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Simultaneous photovoltaics and photosynthesis- a Complete Solar light harvesting solution for Indian Homes and Farms

1. Background and Motivation

Solar light harvesting is an attractive renewable energy option, especially for India. However, finding spaces for solar panel installation is a hard task in our country of 134 crores population. Sacrificing farmlands, backyards or terraces for solar panel installations is a hurdle and challenges the already depleting agriculture and small-scale farming. Farmlands are selected based out of enough availability of sunlight and the requirement for solar cell installation also remains the same. Once the solar panel is installed in a farmland, farmers cannot do anything underneath which would affect the agricultural productivity of the country while ensuring marginal increase in production of renewable energy. One direct example that can be quoted is the solar panel installations near airports for example Kochi (Please see Figure 1), which has increased the pride of our nation by becoming power neutral by this method, however use lot of land which could have been utilized for agriculture. Same challenge applies to the conflict between terrace farming - rooftop solar panel installations, an urban situation, very relevant in most of the present Indian cities. A solution to this, allowing both processes to co-exist is relevant to Indian society.

Figure 1 Solar power plant at Kochi airport producing 12 MWp; 46,150 solar panels laid across 45 acres

While looking for such a solution, most important question to answer is which material do we use and can we have an indigenous technology. All the commercial panel installations in India are Si-based because it is stable. However, we do not have any of the possible technology for the production of Si solar cells including sources for Si, single crystal pulling, as well as manufacturing of solar cell. It is hence time to develop indegenous **technology for solar cells in India.** Silicon does not qualify for this purpose and the research on Si solar cells is saturated enough that we need to look for alternative materials for balancing efficiency- stability-cost triangle. There is a need to substitute Si and **perovskites are alternate choice as alternate material for India due to low cost, mineral availability and tunability of structure and bandgap**. This is clear from the enormous research happening in around the world, on perovskites.

2. Proposed work

In the total solar spectrum, visible region constitutes of 47 % of the total energy and infrared (IR), 51 %. Remaining 2 %, are the other wavelengths including UV. Photosynthesis does not use most of the visible light, rather a window approximately in 500-600 nm range is reflected off the leaves. **A technology of semi-transparent solar panel roofs where some light is used for solar electricity generation and the remaining transmitted radiation is used for plant cultivation thereby providing maximum utilization of solar energy, is highly promising and exciting.** Proof of concept of such a technology is the principal idea of the proposed work. Research on solar cells in view of sustainable energy production has to be branched out into materials engineering, chemical engineering, energy management, semiconductor physics, as well as electronics and electrical engineering. Selection of material or solar cell technology is very important in the proposed work. New generation materials have to be designed with enhanced efficiency. Silicon is the most widely used as well as established material for photovoltaic applications at present. However, the low bandgap (1.1 eV) of silicon causes the solar cell, not to absorb significant visible and UV portion of the solar spectrum [1]. Also, the high energy photons absorbed on silicon solar cell release the remaining energy in the form of heat, causing undesirable temperature rise in the solar cell, illustrated in Figure 2. Organic and dye-sensitized solar cells are alternative emerging technologies to

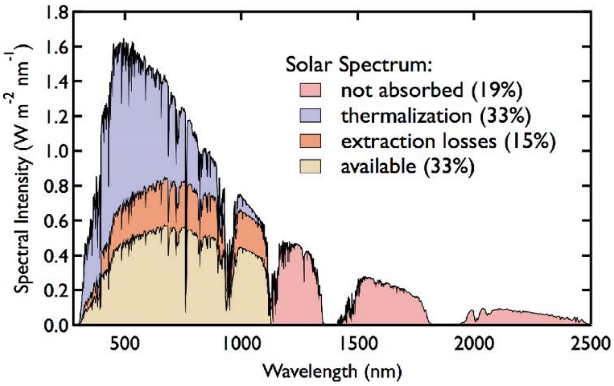

Figure 2 Absorption of solar light by Si solar cell; thermalization losses are very high

solve the drawbacks of silicon based solar cells. Organic solar materials have been tried for simultaneous photosynthesis/photovoltaics [2]. Some of the alternative materials considered were wide bandgap, oxide and sulphide semiconductor materials such as TiO_2, ZnO, PbS and CdS. Recently, Perovskite materials have become important, due to rapid increase of solar light harvessting efficiency demonstrated [3]. Perovskite materials are a choice for implementing the proposed technology since the flexibility of ABX_3 structure allows one to use several anions and cations in the structure, leading to wide range of physical properties and their application potential can become highly competitive to existing solar cell materials such as silicon.

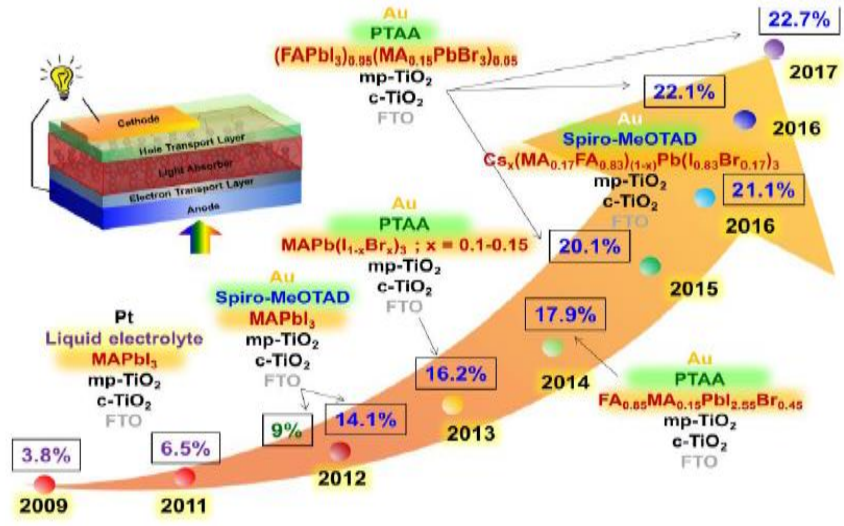

Figure 3 Perovskite solar cells : Large increase in efficiency within a decade

In particular, hybrid organic-inorganic perovskites are attractive since the organic group can give additional functionalities which are not found in purely inorganic structures. The efficiency of perovskite based solar cells has increased from 3.8 to 22 % as seen from Figure 3 [3], a motivating fact for our proposal.

The hybrid solar cells have achieved this efficiency in less than a decade showing superior performance than any other solar cell technology. Hence, this proposal aims to develop a **Simultaneous photovoltaics and photosynthesis solution using perovskite based materials**. Scope of the proposed research includes proof-of-concept of the idea, starting with DFT based material simulation and stability analysis and small-scale field trials on roof tops and homes. Figure 3 indicates the ideas leading to the proposal.

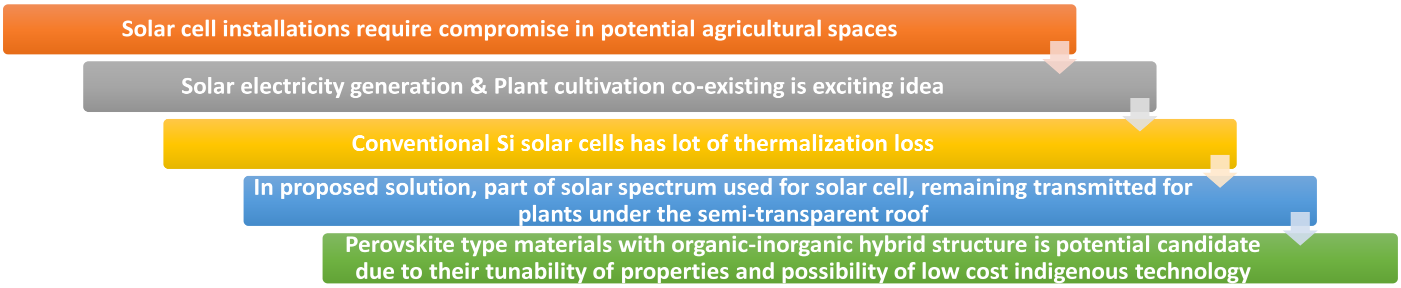

Figure 4 Flow of motivational ideas leading to the proposal

3. Important scientific advancements and breakthrough

(1) Advance the material level technology of pervoskite solar cells to achieve desired characteristics:

Perovskite materials have the attractive ABX_3 structure and a wide selection of A, B, X ionic materials with a mix of organic/inorganic groups for A and B positions as illustrated in Figure 5 [4], bandgap can be tuned and so the other properties [5-7]. Also, compared to Si based technology, perovskites can be implemented in lower costs. A natural question that would arise would be why not silicon for this application. Important requirements for a simultaneous photovoltaic/photosynthetic system is (a) good transparency to visible light (b) high absorption in visible NIR wavelengths. Semi-transparent solar cell materials have been tried earlier. Sanyo Electric Co., Ltd. developed a see-through a-Si solar cell and was installed in office buildings for windows [8-9]. The a-Si p-i-n solar cell was made transparent by fabricating a series of micro-holes on the film, and transmitted all wavelengths above 500 nm approximately. Si in amorphous state has a lower efficiency compared to many other materials (Figure 5 [3]). Also, fabrication and use of the complex mask to produce appropriate-sized microholes can be costly and complicated,

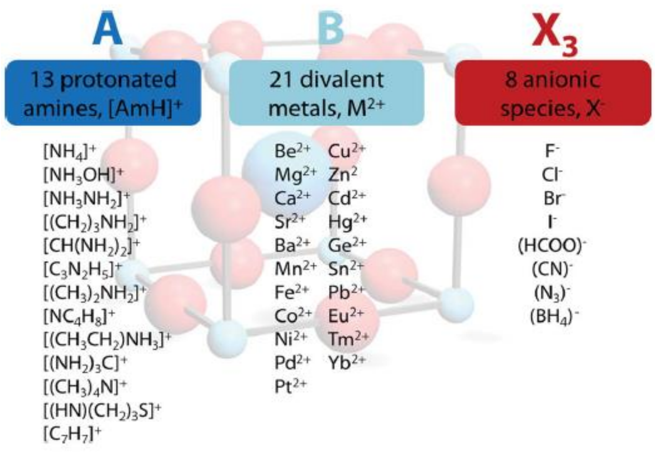

Figure 5 Few possible choices of A, B, X in ABX_3 **structure of perovskites**

which diverts our attention to other possible materials such as perovskites.Heterojunction organic photovoltaics are proven to be suitable for IR absorbing transparent photovoltaics with visible light transmission [10] and hence it is worth to consider organic-inorganic hybrid perovskites for the proposed work. Rapid increase in efficiency (Figure 6), for perovskite materials is a positive indication to explore them in solar cells.

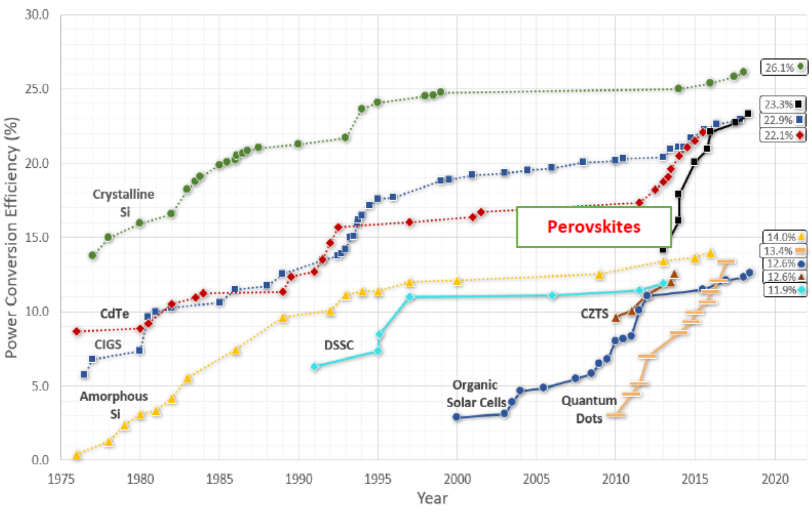

Figure 6 Efficiency of various materials as solar cell

Organic-inorganic hybrids such as MA $Pb_ySn_{1-y}(I_{1-x}Br_x)2$ ($0 \leq x,y \leq 1$, MA-methyl ammonium) can be a starting configuration to experiment with [5]. Formamidinium (FA) anion has shown superior performance recently and can be utilized in the structure [11]. The fundamental advancement in technology in the proposal would focus on overcoming the two challenges for a perovskite based system are (a) less stability (b) presence of toxic metals such as Pb. By using double layer oxides and lowering the defects, it is possible to increase the stability of perovskite cells beyond 1000 hours [12]. Addition of Cs in an organic-inorganic hybrid perovskite, is also shown to improve the stability of the solar cell [13-14]. It is possible to make modifications in device geometry as well as encapsulate the module using suitable materials to protect the device from exposure to moisture [15]. Replacement of lead can be possible by the use of bimetal halides such as $Cs_2BiAgBr_6$ and by using Sn instead of Pb.

(2) Theoretical studies for the optimization of structure and stability analysis and experimentation directions

- Optimization of the structure will be assisted by molecular dynamics / density functional theory based simulations. A simulation software could be purchased from the project.
- The effect of an organic cation of an organic-inorganic hybrid perovskite, on electronic/optical properties can be evaluated by DFT simulations [16].
- Stability is the major concern as we start talking about perovskites. Hence a comprehensive analysis of comparative stability from the energies by DFT is very much desired and beneficial. Theoretical photon conversion efficiencies can also be deduced.
- Theory that will be developed will be advantageously utilized to strengthen the theory group in IIT(ISM)

4. Objectives and methods

The proposal aims to develop a technology for simultaneously using energy from the sunlight, for photosynthesis, thereby growing plants and photovoltaics, producing renewable electricity, using novel perovskite based materials engineered for absorbing light unused for photosynthesis. Brief objectives and methods of the proposed work are given below:

- Exploring materials of perovskite type and engineering the desired absorption and transmission characteristics by incorporating FA-MA groups and double halides of various ratios.
- Conducting theoretical studies to optimize the structure
- Obtain reliable and repeatable morphology and physical properties of the thin films obtained, Optimize the choice of substrate and preparation conditions
- Physical/thermal vapour deposition could be used for the thin-film perovskite solar cells. A sequential deposition can also be used [17-18]. Existing thin film deposition facility at ECE department, IIT (ISM) will be utilized
- Nanostructured contacts made of Ag has drawn attention recently which offer minimal damage to underlying perovskite absorber layer and could be explored [19] for design of device level testing.
- A roof top green house could be setup and small seedlings can be observed for their increase in height with respect to number of days and compared with a normally exposed seedling [2].

3. Utilization of expertise in the department and collaborations

- Dr. Aparna Neettiyath, Dept. of ECE, IIT(ISM) Dhanbad
- Prof. Jitendra Kumar, Dept. of ECE, IIT(ISM) Dhanbad
- Prof. B Viswanathan (Emeritus), Dept. of Chemistry, IIT Madras
- Support from Centre of Excellence in Renewable Energy (CERE), IIT (ISM) Dhanbad for facilities

Approximate budget for starting theory based research:

DFT software (10 lakhs), 2 JRFs (3 year fellowship), Contingency (5 lakhs), Overhead (15-20 %)

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