiati, V., Martín, I., Voz, C., Puigdollers, J., & Alcubilla, R. “N-type emitters passivation through antireflective phosphorus doped a-SiCxNy:H(n) stacks”. Proceedings of Conference of electronic devices, Santiago de Compostela, Spain, 1-3 (2009).
- [5] Orpella A., Martín I., Blanque S., Voz C., Sánchez-Aniorte, I., Colina M., Molpeceres C., Alcubilla R. “Optimization of laser processes in n+ emitter formation for c-Si solar cells”. Proceedings of the 24th EU PVSEC, Hamburg, Germany, 1798–1802 (2009).
- [6] Molpeceres C., Sánchez-Aniorte, M.I., Morales M, Muñoz D., Martín I., Ortega P., Colina M., Voz C., Alcubilla R. Influence of wavelength on laser doping and laser-fired contact processes for c-Si solar cells. Proc. of SPIE 2012; 8473: 847308-1.
- [7] Ortega, P., Orpella, A., Martín, I., Colina, M., G.López, Voz, C., M.I.Sánchez, Molpeceres, C., Alcubilla, R. “Laser-fired contact optimization in c-Si solar cells”. Progress in Photovoltaics. 20 (2) 173-180 (2012).
- [8] Ortega P, Martín I, López G, Colina M, Orpella A, Voz C, Alcubilla R. P-type c-Si solar cells base don rearside laser processing of $\text{Al}_2\text{O}_3/\text{SiCx}$ stacks. Sol. Energ. Mat. Sol. 2012; 106: 80-83.
- [9] Martín I, Ortega P, Colina M, Orpella A, López G, Alcubilla R. Laser processing of $\text{Al}_2\text{O}_3/\text{a-SiCx:H}$ stacks: a feasible solution for rear surface of high-efficiency p-type c-Si solar cells. Prog.InPhotovol. 2012; DOI: 10.1002/pip.2207.