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PhD position in thin film solar cells for indoor photovoltaic applications

Description: The proposed work will be highly experimental. Hence, the candidate will fully synthesize thin film photovoltaic devices and characterize them both optically and electrically, in order to correlate performance with the synthesis parameters and the material/optoelectronic properties of the synthesized films. The proposed PhD thesis will be carried out at the Institut des Matériaux de Nantes Jean Rouxel, in the heart of the city of Nantes, France. It is part of the SIPHON project which is funded by the French National Agency and has been certified by the competitiveness cluster specialized in energy management S2E2.

Key-words: Experimental work, thin films, photovoltaic, chalcogenide, material growth and characterization, wide band gap, indoor energy harvesting, IoT

Context: 12.2 billion Internet of things (IoT) devices were already connected in 2021 and forecasts suggest 20 billion in 2025. Among these connected devices, most of them are wireless, operate indoors and are powered through a primary battery which generally lasts between 8 and 25 months [1]. The proliferation rate of IoT devices is so high that in few years hundreds of millions of IoT batteries may have to be replaced every day, implying overhead maintenance costs, not to mention production and recycling or disposal of the batteries. Recent developments in low-power electronics and low-energy wireless communication protocols have considerably lowered the energy and power demand for IoT devices and opened new perspectives for powering them through indoor ambient light energy harvesting.
Indoor photovoltaic devices based on organic or hybrid absorbers have reached significant power conversion efficiency (PCE) and numerous materials have been tested over the past few years. However, they still suffer from stability issues that limit their commercial acceptability. The major conclusion of a recent review [2] on the subject is that "an inorganic solar cell that retains more than 80% of its initial PCE value even after 10 years of its fabrication needs to be developed to compete with the currently used power sources in IoT devices."

The project: The objective of the project is to produce energy for IoT devices from ambient artificial light using thin film solar cells based on stable, inorganic $CuGaSe_2$ (CGS) chalcopyrite semiconductor grown on flexible substrates. Such devices have the potential to convert up to 50% of the indoor artificial light spectrum [3] since the 1.7eV bandgap of the absorber allows the absorption of all of the above 1.8 eV-photons of the LED spectra without excessive thermalization losses. The synthesis of large-scale, homogeneous, single-phase, wide bandgap CGS thin films is challenging, especially at low temperature, which is necessary for deposition on flexible substrates. Such semiconductor growth being limited by slow kinetics of formation [4], high efficiency devices are generally obtained using long relaxion steps at high substrate temperature [5,6]. We recently demonstrated that metal halide post-deposition treatments can be used to drastically decrease the synthesis temperature of CIGS films [7] as well as produce single phase CGS thin film with large grains [8]. This new and unique approach consisting in using metal halides as transport agent enhancing grains growth has therefore all the ingredients to break the technological locks that, to date, restrain the use of stable and industrially compatible CGS compounds for Indoor PV applications on flexible substrates. This project will also focus on heavy alkali post-deposition treatments in a sulphur atmosphere in order to improve the bulk and junction quality based on such absorber, since IMN has developed and masters this type of treatments on narrow bandgap [9–12]. Finally, the material consumption will be optimized by reducing the thickness of the layers constituting the cell stack and the toxic CdS buffer layer will be replaced by an alternative buffer layer based on non-toxic and earth-abundant materials.

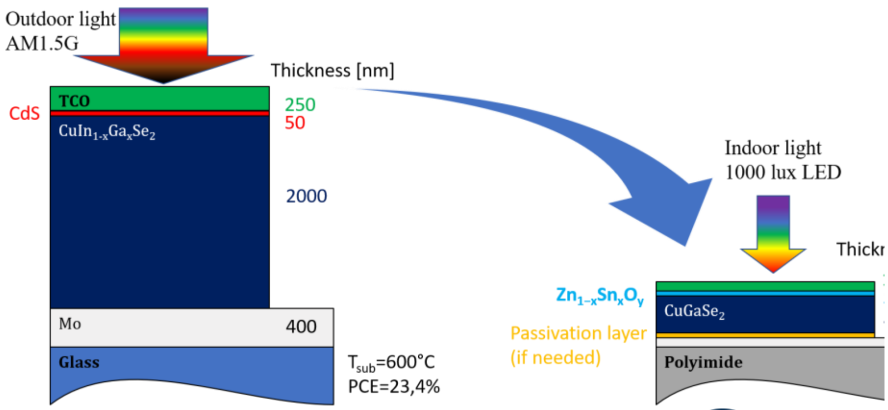

Fig1: Graphical objectives

References:

1. Pecunia, V., Occhipinti, L. G. & Hoye, R. L. Z. Emerging Indoor Photovoltaic Technologies for Sustainable Internet of Things. *Advanced Energy Materials* **11**, 2100698 (2021).
2. Biswas, S. & Kim, H. Solar Cells for Indoor Applications: Progress and Development. *Polymers (Basel)* **12**, 1338 (2020).
3. Freunek, M., Freunek, M. & Reindl, L. M. Maximum efficiencies of indoor photovoltaic devices. *IEEE Journal of Photovoltaics* **3**, 59–64 (2013).
4. Kim, W. K. *et al.* Reaction kinetics of CuGaSe2 formation from a GaSe/CuSe bilayer precursor film. *Journal of Crystal Growth* **310**, 2987–2994 (2008).
5. Larsson, F. *et al.* Record 1.0 V open-circuit voltage in wide band gap chalcopyrite solar cells. *Progress in Photovoltaics: Research and Applications* **25**, 755–763 (2017).
6. Tsoulka, P., Rivalland, A., Arzel, L. & Barreau, N. Improved CuGaSe2 absorber properties through a modified co-evaporation process. *Thin Solid Films* **709**, 138224 (2020).
7. Marsillac, S. High-Rate and Low-Temperature Fabrication of Cu(In,Ga)Se2 Solar Cells using AgBr Induced Recrystallization. *Journal of Photovoltaics* (2022).
8. Palmiotti, E. *et al.* Homogeneous CuGaSe2 Growth by the CuPRO Process with In-Situ AgBr Treatment. *Thin Solid Films* 139488 (2022)
9. Tsoulka, P., Crossay, A., Arzel, L., Harel, S. & Barreau, N. Alternative alkali fluoride post-deposition treatment under elemental sulfur atmosphere for high-efficiency Cu(In,Ga)Se2-based solar cells. *Progress in Photovoltaics: Research and Applications* **30**, 835–842 (2022).
10. Wands, J., Tsoulka, P., Lepetit, T., Barreau, N. & Rockett, A. Effects of Novel In+RbF Post-Deposition Treatment on Cu(InxGa1-x)Se2 Solar Cells. in *2022 IEEE 49th Photovoltaics Specialists Conference (PVSC)* 0415–0417 (2022).
11. Harel, S., Jonnard, P., Lepetit, T., Arzel, L. & Barreau, N. Impact of KF-post deposition treatment on Cu(In,Ga)Se2 surface and Cu(In,Ga)Se2/CdS interface sulfurization. *Applied Surface Science* **473**, 1062–1065 (2019).
12. Harel, S., Arzel, L., Lepetit, T., Zabierowski, P. & Barreau, N. Influence of Sulfur Evaporation during or after KF-Post Deposition Treatment On Cu(In,Ga)Se2/CdS Interface Formation. *ACS Appl. Mater. Interfaces* **12**, 46953–46962 (2020).

Missions: The recruited student will be in charge of synthesizing the thin films of CGS by vacuum co-evaporation technique on glass substrates. He/she will also be in charge of the completion of the entire stack (CGS / buffer layer / transparent oxide conductor / grids) that constitutes the solar cell. The person recruited will be responsible for implementing technical solutions for deposition on flexible polyimide substrates. She will also be in charge of developing an optical measurement bench dedicated specifically to indoor measurements. All routine material analyses (XED, SEM, vibrational spectroscopies) will be carried out within the IMN as well as part of the optoelectronic analyses of the devices (IV, EQE, I(V,T)).

Expected skills: The person recruited must hold a Master (or equivalent) from education ensuring deep knowledge in materials science and optoelectronic components (especially in photovoltaic devices). She will have to show strong aptitude for experimental sciences (synthesis and analysis), organizational skills, and to communicate easily in English. Knowledge in the field of CIGS thin film photovoltaic devices will be an undeniable asset.

The research group: The Institut des Matériaux Jean Rouxel (IMN, UMR6502, http://www.cnrs-imn.fr) is a joint CNRS– University of Nantes research unit, composed of more than 200 staff, including about 120 permanent staff and 80 doctoral and post-doctoral students, bringing together physicists and chemists conducting research activities to develop a fundamental understanding of the science of materials and their properties from the atomic scale upwards. This allows the design, characterization and optimization of new materials for a diverse range of high technology applications, including next generation solar cells, fuel cells, electric car batteries, nanotechnology, smart materials, materials for microelectronics, photonic and optical materials. The person recruited will evolve within the MIOPS team (Innovative Materials for Optics, Photovoltaics and Storage) which is involve in several national or international projects in the field of photovoltaics. All the common IMN facilities will be available for the success of the project, in particular microscopies, optoelectronic and vibrational spectroscopies characterization tools.

Contact and information:

Starting: early 2024
Duration: 36 months
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