amU Aix Marseille Université

Job description : Post-doctoral contract

Category: A
Research Unit: IM2NP (Institute Materials Microelectronics Nanosciences of Provence) CNRS 7334 AMU
Location: Campus de Saint Jérôme, Escadrille Normandie Niemen, 13397 Marseille Cedex 20, FRANCE
Foreseen duration: 12 to 18 months
Work share: 100 %

NAME AND DESCRIPTION OF THE RESEARCH PROJECT:

TITLE: Post-doctoral position in *in situ* X-ray imaging characterization of crystal distortions and defects in silicon during heating and solidification in view of its application to Photovoltaic solar cells.

The post-doctoral research work will be part of the DeFI2 project (Defects and deformation in crystalline silicon ingots for photovoltaic applications towards the industrial processes) funded by the ANR (ANR-23-CE50-0022-01).

The DeFI2 project gathers three partners : IM2NP (Institute Materials Microelectronics Nanosciences of Provence) CNRS 7334 AMU site de Marseille, MSMP (Mechanics Surfaces Materials and Processes) laboratory, Ecole Nationale des Arts-et-Métiers, Aix-en-Provence et CEA LITEN, Solar Technologies department, National Solar Energy Institute, Chambéry.

Innovative processes for the fabrication of silicon (Si) ingots for photovoltaic (PV) cells are presently implemented in industrial plants. The recent demand for larger wafer dimensions generates new issues regarding the crystal defects and mechanical stress. To answer to these scientific key-issues, the DeFI2 project focuses on the mechanisms of the crystal structure deformation, on the origin and propagation of main structural defects, on the impact of the oxygen which is one of the most deleterious impurities, in particular for the mono-crystalline Czochralski (Cz) process and of doping impurities with a particular focus on Gallium due to its current importance. The objectives of the project will be achieved by an interdisciplinary joint experimental and simulation approach based on original or unique tools and skills: characterisation of the dynamics of structural defects (in situ studies) and deformation in the presence or not of impurities; simulation of the thermomechanical history at grain- and ingot- scales to evaluate the multiscale residual stress fields and their impact on defects; characterization of the electrical properties for the defects under study. The DeFI2 project will contribute to the understanding of the basic phenomena concerning deformation and defects, allow the development of adapted thermomechanical models, and of experimental advanced characterisation devices. The subject of Si deformation during the manufacturing process, on which the DeFI2 project will provide basic knowledge, is of major interest for the French PV industry working on the growth of Cast-mono ingots. Moreover, the knowledge gained on the structural defect organisation in large-size Cz ingots and their impact on carrier lifetimes could contribute to the background for the development in Europe of factories for Si-based solar cells, heterojunction or TOPCon.

MISSIONS AND MAIN ACTIVITIES OF THE POST-DOCTORATE RESEARCHER:

The postdoctoral fellow will participate in the tasks carried out by IM2NP as part of the DeFI2 project. The GaTSBI (Growth at high Temperature observed by Synchrotron Beam Imaging) furnace developed by the MCA team at IM2NP allows the *in situ* monitoring of the different steps of heating, melting and directional solidification of silicon (Si) samples. Thus, the dynamics and morphology of the solid-liquid interface and of the crystalline defects, in particular dislocations and sub-boundaries, of Si can be characterized. These experiments are carried out using the synchrotron X-ray radiation of the ESRF (Euro-

pean synchrotron radiation facilities). They are supplemented by *ex situ* measurements: EBSD (Electron Backscatter Diffraction) maps to characterize the grain structure and quantitative measurements of the distortion of the crystal and sub-boundaries using the Rocking Curve Imaging method.

The candidate will focus his/her work on the analysis of the *in situ* images of the solid-liquid interface, crystal distortions and crystal defects generated during the project and concerning heating and directional solidification from seeds from semi-industrial ingots solidified at INES. A first experimental campaign has already been carried out at the ESRF but a second campaign should be organized during the postdoctoral contract.

Selection of publications from the team on the subject:

1. S. Houam, H. Ouaddah, G. Regula, I. Périchaud, G. Reinhart, M. Di Sabatino Lundberg, L. Vines, M. G. Silly, F. Guittonneau, L. Barrallier, E. Pihan, N. Mangelinck-Noël, «A method to relate the presence of structural defects and impurities and their impact on the electrical activity in silicon for photovoltaic applications », Solar Energy Materials & Solar Cells 282 (2025) 113415.
2. H. Ouaddah, G. Regula, G. Reinhart, I. Périchaud, F. Guittonneau, L. Barrallier, J. Baruchel, T.N. Tran Caliste, N. Mangelinck-Noël, "Crystal distortions and structural defects at several scales generated during the growth of silicon contaminated with carbon", Acta Materialia 252 (2023) 118904.
3. E. Pihan, M. Albaric, G. Regula, N. Mangelinck-Noël, "Attempt to correlate dislocations network and distribution to macroscale plane rotations in cast-mono ingots", Solar Energy Materials & Solar Cells 249 (2023) 112022.
4. M.G. Tsoutsouva, G. Regula, B. Ryningen, P.E. Vullum, N. Mangelinck-Noël, G. Stokkan, "Dynamic observation of dislocation evolution and interaction with twin boundaries in silicon crystal growth using in - situ synchrotron X-ray diffraction imaging", Acta Materialia, 210 (2021) 116819.
5. M. Becker, E. Pihan, F. Guittonneau, L. Barrallier, G. Regula, H. Ouaddah, G. Reinhart, N. Mangelinck-Noël, "Investigation of sub-grains in directionally solidified cast mono-seeded silicon and their interactions with twin boundaries", Solar Energy Materials and Solar Cells 218 (2020) 110817.

Contact person for any additional information: Nathalie Mangelinck-Noël (nathalie.mangelinck@im2np.fr)

RESULTS EXPECTED AT THE END OF THE POST DOCTORAL CONTRACT

The postdoctoral fellow will therefore generate results concerning the dynamics of defects in silicon with a view to its application to photovoltaic solar cells. He or she will present his or her results in the form of presentations during project meetings or in international conferences and in writing (project reports and publications in peer-reviewed journals). If desired, the candidate will have the opportunity to participate in actions to disseminate scientific and technical culture.

REQUESTED COMPETENCES:

Professional and/or technical skills:
The candidate is expected to have professional and/or technical skills in the field of crystallization and crystal defects in materials and if possible in silicon. Experience in X-ray imaging methods or characterizations by X-ray diffraction methods would be a plus.

Transverse competencies:
The candidate must be able to carry out his/her research work independently, take initiatives and collaborate with the DeFI project teams. Writing skills and presentation of results in French and English are expected. Experience in or a particular interest in the field of solar photovoltaics would be appreciated.

Required degree: PhD degree.

ENVIRONMENT / CONTEXT/ WORKING CONDITIONS

The post-doctoral fellow will carry out his or her research in the laboratory IM2NP (Institute Materials Microelectronics Nanosciences of Provence) CNRS 7334 AMU (Ai Marseille Université) in the MATER department (Structure and chemistry of materials), MCA (Auto-organised growth microstructures) team.

The MCA team premises are located on the campus of Saint Jérôme d'Aix-Marseille University. The candidate will most likely participate in experiments at the ESRF in Grenoble, travel to the sites of the project partners and to the venue of national and international conferences.