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Perovskite Solar Cell - A Source of Renewable Green Power

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Abstract- The earth receives 2.9X10^{15} kW of energy every day in the form of electromagnetic radiation from the sun, which is about one hundred times the total energy consumption of the world in a year. Bell Telephone Laboratories produced a silicon solar cell in 1954 with an efficiency of 4% efficiency which later enhanced to achieve 11%. The cost of generation of one watt of solar power in 1977 was $77/watt which was later brought down to about 80 cents/watt. Recently a new substance called a perovskite used for solar cell preparation could cut the cost of a watt of solar generating capacity by three-quarters. The potential of this material that it could lead to solar panels that cost just 10 to 20 cents per watt has been presented.

The characteristics of Perovskite, a calcium titanium oxide mineral species composed of calcium titanate. Perovskites solar cells first tried in 2009 converted about 3.5 percent of the energy in sunlight into electricity. PV device have already achieved 15% efficiency and aiming for higher efficiency upto 20% has been discussed.

Based on organic-inorganic perovskite-structured semiconductors, the most common of which is the triiodide ($CH_3NH_3PbI_3$), these perovskites tend to have high charge-carrier mobilities. The flexible transparent panel made from cultured colored perovskite proved that future solar cells can be beautiful facades with architectural designs for the building in addition to generating power required for the buildings. Further one could charge the car battery when parked in sun and will soon become the reality with flexible solar cell painted on car roof and other surfaces. The perovskite material is dirt-cheap and has a bright future in solar cell industry for renewable energy generation.

Index Terms- Solar energy, Perovskite, renewable energy, renewable energy, Perovskite solar cells, High efficiency solar cells, Replacement of tin in perovskite, flexible solar cells, Solar cells painted on sky scrapers, Perovskite cell as lasers.

I. Introduction

The earth receives 2.9X10^{15} kW of energy every day in the form of electromagnetic radiation from the sun, which is about one hundred times the total energy consumption of the world in a year [1]. Solar technology isn't new. Its history spans from the 7^{th} Century B.C. to today. We started out concentrating the sun's heat with glass and mirrors to light fires. Today, we have everything from solar-powered buildings to solar powered vehicles. The solar energy falling on earth has been quantified as "Sun" and is approximately equal to 100 watts/ft^2 or 1000 watts/m^2.

Daryl Chapin, Calvin Fuller, and Gerald Pearson Daryl Chapin, Calvin Fuller, and Gerald Pearson at Bell Telephone Laboratories, USA produced a silicon solar cell with 4% in 1954 efficiency and later achieved 11% efficiency [2]. The development of solar concentrators was necessitated due very low current and voltage capabilities of a solar cell and it all started only after 1970s. Today we have everything from solar powered buildings to solar powered vehicles. However, till date the efficiency of the solar cells could not cross 16 to 17% and the electrical power produced by solar costs $5-6 per watt.

Fig. 1: The Perovskite Mineral

Recently in 2009 a new substance called a perovskite as shown in Fig. 1 has been identified for the preparation of photovoltaic (PV) devices solar cells that could cut the cost of a watt of solar generating capacity by three-quarters. The potential of this material is enormous and could soon replace silicon the base material used so for the fabrication of solar cells. It is expected that the solar energy converted to electrical energy by these perovskite solar cells/ and the panels would cost just 10 to 20 cents per watt.

The **Perovskite** mineral is a calcium titanium oxide mineral species composed of calcium titanate, with the chemical formula $CaTiO_3$.The mineral was discovered in the Ural Mountains of Russia by Gustav Rose in 1839 and is named after Russian mineralogist Lev Perovski (1792–1856). It lends its name to the class of compounds which have the same type of crystal structure as $CaTiO_3$ ($^{XII}A^{2+VI}B^{4+}X^{2-}{}_3$) or $CH_3NH_3PbI_3$ known as the perovskite structure. The crystal structure shown in Fig. 2 was first described by V.M. Goldschmidt in 1926. The crystal structure was later published in 1945 from X-ray diffraction data on barium titanate by the Irish crystallographer Helen Dick Megaw (1907–2002). It has a formula mass of 135.96 and its color is black, reddish brown, pale yellow, yellowish orange.

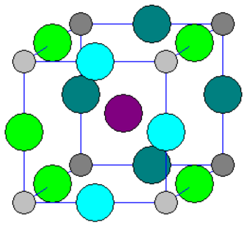

Fig. 2: Perovskite Crystal Structure

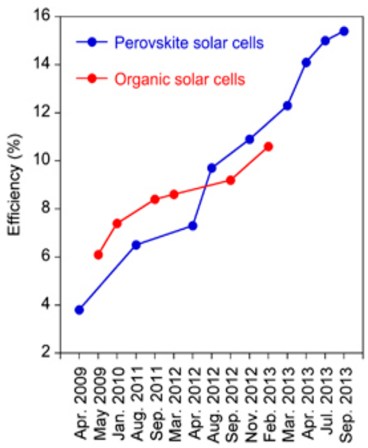

Fig. 3: Efficiency of perovskite solar cells with time

New solar cell material perovskite offers both cheap and efficient power. When perovskite solar cells were first tried in solar cells in 2009 converted about 3.5 percent of the energy in sunlight into electricity. With consistent research at different labs work perovskite PV device have already achieved 15% efficiency and scientists are aiming for higher efficiency upto 20% [3].

The progress since 2009 has been astonishing, even for a dynamic sector like solar: from 4% to 19% efficiency in five years. Chart from Burn & Meredith, Nature, January 2014. The chart is out of date and the record has risen to 19.3%, announced by Yang Yang at UCLA [4].

Functioning of perovskite solar cell

Photovoltaic energy conversion offers one of the best means for the future of renewable energy in the world. The efficiency of solar cells depends heavily upon the light-absorbing materials they use. Photovoltaic systems based on lead halide perovskite are a new, revolutionary type of device with efficiencies currently exceeding 16%. However, a detailed description of how these solar cells turn light into electrical current is still lacking. Publishing in Nature Photonics, scientists from Ecole Polytechnique Fédérale de Lausanne (EPFL), Netherlands have investigated how the generated electrical charge travels across the perovskite surface of solar cells built with different architectures [5].

Lead an environmental drawback in perovskite replaced with tin

In four years, perovskite's conversion efficiency has grown from 3.8% in 2009 to just north of 16%, with unconfirmed reports of even higher efficiencies arriving regularly. That's better than a four-fold increase. By contrast, efficiencies of single-crystal solar cells grew by less than 50% during their first five years of development, and most other types of solar cells showed similar modest improvements during their first few years. As seen above, the presence of lead (Pb) in perovskite however is major drawbacks. Hence the early perovskite-based solar cells containing lead a material that is not without its environmental drawbacks as the light-absorbing layer.

Tin Replaces Lead in Promising Solar Cell

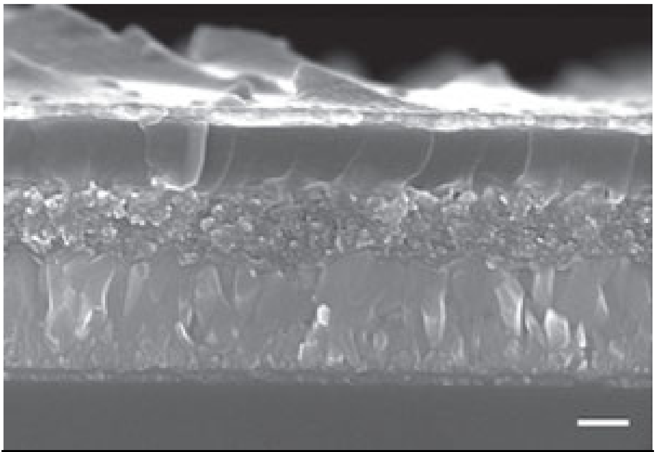

Fig. 4: Cross-sectional view of a completed photovoltaic device using tin perovskite. Courtesy: Nature Photonics.

Efforts were made at Northwestern University to develop a new form of perovskite-based solar cell that replaces lead with tin, a commonly available and much more benign material. The efficiency of this early tin-based cell is a just below 6 percent, but it is believed that there is no reason that tin perovskite solar shouldn't achieve much greater efficiencies on a par with lead. Oxford Photovolatics (Oxford PV), which is commercializing the technology developed by award-winning physicist Professor Snaith, says that omitting lead from the product will make it even more attractive to the potential licensees and customers. The future is lead-free for perovskite solar cells. The new solar cell uses a structure called a perovskite but with tin instead of lead as the light-absorbing material. Lead perovskite has achieved 15 percent efficiency, and tin perovskite should be able to match and possibly surpass that. Perovskite solar cells with tin are being touted as the "next big thing in photovoltaics" and have reenergized the field. “There is no reason this new material can't reach an efficiency better than 15 percent,” said lead researcher Mercouri G. Kanatzidis, an inorganic chemist with the Weinberg College of Arts and Sciences at Northwestern. “Tin and lead are in the same group in the periodic table, so we expect similar results” [6].

Lead free perovskite cells could speed up delivery of low cost solar power

Although the quantity of lead in Pb-based perovskites is miniscule, the research team, recognizing the requirement to eliminate lead in electronics, has been looking for a substitute that is more sustainable and also inexpensive and abundant. A new breed of solar cells, developed at the University of Oxford by Professor Henry Snaith and his research team, could bring low cost electricity to the market sooner than predicted following the development of a perovskite cell which uses tin instead of lead. "The use of tin has given the scope to produce incredibly cost effective solar cells and it is predicted that tin based solar cells could generate power for as little as $0.20/Watt and even this could drive down costs even further." Professor Snaith acts as the firm's Chief Scientific Officer. He was recently awarded Outstanding Young Investigator of the year by the Materials Research Society for his pioneering work on perovskite solar cells and was one of Nature magazine's ten nominated people who made a difference in science during 2013.

Diffusion Length

'The diffusion length tells us the average distance that charge-carriers (electrons and holes) can travel before they recombine,' says Dr Sam Stranks. 'Recombination happens when excited electrons and holes meet, leaving behind a low-energy electron which has lost the energy it gained from the sunlight.
If the diffusion length is less than the thickness of the material, most charge-carriers will recombine before they reach the electrodes so you only get low currents. You want a diffusion length that is two to three times as long as the thickness to collect almost all of the charges.'

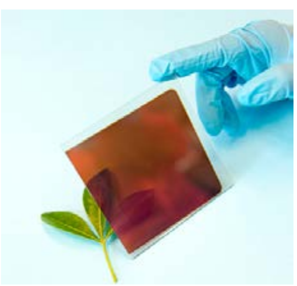

Fig. 5: Perovskite Fabricated on a Glass Sheet

Fig. 6: A Painted Flexible Coloured Solar Cell

Previously, researchers were able to get mesostructured perovskite cells to 15% efficiency, using a perovskite compound with a diffusion length of around 100 nanometres (nm). But by adding chloride ions to the mix, [the group] achieved diffusion lengths over 1000nm. These improved cells can reach 15% efficiency without the need for complex structures, making them cheaper and easier to produce.

There's a huge amount of research going on into solar PV, in many different avenues and the scientists are looking for following aspects and innovations:

- enhance efficiency, not simply reduce costs,
- look reasonably close to marketable products,
- use cheap not exotic materials and straightforward methods of fabrication,
- build on silicon, the dominant technology today.

Ultrathin Solar Cell is efficient and easy to make

Researchers at Oxford University in the UK have made a thin-film solar cell with better than 15% light-conversion efficiency from an emergent class of semiconductors known as perovskites. The devices have a simple architecture and could easily be produced in large quantities because the vapour deposition process used to make them is compatible with conventional processing methods for fabricating such solar cells. The perovskite cell fabricated on glass sheet is shown in Fig. 5, 6.

Use of nanoparticles in the manufacture of solar cells: Benefits

- Reduced manufacturing costs as a result of using a low temperature process
- Reduced installation costs achieved by producing flexible rolls instead of rigid crystalline panels.
- Currently available nanotechnology solar cells are not as efficient as traditional ones; however their lower cost offsets this. Nanotechnology using quantum dots would increase efficiency levels significantly.
- It is believed that solar cell technology will be contributing significantly to our energy needs by 2020 as costs are dropping rapidly.
- Accordingly to Deli Wang the efficiency of nanowire solar cells have been increasing dramatically in the past few years, from tenth of 1% to 15-16%. While it is still lower than the best Si cells (silicon), but it is fast improving.

Latest Developments & Highlights

Now there is excitement, and it is over a class of materials known as perovskites. Perovskite materials for solar cells were first reported in 2009 (organo-lead halides, in case you are interested), but they were very low efficiency and had to remain liquid in use. Not promising. . By doing some clever polymer chemistry, they were able to make solid perovskite solar cells, and then, in only 18 months, engineered these up to efficiencies of 16%. It took decades of research on silicon to get such improvements. But the polymer was expensive and complex. Still, **Science magazine classed perovskite solar cells as one of the breakthroughs of 2013.** So perovskite PV is at the point of, perhaps, maximum optimism. There are predictions that the efficiencies could reach 50%, the costs could fall to well below where silicon might get to in 10 years, and the science points to it being desirable to make these cells thicker, rather than as thin films, meaning they can be suitable as window or roofing materials. And the prototype cells produced have partial transparency.

II. Study: Perovskite solar cells can double as lasers

The new findings, recently published online in the *Journal of Physical Chemistry Letters*, show that these “wonder cells” can also produce cheap lasers. By sandwiching a thin layer of the lead halide perovskite between two mirrors, the team produced an optically driven laser which proves these cells “show very efficient luminescence”—with up to 70% of absorbed light re-emitted. Perovskite promises solar cell by day, light panel by night. This is seen in Fig. 7.

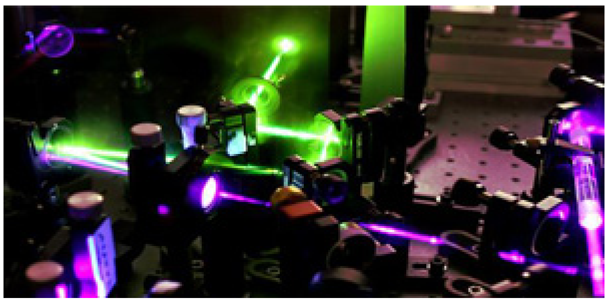

Fig.7: By sandwiching a thin layer of the lead halide perovskite between two mirrors, the team produced an optically driven laser which proves perovskite cells can re-emit up to 70% of absorbed light

1. Lead free perovskite cells could speed up delivery of low cost solar power

A new breed of solar cells, developed at the University of Oxford by Professor Henry Snaith and his research team, could bring low cost electricity to the market sooner than predicted following the development of a perovskite cell which uses tin instead of lead. Oxford Photovolatics (Oxford PV), which is commercialising the technology developed by award-winning physicist Professor Snaith, says that omitting lead from the product will make it even more attractive to the potential licensees and customers. Scientists at Northwestern University in Illinois have become the first to develop a new solar cell with good efficiency that uses tin instead of toxic lead perovskite to convert sunlight into electricity. The breakthrough will enable the manufacture of cheaper solar cells, also called photovoltaic cells or PV cells. The tin solar cell is being hailed as "the next big thing in photovoltaics."

2. Perovskite thin-film using vapour deposition to turn skyscraper as power plant

Fig. 8. The glass sides of skyscrapers will become power plants in the not-too-distant

The glass sides of skyscrapers will become power plants in the not-too-distant. The rapidly falling cost of converting sunlight into electricity means it's just a matter of time before solar power generation is part of the structure of new buildings. At the same time, the development of new photovoltaic materials for turning photons into electrons is increasing the range of ways the sun's energy can be harnessed. The scientists think will be very widespread around the world in the next three to five years. It won't be considered a novelty in new buildings **-** it will be a no-brainer in terms of building cost-effectiveness." **Perovskite solar material to reach conversion efficiency of over 30 percent.** There is a bright future for solar ahead**.** The glass sides of skyscrapers will become power plants in the not-too-distant. This is shown as shown in Fig. 8.

III. Spray-on cells can turn anything into a solar panel:

Scientists from Sheffield have developed low-cost, spray-on solar cells**.** They are applied to surfaces in a similar way to paint or graphic printing**.** The spray-on cells are made perovskite that produces very little waste. They can be easily mass produced, meaning manufacturing costs are low.

IV. Spinning Solar Cells Into Electronics Textiles

Scientists have developed solar cells in the form of fibers that can be woven into textiles, paving the way for powering small electronic devices incorporated into clothing. Although promising as a source of renewable energy, solar cells are facing a trade-off between cost and efficiency: they are either inexpensive or inefficient, or they have a reasonable efficiency and are very expensive. One solution may come from solar cells made of perovskite materials, which are less expensive than silicon and do not require any expensive additives. Perovskites are materials with a special crystal structure that is like that of perovskite, a calcium titanate. These structures are often semiconductors and absorb light relatively efficiently. Most importantly, they can move electrons excited by light for long distances within the crystal lattice before they return to their energetic ground state and take up a solid position, a property that is very important in solar cells.

A team led by Professor Peng Hisheng at Fudan University in Shanghai has now developed perovskite solar cells in the form of flexible fibers that can be woven into electronic textiles (8). Prototype solar panels incorporating nanotechnology are more efficient than standard designs in converting sunlight to electricity, promising inexpensive solar power in the future. Nanostructured solar cells already are cheaper to manufacture and easier to install, since they can use print-like manufacturing processes and can be made in flexible rolls rather than discrete panels as shown in Fig. 6. Newer research suggests that future solar converters might even be “paintable.” The multi colored facades on the buildings as shown will be flexible and will not only be decorative but also will generate electrical energy required for the buildings.

V. Spray Deposition Steers the Perovskite Solar Cells Towards Commercialization

Ultrasonic spray coating has been developed by a team of researchers in the UK. It represents a significant step towards commercializing perovskite solar cells. Thin-film solar cells using perovskite semi-conductors have become a promising form of photovoltaic device achieving power conversion efficiencies of up to 15–19%, surpassing the efficiencies of amorphous silicon and organic semi-conductor photovoltaics. Perovskite films can be fabricated by depositing precursor materials from solution. However, there have been few reports detailing the application of scalable solution-processing techniques to create these films.

Conclusions

1. The future is lead-free for perovskite solar cells.
2. "Solar energy is free and is the only energy that is sustainable forever," Kanatzidis said. "If we know how to harvest this energy in an efficient way we can raise our standard of living and help preserve the environment."
3. Typical solar panels have an efficiency of about 10%; expensive ones perform at 20%. (Fundamental physical laws limit the efficiency of photovoltaic systems to at best 60% with perfect concentrating mirrors or lenses, and 45% without concentration. A mass-produced [photovoltaic] device with efficiency greater than 30% would be quite remarkable.)
4. Accordingly his scenarios assume 20% panel efficiency for residential and 10% for utility. That's till 2050. In 100% renewable scenarios, the volume of solar is constrained by total roof area and competing land uses. So if you could plug in a higher efficiency, the limits shift too.

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