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The 10th International Conference on Software, Knowledge, Information Management and Application (SKIMA 2016) is going to be held from 15 to 17 December 2016 in Chengdu, China. The conference aims to bring together researchers and experts in Knowledge Management, Software Engineering and Information Systems to share their ideas, experiences and insights.

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Multi-Axes Mechatronic System for Printing Ultrathin Layers of Perovskite Solar Cells

Prototype design and manufacture

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***Abstract*— This paper presents main steps in design, develop and manufacture of a mechatronic system for printing ultrathin layers of perovskite solar cells. The innovation of this mechatronic system consists in its modular structure enabling the application of three different printing technologies. Some preliminary tests and results are also evidenced.**

***Keywords*—autonomous systems, robotics, mechatronics sstem; real time control systems**

I. Introduction

Solar photovoltaic, PV, generates no pollution. The direct conversion of sunlight to electricity occurs without any moving parts [1]. A typical photovoltaic system employs solar panels, each comprising a number of solar cells, which generate electrical power. The first step is the photoelectric effect followed by an electrochemical process where crystallized atoms, ionized in a series, generate an electric current [2].

Photovoltaic cells are an integral part of solar-electric energy systems, which are becoming increasingly important as alternative sources of utility power. Photovoltaic systems have been used for fifty years in specialized applications, standalone and grid-connected PV systems have been in use for more than twenty years [3].

They were first mass-produced in 2000, when German environmentalists and the Eurosolar organization got government funding for a ten thousand roof program [4] – as presented in Fig. 1.

Fig. 1. The Solar Settlement, a sustainable housing community project in Freiburg, Germany. [5].

A perovskite is any material with the same type of crystal structure as calcium titanium oxide($CaTiO_3$), known as the *perovskite structure*, or $^{XII}A^{2+VI}B^{4+}X^{2-}{}_3$ with the oxygen in the face centers [6] Perovskites take their name from the mineral, which was first discovered in the Ural mountains ofRussia by Gustav Rose in 1839 and is named after Russian mineralogist L. A. Perovski (1792–1856). The general chemical formula for perovskite compounds is ABX_3, where 'A' and 'B' are two cations of very different sizes, and X is an anion that bonds to both. The 'A' atoms are larger than the 'B' atoms. Synthetic perovskites have been identified as possible inexpensive base materials for high-efficiency commercial photovoltaics that *can be manufactured using the same thin-film manufacturing techniques* as that used for thin film silicon solar cells [7].

A perovskite solar cell is a type of solar cell which includes a perovskite structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer [8]. Solar cell efficiencies of devices using these materials have increased from 3.8% in 2009 [9] to 22.1% in early 2016 [10], making this the fastest-advancing solar technology to date.

The typical solar cell includes a transparent electrode (ITO or FTO, both quite expensive and with deficient materials), a TiO_2 layer as electron transporter, a halide perovskite as light absorber, a hole transporter (e.g. spiro-OMeTAD), and a counter electrode (e.g. Ag) – see Fig. 2 [11].

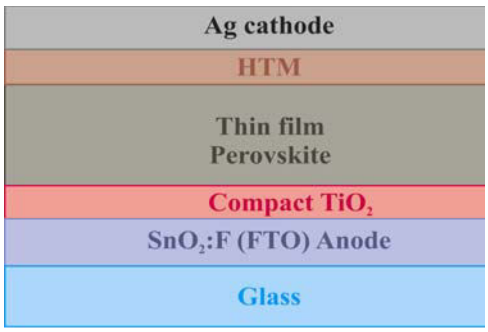


Fig. 2. Perovskite solar cells with spiro-OMeTAD as hole transporter material (HTM) and halide perovskite as light absorber - thin-film planar structure [11].

All these layers can be deposited by low cost technologies. The combination of the relatively high PCE with the low cost technologies makes this type of hybrid photovoltaic solar cell very attractive for future development.

With the potential of achieving even higher efficiencies and the very low production costs, perovskite solar cells have become commercially attractive, with start-up companies already promising modules on the market by 2017 [12].

II. Low Cost Techinques and Equupments for Thin Film Deposition

The use of thin film techniques offers obvious advantages in terms of materials and production costs. The films are sequentially deposited on a large area substrate, with affordable costs and appropriate electrical characteristics.

There is a large variety of low cost thin film deposition techniques used to deposit the thin films on an inert substrate, such as glass, or a plastic or metal foil, such as: Physical Vapour Deposition (PVD), Chemical Vapour Deposition (CVD), Spin Coating (SC), Roll to roll (R2R), Wire-bar Coating, Doctor Blade, Screen Printing.

Some of the main techniques, and their corresponding equipments, used for deposition of ultrathin layers of perovskite solar cells are presented next.

A. *Wire Bar Coating*

Wire-bar coating is a simple deposition method for preparing large areas of organic films at low cost, while the processes developed on such equipment are amenable to scale-up. It has particular benefits, including excellent control of solidification rate and deposition temperature, compatibility with flexible substrates, capability for a wide range of substrate sizes, from mm to tens of cm, plus a high degree of coating reproducibility. Controlled deposition speed and pressure are important factors in achieving high quality films, which are applied by wire wound bars which meter the ink used for coating – see Fig. 3 [13]. Layer thickness is controlled by the diameter of the wire, as well as the ink formulation and ambient conditions.

A wire-bar coating equipment, produced by RK PrintCoat Instruments is shown in figure 4.

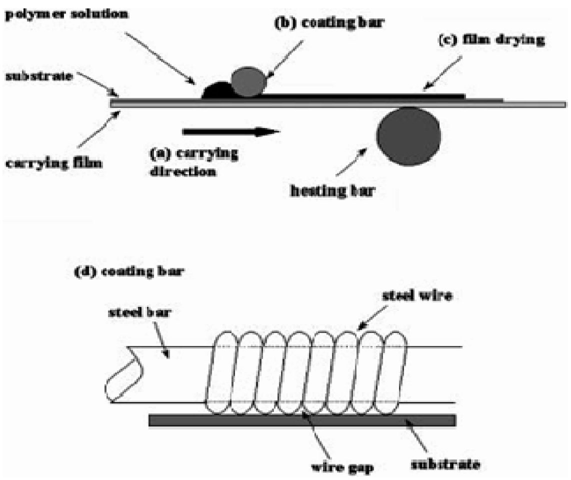


Fig. 3. Scheme of the wire-bar coating process. [13].

Main Features
- controlled speed and pressure ensure repeatable results
- coating by wire wound bars or gap applicators
- coated areas up to 170 x 250mm or 325 x 250mm
- multiple coatings in one operation for comparison purposes

Fig. 4. RK Control Coater. [14].

B. *Doctor Blade*

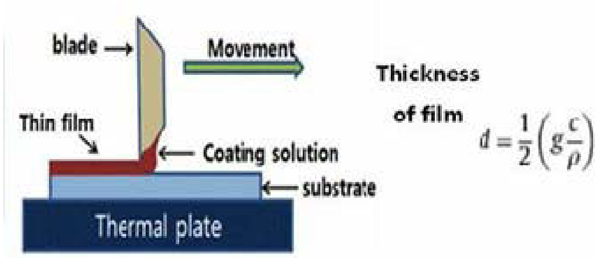
In the doctor blade process, a well-mixed slurry consisting of a suspension of ceramic particles along with other additives (such as binders, dispersants or plasticizers) is placed on a substrate beyond the doctor blade. When a constant relative movement is established between the blade and the substrate, the slurry spreads on the substrate to form a thin sheet which results in a gel-layer upon drying – see Fig. 5 [15].

Specific equipment for doctor blade technique is shown in figure 6.

C. *Screen Printing*

In [15] screen printing is defined as a way inserting paste into the opening of the dense mesh screen made of plastic or metal fiber in order to form asking shape on the substrate.

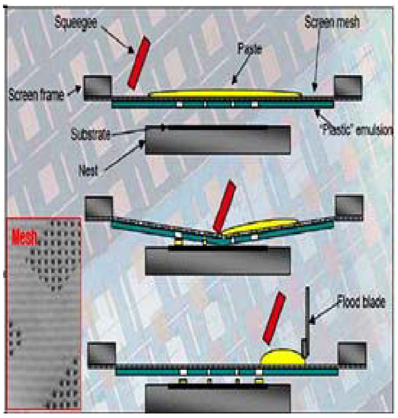
This method forms patterns on the screen with emulsion that the solution is not stained on emulsion. That is, after moving the screen filled with solutions on the surface without emulsion toward the substrate, by pressing the screen with the squeeze, the screen paste is printed on the substrate. At this point, the total paste is not printed. It depends on the squeeze pressure, the squeezing distance, the squeeze moving speed, and the solution viscosity – see Fig. 7.



d is the thickness, g - gap between the substrate and the blade,
c - solid content [g/cm3], ρ - final density[g/cm3] of the thin film.

Fig. 5. Scheme of the Doctor-Blade process. [15].

Fig. 6. Doctor-Blade applicators. [16].



process scheme [15]

Dyesol equipment [17]

Fig. 7. Screen Priting

A screen printing equipment, produced by DYESOL company is also shown in Fig.7**.**

At Fraunhofer Institute for Solar Energy Systems, ISE, it is evidenced the fact that the dye solar cell module is still a young photovoltaic technology. A large challenge in the development of new photovoltaic technologies is the transfer from the laboratory to the industrial level. This is why, the development of new, performance equipments, fit for industrial production of perovskite solar cells is worth to be considered.

III. PRROTOTYPE DESIGN AND MANUFACTURING

A. Design concept

The new equipment, that is a multi-axes mechatronic system, is aimed to enable the deposition of ultrathin layers of perovskite on both glass and flexible substrates, so that perovkite solar cells with power conversion efficiencies approaching 20% to be fabricated with affordable, environmental friendly materials and low cost technologies

This is why, its basic concept ideas are as follows:

- Prototype, that is a demonstrator equipment for printing technologies of perovskite solar cells.
- Positioning and repeatability accuracy of vertical subassembly motion, up to 2 µm.
- Up to four motion axes – for the moment, there are three motion axes, one vertical (OZ) and two others horizontals (OX and OY).
- Two workstations (zones):
  - zone 1: for perovskite material / layer deposition;
  - zone 2: for layer heating, up to 120 °C
- Printing tool modules – enabling application of three different priting techniques, that are:
  - screen printing;
  - doctor blade;
  - wire bar.

CAD model of the printing equipment, multi-axes mechatronic system, is presented in Fig. 8.

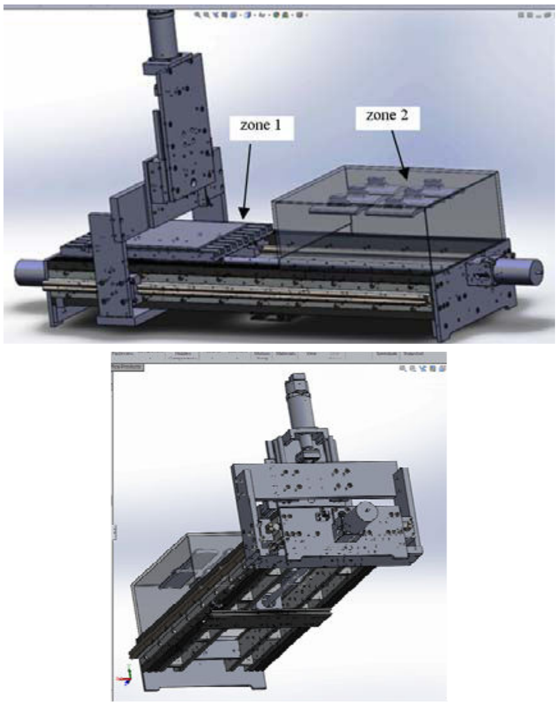


Fig. 8. CAD model of the printing equipment

Modularity of this mechatronic system refers to the vertical subassembly, called "Blade subassembly". This subassembly, made of mechanical and electronic components (Aluminum profiles, DC servomotor, encoder, perovskite reservoir) is designed so as to enable fast change of modules (blade, printing screen, wire bar) specific to each of the three low cost printing techniques (mentioned above).

In Fig. 9, Fig. 10 and Fig. 11, there can be noticed CAD models for the modular structures required by each of the considered printing techniques.

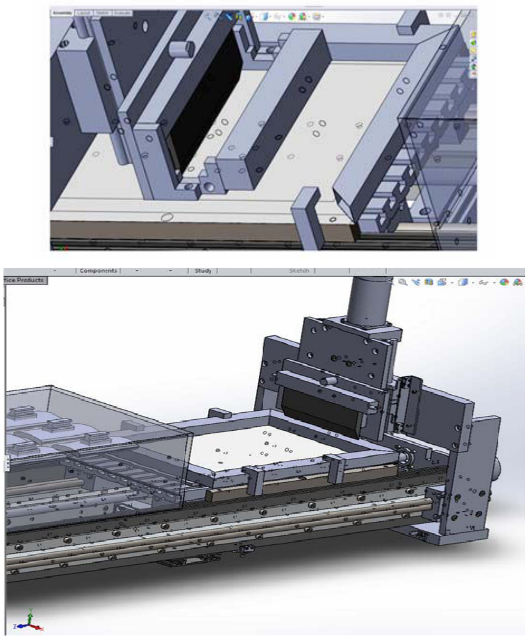


Fig. 9. CAD model of the printing equipment – for screen printing

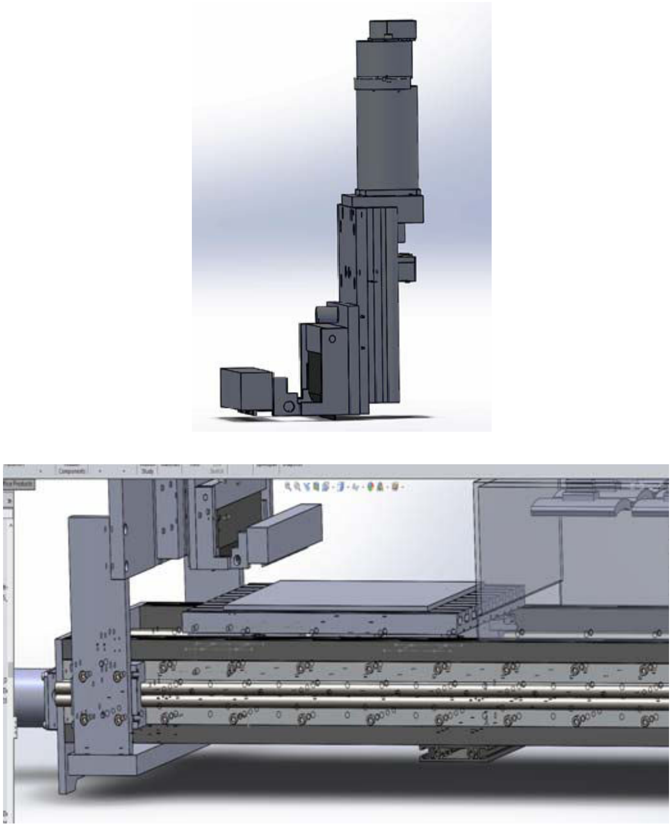


Fig. 10. CAD model of the printing equipment – for doctor blade

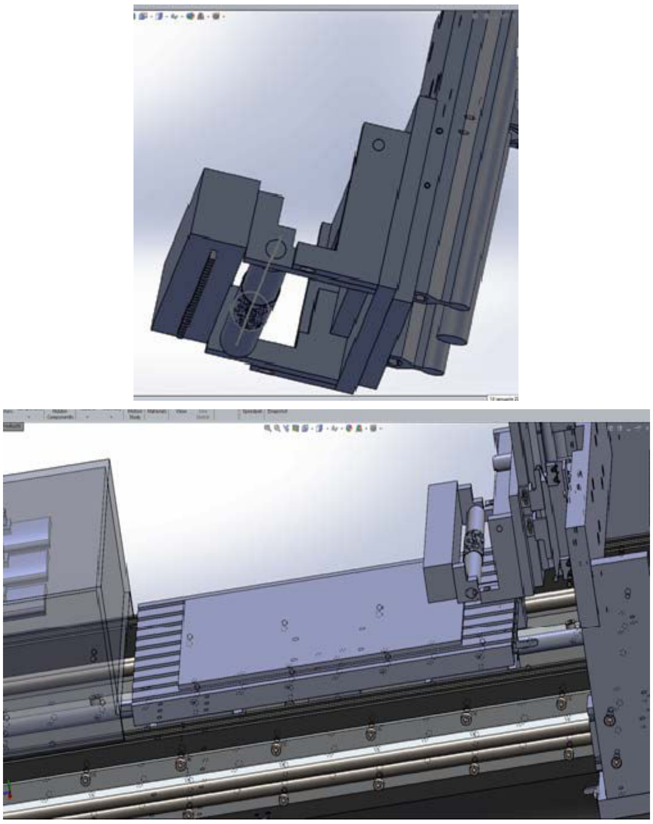


Fig. 11. CAD model of the printing equipment – for wire bar

The *control system* of printing equipment is a powerful drive controllers (Controller iPU-DC) for three linear, or rotational, axes. Brush-coated DC servo motors (DC 100) are the entry level of controlled drive technology. The added-on encoder allows for very precise positioning, up to 2 μm [18].

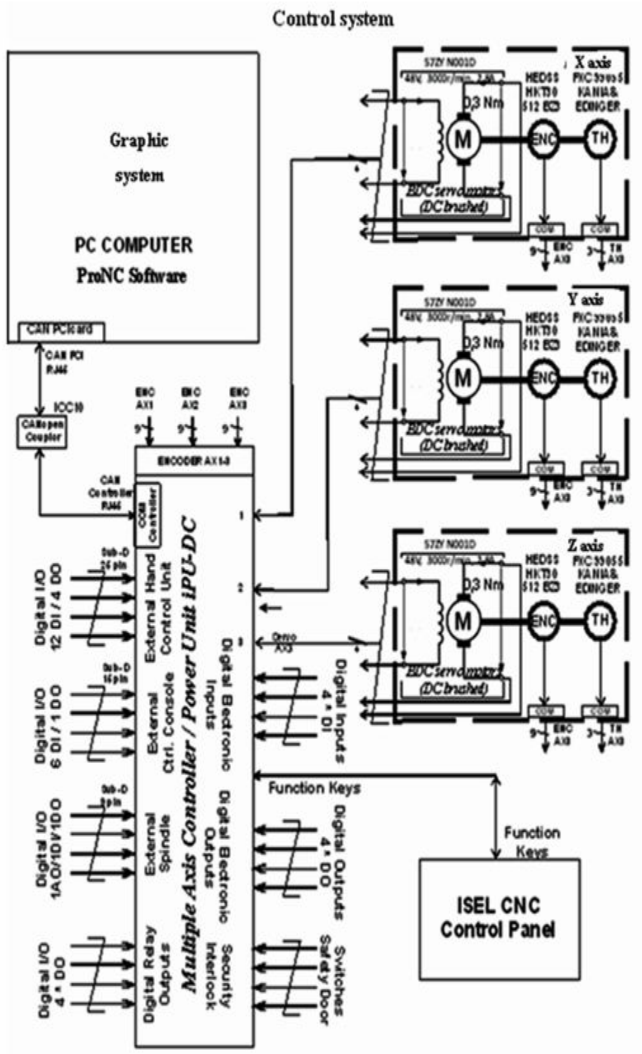


Fig. 12. Architecture of the control system of the printing equipment [11]

Arhitecture of the control system of printing equipment, is evidenced in Fig. 12. In order to improve the control system performances of this mechatronic system, there were applied important advances in the integration of real time control laws by the versatile, intelligent, portable VIPRO Platform. [19,20].

The VIPRO Platform is based on the virtual projection method, known as Vladareanu-Munteanu method [21, 22].

In this context the VIPRO platform brings back the virtual robots / mechatronic systems into real world, based on virtual projection method. This method is aimed at improving control performances and is fit for application in control systems of nano/micro/macro manipulators, robots and mechatronic systems. The problem solved by the virtual projection method is that of enabling to desgin, test and experiment different control methods (exetnics, neutrosophic, fuzzy) on a real time control system, on-line, even if there is no real mechanical structure [23-25].

B. Protoype manufacturing

Most of the mechanical components were submitted to manufacturing processes, on classic or CNC machine-tools, so that from workpieces they were transformed into parts / components. Further, these components had to be assembled and mounted, together with most of the electronic ones (servomotors, encoders, brake, micro-switches), so that, finally, the multi-axes mechatronic system accurately works. Some images of the assembling process are shown in Fig. 13.

Preliminary tests were performed so that to check accuracy positioning, specially for the "Blade" subassembly – which is the one supporting the blade for layering printed perovskite material. The required movement that ensures ultrathin layers thickness is the vertical one (along OZ axis). Images taken while checking repeatability positioning accuracy are presented in Fig. 14.

assembly the components of "Frame" subassembly

mounting DC servomotors

mounting bed & micro-switch

Fig. 13. Printing equipment subassemblies' manufacturing

Fig. 14. Checking repeatability positioning accuracy

IV. Conclusion

Perovskite solar cells have become commercially attractive, due to their potential of achieving even higher efficiencies and the very low production costs.

Printing equipments available on the market are specialized ones, and enable application of only one low cost printing technology for obtaining solar cells.

Research presented by this paper is focused on the development (design and manufacture) of an innovative printing equipment, in fact a three axes mechatronic system, that is fit for printing ultra-thin layers of perovskite solar cells, with three different printing technologies (screen printing, doctor blade, wire bare) , due to its modular structure.

Further development of this work will be focused on the improvement with a fourth axis for the motion of perovskite material's reservoir; on the dimensioning calculi for the IR ceramic resistors to be used in the heating zone; on the setup of parameters for controller, servomotors and encoders. Finally, tests and experiments in a clean room will be done, so that to validate all this research results.

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