Solar: paper like cells

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1. Theme description

There is a significant interest for the production of renewable energy. The researchers try every day to find or improve methods to produce green energy. One of the best renewable energy is the solar energy: available every day (though discontinuously)[1].

A new system to capture and use the solar energy is 3PV (printed paper photovoltaics)[2]. This technology uses an ink with electrical properties to print on a lot of materials (paper too) an advanced system of solar cell[3].

The 3PV is developed and study for the first time by the MIT researchers in 2011[4].

This new technology could be incorporated into clothing, accessories and etc. opening the ways to new method to use the solar energy[5]. The printed cells are flexible so it could be use in documents, windows, wall coverings, etc. adapting its form. Furthermore, this cheap technology could lead to produce new solar system in rural areas, needing reliable source of electricity.

The efficiency of the 3PV started in 2011 with 1%, reaching now about the 20%[6].

Additionally, the power-to-weight ratio of this technology is among the highest ever achieved: it is more efficient than common photovoltaic cells on glass substrates.

In the following, an overview of 3PV and the major results obtained by this technology until now are reported.

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[1] https://www.renewableenergyworld.com/index/tech.html
[2] http://blog.drupa.com/de/solar-cells-printed-paper/
[3] https://inhabitat.com/paper-thin-printed-solar-cells-could-provide-power-for-1-3-billion/
[4] http://energy.mit.edu/news/solar-cells-printed-on-paper/
[5] https://www.treehugger.com/clean-technology/solar-cells-can-now-be-printed-on-anything-even-paper-and-fabric.html
[6] http://blog.drupa.com/de/solar-cells-printed-paper/

2. 3PV Technology

This kind of technology could be printed on normal paper that is cheaper than traditional glass substrate and common plastic (about 0.01 $\$*m^{-2}$ vs 10 $\$* m^{-2}$ and 0.2-3 $\$*m^{-2}$).This is an important factor, because the 25-60% of total material costs is in current solar modules[7]. The vapor printing process deposits the conductive polymer poly (3,4-ethynelenedioxythiophene) on any substrate (glass, plastic or paper)[8].

This process combines in situ shadow masking with oxidative chemical vapor deposition (oCVD) to create polymer patterns on the chosen surface. The printed polymer patterns (about 20 µm resolution) result from the presence of a shadow mask, maintaining the partial pressure of the vapor-delivered oxidant species close to its saturation pressure at the substrate, which reduces mask undercutting. This process of vapor delivery of the oxidant species results to be unique from other techniques, because it doesn't rely on solvent casting of oxidants prior to vapor delivery steps[9].

The conducting polymer layer must have low sheet resistance (R_{sh}) and high optical transmittance (T) to be used as a transparent electrode, the which are related by the following equation[10]:

$$T = (1 + \frac{Z_0}{2R_{sh}} \frac{\sigma_{op}}{\sigma_{dc}})^{-2}$$

Where:

- Z_0 is the impedance of free space;
- σ_{dc} and σ_{op} are the cd and optical conductivities.

The power lost from the electrode sheet resistance for a cell of width *w* and length *l* (remembering that current is collected along *l*), can be estimated by the following equation[11]:

$$P_{loss} = \frac{R_{sh} J_{sc}^2 w^3 l}{3}$$

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[7] K. Zweibel, Sol. Energy Mater. Sol. Cells 2000, 63, 375

[8] Miles C. Barr, Jill A. Rowehl, Richard R. Lunt, Jingjing Xu, Annie Wang, Christopher M. Boyce, Sung Gap Im, Vladimir Bulovic´ and Karen K. Gleason, Direct Monolithic Integration of Organic Photovoltaic Circuits on Unmodified Paper, Materials Viewes, 2011

[9] B. Winther-Jensen, K. West, Macromolecules 2004, 37, 4538

[10] V. Scardaci, R. Coull, J. N. Coleman, Appl. Phys. Lett. 97.

[11] M. W. Rowell, M. A. Topinka, M. D. McGehee , H. J. Prall , G. Dennler , N. S. Sariciftci , L. B. Hu , G. Gruner , Appl. Phys. Lett. 2006, 88

Where J_{sc} is the reverse saturation current.

Paper substrates have a range of light transmission properties, characterized by high light dispersion (transmissive and reflective) due to surface roughness, but low absorptive losses.

The external quantum efficiencies are lower on the paper substrates due to substrate/electrode losses, while the estimated internal quantum efficiencies are comparable across the visible spectrum, indicating similar upper bounds on efficiency for both the paper and conventional ITO/glass structures (if effective light trapping schemes are incorporated). These schemes may be uniquely designable for paper substrates because of their good reflectance and scattering properties, where more than 90% of the light absorbed by the active layer in the paper-based devices stems from diffuse transmission (scattering) compared to 10% on smooth ITO/glass.

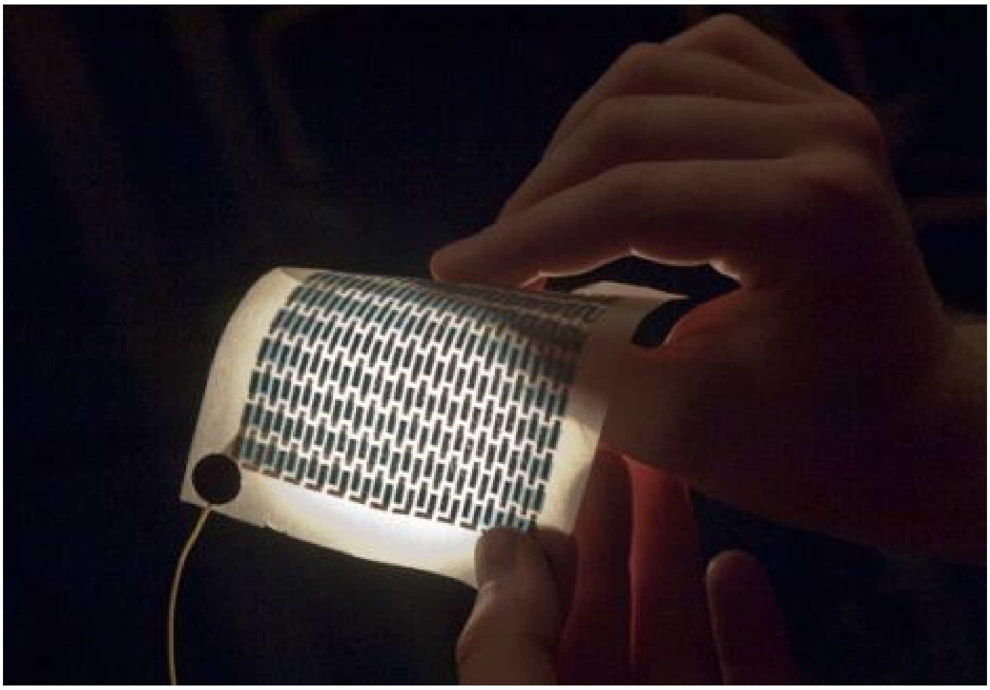

Figure 1. PV example.

The integration of arrays of individual PV cells is enabled by the ability to print patterned device layers on any substrate[12].

[12] Solar cells with inkjet printed polymer layers, Alexander Lange, Michael Wegener, Bert Fischer, Silvia Janietz, Armin Wedel, SciVerse ScienceDirect, 2011

The pattern for each device layer needs to have anode-to-cathode interconnections between the individual cells. At last, the specific circuit design should be optimized to minimize efficiency losses due to parasitic resistances, fractional device coverage and absorption.

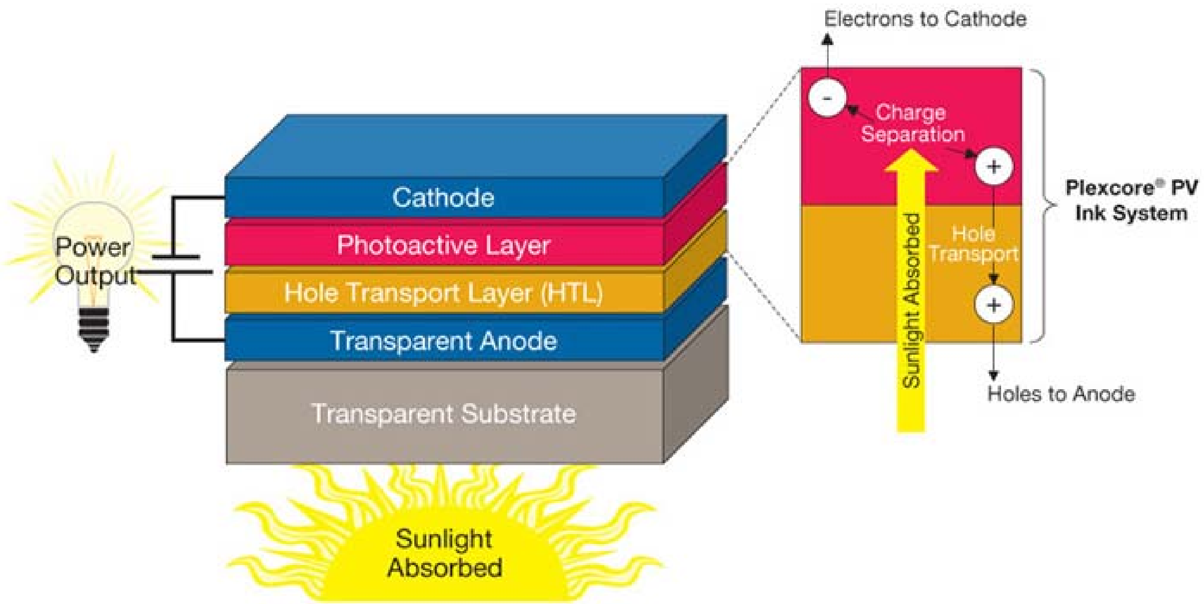

Figure 2. PV structure[13].

The layer structure could be paper/Zn/ZnO/photoactive layer/PEDOT:PSS, where Zn and PEDOT:PSS are used respectively as cathode and anode. A blend of P3HT and PCBM acts as the photoactive layer. An interlayer of ZnO between metallic Zn and the photoactive layer acts as a hole-blocking layer[14].

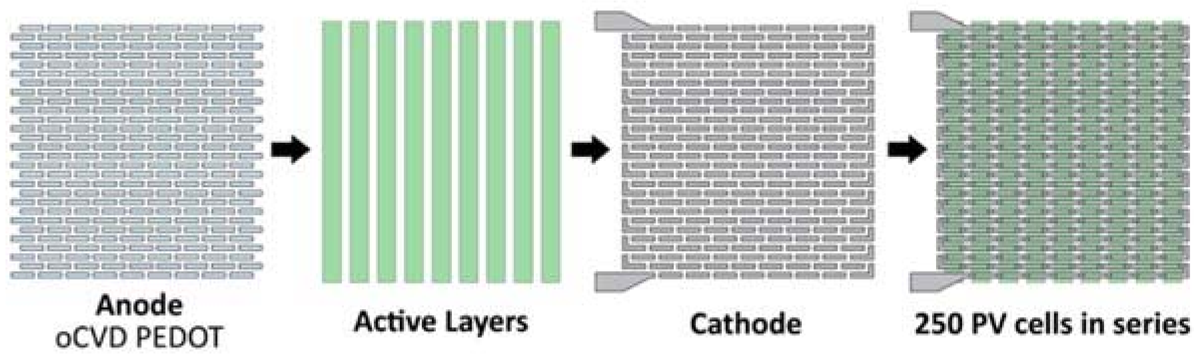

Figure 3. PV printing steps[15].

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[13] https://www.sigmaaldrich.com/technical-documents/articles/technology-spotlights/plexcore-pv-ink-system.html
[14] H.-L. Yip, S. K. Hau, N. S. Baek, A. K.-Y. Jen, Appl. Phys. Lett. 2008, 92, 193313
[15] http://energy.mit.edu/news/solar-cells-printed-on-paper/

Solar cells were printed using only three printing steps:

- first, cold-foil transfer printing of an oxidized Zn cathode on a glossy paper;
- second, gravure printing of the photoactive layer (P3HT:PCBM);
- third, flexographic printing of the PEDOT:PSS anode.

For final deployment these lightweight structures will need flexible thin film encapsulation to reach sufficiently long lifetimes and provide other environmental protections[16].

250-cell series-integrated arrays on tracing paper were protected on both sides with three encapsulants[17]:

- 5-mil thick plastic laminate applied with an office laminating machine;
- 750-nm thick poly(monochlorop-xylylene) deposited by self-initiated CVD polymerization;
- 750-nm thick hydrophobic and crosslinked poly(1H,1H,2H,2H-perfluorodecyl acrylate) film deposited by initiated CVD polymerization.

Finally, the various encapsulating films can also add specific functionalities to the integrated arrays of paper photovoltaics: the submicron iCVD-coated array is hydrophobic and foldable.

3. Conclusion

In conclusion, printed photovoltaic technology is the new frontier for the photovoltaic. It has a low cost of production, because it used an inkjet printer on paper substrate. Furthermore, the ink is composed by a low-cost metal salt blend, reducing the cost of the solar cells. The printer's ability to create precise patterning produces a very little waste of materials[18].

Also, the 3PV on paper substrate offers:

- Greater flexibility: being lightweight and flexible, 3PVs can be integrated into windows, window furnishings, tent and etc.[19];

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[16] M. Jorgensen, K. Norrman, F. C. Krebs, Sol. Energy Mater. Sol. Cells 2008, 92, 686

[17] M. E. Alf, A. Asatekin, M. C. Barr, S. H. Baxamusa, H. Chelawat, G. Ozaydin-Ince, C. D. Petruczok, R. Sreenivasan, W. E. Tenhaeff, N. J. Trujillo, S. Vaddiraju, J. Xu, K. K. Gleason, Adv. Mater. 2010, 22, 1993.

[18] Wang, Wei (September 2011). "Inkjet printed chalcopyrite CuInxGa1−xSe2 thin film solar cells". *Solar Energy Materials and Solar Cells*. **95** (9): 2616–2620.

[19] https://www.bloomberg.com/news/articles/2012-04-19/miles-barr-printing-solar-cells-on-paper-and-clothes

- Portability: this technology can provide immediate power to cater to the energy needs for remote outback locations and developing communities[20].

It could be used in rural region or developing nations to produce energy at low cost, ensuring energy from a renewable source.

In 2011 the efficiency is the only disadvantage of the 3PV technology (efficiency equal to 1%), but today, developing new materials and processes, the efficiency is greater than 19 per cent on small-scale devices.

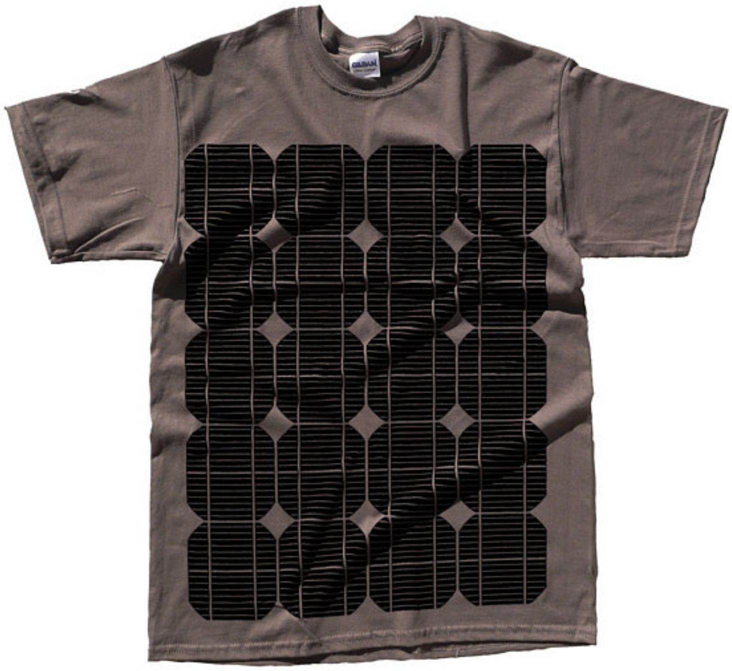

Figure 4. PV technology on a T-shirt.

[20] https://www.csiro.au/en/Research/MF/Areas/Innovation/Flex-Electronics/Printed-Solar-Cells