Efficiency of inkjet printing in fabrication Organic Solar cells

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Abstract:
Where the previous OSCs traditional methods were spin coating and evaporating or roll to roll compatible, whereas printing methods were pad printing, gravure, screen printing used in OSCs printing. There is lack of clean and eco-friendly energy fabricating solar cells with the 2D and 3D inkjet printing in Egypt as well or its efficiency in fabricating the cells. The research methodology to achieve the research objectives, conclusions and recommendations is the descriptive approach, which is based on describing the innovative techniques used in fabrication of OSCs and the effective factors on production process, in order to increase its productivity, in addition to, the study had studied the effect of using the new spotted technology in printing on several organic or hybrid (organic/inorganic) materials with the ability to produce OPV in new aesthetic freedom designs, colors and shapes, that could allow creating solar cells on blinds, in windows, curtains, shade umbrellas, tents and almost everywhere in or outside home. For that special emphasis on the relevance of inkjet in the manufacturing of the device showing in each of the revised technologies, main achievements, applications and challenges The study has a different results about solar cells which are critical source of energy and very needed nowadays, the use of solar photovoltaic to generate electricity will grow efficiently using IJP, inkjet solar cells should alternate the pervious types of energy with a clean, cheap one' with its flexibility of aesthetic designs use..

Keywords:
Inkjet Printing, Organic Solar Cells, EHD Inkjet Printing, organic photovoltaic, printed electronics, module design, freedom of design

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1. Introduction

Inkjet printing, traditionally used in printing graphics, has been widely investigated as a valuable tool in the preparation of functional surfaces and devices. In the last few year it turned focus in prints fabrication photonic devices.

Inkjet printing is a non- contact method so there is a large flexibility in the use of substrates of different materials, size and even not flat or flexible ones. Despite inkjet printing is a serial process, it is scalable technology able to deliver high throughput, for example, multiple printheads, each have a large number of nozzles ejecting at very high frequencies can be used, allowing multi-ink wide print-width with a single path leading to a high productivity. It is completely different from the other conventional printing processes, inkjet as a digital technique, enables inline correction of defects or distortions, by automatically adjusting the printing configuration of nozzles when a defect is detected, what is critical to obtain production at high yield in certain defect sensitive applications. In addition, inkjet printing is compatible with roll to roll (R2R) processing and can be effectively combined with other old printing techniques such as gravure, screen printing, offset lithography or flexography to optimize the production process of OCSs.

2. Research Problem

Previous OSCs traditional methods like spin coating and evaporating or roll to roll compatible as well as printing methods such as Pad printing, Gravure, Screen printing were used in its fabricating, whereas there is lacking of clean and eco-friendly energy fabricating solar cells with the 2D and 3D inkjet printing in Egypt as well as its efficiency in fabricating the cells.

3. Research Methodology

The research methodology is the descriptive approach, based on describing the digital printing innovative techniques used in photovoltaic devices in order to increase clean power resources productivity.

4. Research Objectives

1. Increased awareness of the global innovative technologies in photovoltaic devices to raise its productivity in Egypt
2. Studying the factors affecting on the production to achieve quality models.
3. Applying of freedom designs in printed solar cells photovoltaic devices

5. Inkjet printing

5.1: Advantages of using Inkjet printing in comparison with the other methods

Inkjet printing is now being used in place of screen printing to make electrical connections during the process of making more conventional crystalline silicon solar modules. The inkjet method can be more precise than previous methods, and since the print heads do not make contact with the silicon, a thinner, more fragile piece can be used. Conventional screen printing methods need to use silicon wafers that are at least 200 micrometers thick because any thinner wafer will likely break. It is estimated that 100 micrometers of silicon can be used with the inkjet process, and since silicon can account for 75% of the total cost of materials and production, this could greatly reduce overall costs (Bullis 2009). The silver gridlines can be printed with inkjet printing and the ink used is more conductive than the silver paste in screen printing. Maikel van Hest, a scientist at the National Renewable Energy Laboratory, noted more precise lines of 35 to 40 micrometers wide, compared with 100 to 125 micrometers wide with screen printing can also be printed (Bullis 2009). This ultimately means that not as much silver will need to be used, saving additional money and resources. The thinner lines also can block less of the solar collecting material, so that the sun's radiation can hit more of the surfaces that are actually collecting it, as opposed to bouncing off because of the thicker silver lines. These thinner lines make the cells more efficient, although at the moment the amount of increased efficiency is unknown.

No matter what application inkjet printing is being used in, the process is proving to be a very important part of making photovoltaic solar cells more economical and more accessible. While currently it is only used in mass production, the potential of being able to print on a personal printer is definitely a considerable advantage that this process has over any of the others. Not only is inkjet printing improving already-developed PV manufacturing processes, but it is also a key component to an entirely new type of thin film that could be used for any number of purposes. Inkjet printing is helping to reduce costs of manufacturing and increase the efficiency and availability of solar cells, which are currently vital goals of the photovoltaic solar industry.

5.2: Inkjet of Organic Solar Cells Materials

5.2.1: The polymer materials of inkjet organic OSCs

The primate commonly used polymer for inkjet organic OSCs can be classified as: [Poly (3,4-ethylenedioxythiophene), Poly (styrenesulfonate) (PEDOT: PSS), Poly (3- hexylthiophene) (P3HT), [6,6] phenyl C61-butyricacid methylester (PCBM,99%)] (Eggenhuisen 2015), [Solvents, PEDOT Agfa (P3HT (Mw 19kg/mol), Activink, PCBM,99%, Suntronic U5603 AG Nanoparticle ink] (Biezemans 2015), [Regioregular P3HT (Mw=31,300g/mol,RR=93.6), PCBM(99%), Polystyrene varieties with molecular weight of 35,000/mol(PS-M) and 350,000g/mol (PS-H) 1,2,3,4-Tetraphydronapthalene (tetralin,99%), indan(95%) and o-xylene(97%)] (Lamont 2015), [The polymers PCPDT and PSBTBT, mono-PCBM and bis-PCBM(99%pure), The solvents chlorobenzene(CB) and ortho-dishlorobenzene(o-DCB)] (Teichler 2011), [P3HT,PCBM] (Aernouts 2008), [High-conductivity PEDOT: PSS,5wt%DMSO and 0.1% fluorosurfactant, PCDTBT:PC70BM, AG Nanoparticle Ink] (Jung 2014), (please find all materials abbreviations explanation in Glossary).

The performance of printed electronic devices is strongly affected by the optical transparency, electrical and structural characteristics of polymer substrates. (Logothetidis 2008)

5.2.2: Paper for solar cells

Paper should act as a flexible and conductive substrate that works as a current collector. the goal is to get a highly conductive paper that is flexible, mechanically resistant, and highly accessible to ions in the electrolyte (Hu 2012), for this goal, mainly based on functionalization with single-walled carbon nanotubes (SWCNTs), silver nanowires (AgNWs) (La Mantia 2009), graphene (Weng 2011), Nanoparticles (Ko 2017), etc. The characteristic of these coatings lies in their feature to completely cover the cellulose fibers and electrically connect neighbor fibers. Fig (1)

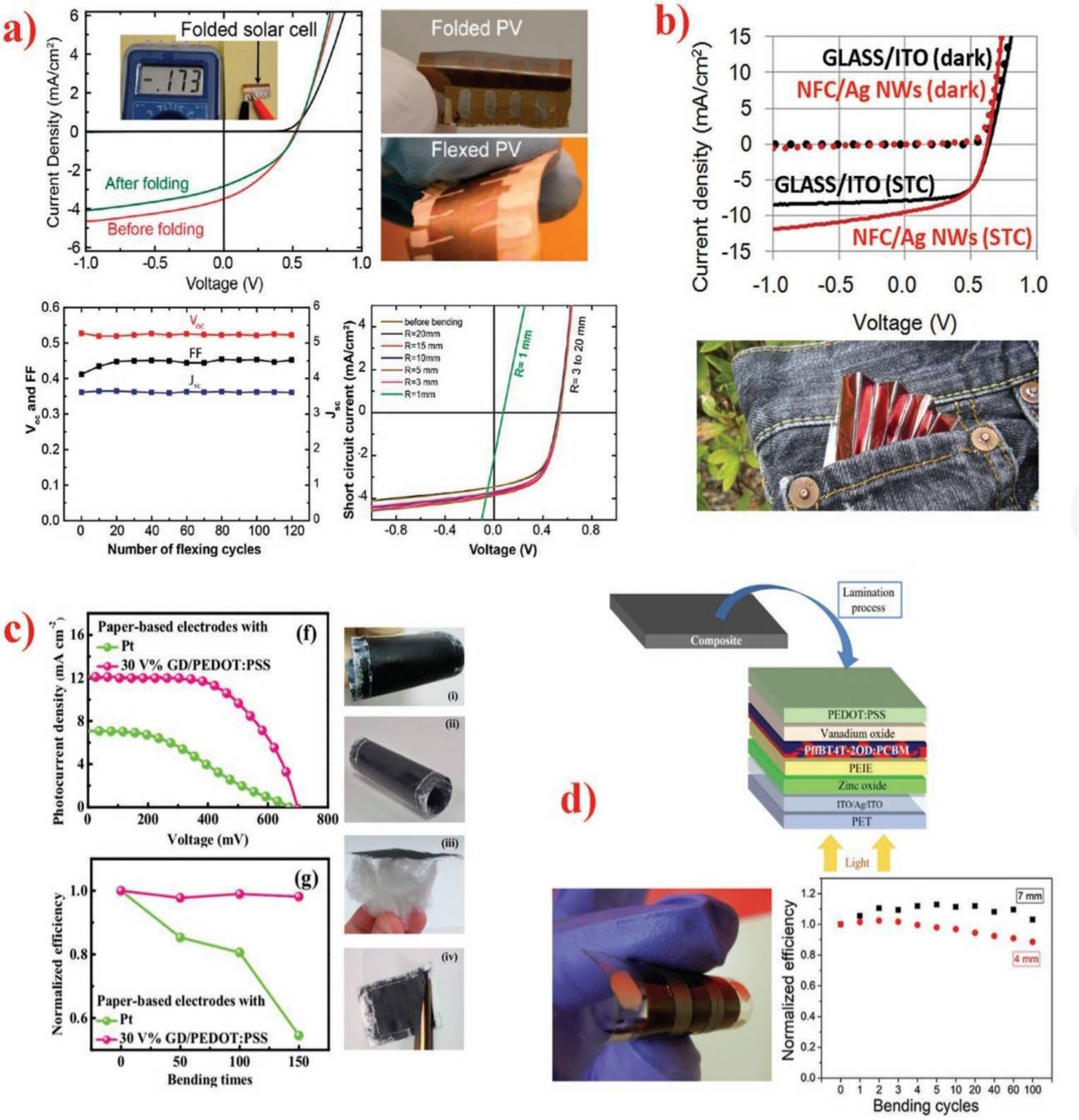

Figure (1): a) Flexible and foldable Cr/Au/CuInSe2/CdS/ZnO/ITO solar cell on bacterial cellulose: top left, J–V curves of the device measured in a pristine state (red curve) and after folding (red curve), with inset picture showing that the solar cell maintains its functionality even when folded; top right, photographs of the folded and bended CuInSe2 paper solar cell; bottom left average photovoltaic parameters (statistics over four samples) of CuInSe2 devices as a function of the number of flexing cycles at 5 mm bending radius; bottom right, , J–V curves of a CuInSe2 solar cell before bending and after bending at radii from 20 to 1 mm. (Voggu 2017) b) Foldable organic solar cells on AgNW-coated NFC: on the top, J–V curves in the dark (dotted lines) and at STC (continuous lines) of glass/ITO/PEDOT:PSS/P3HT:PCBM/Al (black lines) and NFC/AgNW/ PEDOT:PSS/P3HT:PCBM/Al (red lines) solar cells; on the bottom, picture of the foldable organic solar cell. (Nogi 2015) (c) Top left, J–V curves of flexible DSSCs fabricated with PEN/ITO/N719-sensitized TiO2 photoanodes and paper counter electrodes based on printed GD/PEDOT:PSS (pink curve) or sputtered Pt (green curve); bottom left, normalized efficiency vs bending cycle of the same devices; on the right, photographs of paper-based GD/PEDOT:PSS counter electrodes, highlighting their flexibility and light weight. (Lee 2017) d) On the top, structure of a flexible fully sprayed ZnO/PEIE/PffBT4T-2OD:PC70BM/V2Ox/PEDOT:PSS organic solar cell fabricated on PET/ITO/Ag/ITO bottom electrode and assem bled with a laminated cellulose–graphene top electrode; bottom left, photograph of the flexible organic solar cell; bottom right, normalized device efficiency vs bending cycles at bending radii of 7 nm (black data points) or 4 mm (red data points). (Note 2018)

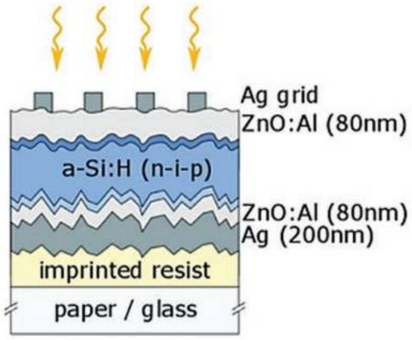

Figure (2): paper surface modification with a UV resistive resin. Resin allowed a controllable design of surface pattern that enhanced the light scattering in an a-Si solar cell (Smeets 2017)5.3: Challenges in using Inkjet Printing

The biggest challenge of using inkjet printing lies the early development of inks and the time it takes for optimization of printing parameters. While rarely reported, success of IJP depends on an interplay of a complex set of parameters such as droplet generating voltage waveform, drop spacing and volume, surface characteristics of the substrate, environmental conditions during printing, ink characteristics and the deposition temperature. Particularly, the waveform and contact angle of the ink is rarely reported which severely limit the implications of these work to other groups. Thus, immense amount of work goes into reaching an optimized printing condition in IJP which needs to be repeated all over again for a new set of inks. Nonetheless, the intensive research into IJP of Organic Solar Cells have led to a wealth of knowledge regarding ink formulations and printing conditions for all functional materials as evidenced by the demonstration of all inkjet printed and functional OSCs in the shape of a Christmas tree.

Further ink development have shown multiple functional materials (carbon electrode and perovskite precursors) can be printed in one-step, thus simplifying production and saving cost.

There were a very successful printed organic solar cell of that Christmas tree with performance more than 75% suitable for large areas were printed in single passes printer head with 6 printed layers using 4 types of inks using freedom design with halogenated –free ink system (Biezemans 2015)

5.3.1: Rheological properties of the ink

The jettability of ink for the ink jet printing is primarily determined by suitable ink formulation, several properties such as density, viscosity, surface tension, stability, pH and ionic conductivity are crucial in determining the jetting behavior of ink. The inverse of Ohnesorge number, Z (1/Oh) depends upon some of these physical properties of the ink.

The viscosity of the fluid, surface tension of the fluid, the density of the fluid, diameter of the nozzle (x.y). As shown by Derby, ideally the value of Z should be in the range of 1 to 10, based on simulated conditions (Reis et al., 2005), later, Jang et al. redefined the range between 4 and 14 by considering some of the experimental aspects (Jang et al., 2009). The drop ejection and stable droplet formation depends on the optimum value of Z, lower value inhibit the drop ejection from the nozzle due to higher viscosity of ink and high value resulting to more number of satellites along with primary droplet. Ink formulation has a great effect on inkjet printing (Søndergaard 2013), low viscosity and high surface tension is required to generate a stream droplets.

5.3.2: Jettability of ink

The standard of jetting is controlled by solvent composition, surface tension, vapor pressure, viscosity as well as the solid content of an ink (Rhaman 2015). In recent years, metal NPs and NWs as well as graphene and CNTs inks were utilized for printing the electrodes for flexible OSCs, Graphene electrodes were patterned on flexible OSCs fabricated on PET and PEN substrates, Transparent conductive electrodes with improved performance were patterned on PET by combining graphene films and Ag grids. CNT based electrodes were patterned on flexible OSCs fabricated on PET and PEN.

To provide good electrical conductivity of metallic printed structures, highly conductive metals which are stable to oxidation, such as silver and gold are the best for utilization in conductive inks, and currently silver is the most widely used material, however, due to its high cost, a major challenge is to replace the silver with cheaper ones, like copper, nickel and aluminium. the size of the particles in the case of inkjet ink should be, as a guide, about 0.01 of the diameter of the printhead orifice (typically 20–50 mm) to avoid its clogging and blockage (the smaller the particles the better, so an average particle size of 30–50 nm is preferable). (Rae 2006/ Kamyshny2005)

5.3.3: Halogen free inks

A large effort is being made to eliminate halogenated solvents, typically used in research for organic photovoltaic device preparation, from industrial inks trying to reduce environmental impact (Biezemans 2015, Lange 2013). Chlorine-free solvent mixtures have been demonstrated to lead to photovoltaic efficiencies closer to those reached when using chlorinated solvents in the application of the photoactive layer as shown by Lange and co-workers (Lange 2013). A high power conversion efficiency over 9.4% was realized in polymer solar cell by halogen-free solvent processing as shown by Zhao and co-workers, the developed halogen-free mixture solvent system (XY [as the host solvent]–2% NMP [the Additive solvent]) can be widely applied in various high-efficient active layers including PBDTTT-EFT:PC71BM, PBDTTT-C-T:PC71BM, PTB7:PC71BM, PBDTBDD-T:PC71BM, PBDT-DPP:PC71BM, PBDT-TPD:PC71BM, PDTG-IID:PC71BM and P3HT:PC71BM and comparable performance was also achieved , fig(3) (Zhao 2015)

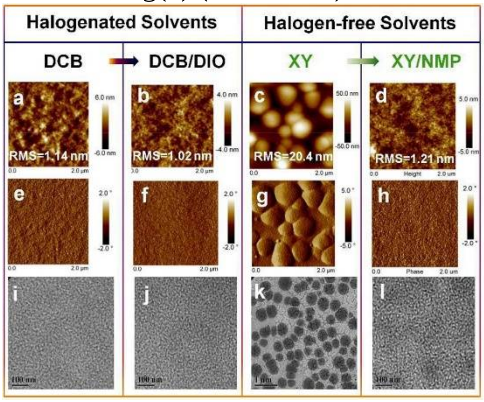

Figure (3): AFM topography (a, b, c, d), phase (e, f, g, h) and TEM (i, j, k, l) images of the films cast from: DCB, DCB/3% DIO halogenated solvents, XY and XY/2% NMP halogen-free solvents, respectively

5.3.2: Coffee ring effect

I Inkjet in printing solar cells is still in infancy and faces a number of challenges related to the drying-induced distortion of films that are not deposited into confinement wells (Kawase 2005, Teichler 2011)

Solid spread in a drying drop will move to the edge of the drop and form a solid ring, which is named as coffee ring effect or coffee stain rim (Kang 2016). This problem is a consequence of the low viscosity in the ‘‘inks’’ printed by conventional inkjet printing. As the solvent evaporates after deposition of the fluid puddle, the contact-line of the puddle retracts, which causes the footprint and position of the remaining fluid puddle to change. As the solvent evaporates further, materials deposition occurs and the contact line becomes pinned to the substrate. The puddle footprint now becomes fixed, but an evaporation-induced fluid flow towards the edge continues which piles up material to give a coffee-stain rim. These effects have been extensively studied for single printed droplets (Kajiya 2008, Ikegawa 2004), all studies reported that droplet size, solvent evaporation time and solute diffusion time are the reasons for coffee ring effect. It is also found that, if solvent evaporation time is more than the solute diffusion time, the formation of the coffee ring can be ceased. On the other hand, the increase in ink viscosity can lead to slow particle motion and hamper the coffee ring formation, thus, addition of polymers in the inks can also ease the coffee-ring effects during droplet evaporation (Cui 2012).

In another effort, it was shown that if we can control the evaporation profile of drying drops and lines, where the solute is relocated to the rim, it is possible to control coffee ring effect (soltman 2008).In another effort to print organic solar cells (TiO_2 type), The effect of Polyethylene Glycol solution (PEG) concentration on the suspension dispersion stability of both types of TiO_2 particles was explored, At lower concentrations of PEG the coffee ring effect was notable in deposited drops

For the lower concentrations of 10 and 20%, the outer edges of the ring were pronounced. Once the concentration reached 50%, the drop was more uniform in distribution but often exhibited weak adhesion to the substrate near the edges. Based on the observations, a concentration between 45 and 50% of PEG relative to the weight of the TiO_2 was used for all suspensions prepared for deposition by printing and spin coating (Johnson 2013)

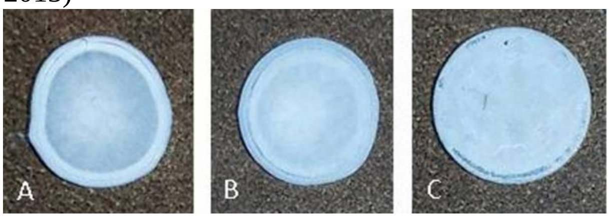

Figure (4): Coffee ring effect observed in deposited drops for different concentrations by weight of PEG20000 relative to TiO_2: A) 10%, B) 20%, and C) 50%

For a non-volatile solvent, i.e. a long evaporation time scale, one expects no outward flow caused by solvent evaporation and thus negligible coffee ring effects. With this concept, Kim et al. used a high boiling solvent with low surface tension, such as ethylene glycol, in silver nanoparticle inks to reduce the evaporative f lux to decrease coffee ring effects on printed conductive tracks (chen 2015)

5.4: Conductivity and inkjet printing of the 2D printed patterns

Stability to multiple bending is a crucial characteristic of conductive coating to be used in flexible electronic devices. It should be noted that by reviewing the literature, it is difficult to compare the reported data on mechanical stability of 2D printed structures, since it depends on many factors, such as ink composition, adhesion of the various inks to specific substrates, thickness of the conducting pattern, quality of sintering (in the case of metallic inks), bending angle

Over the inkjet 2D printing method, ink drops can be deposited on a substrate on demand (Angmo 2013), and has been used to cast the perovskite (organic material), ETL, HTL, and electrode layers by different authors (Angmo 2013, Wei 2012, Hosseini 2014). Layers exhibited homogenous thickness, reproducibility, and controllable size and shape layer area (Wei 2012), fabricated a perovskite solar cell incorporating a nanocarbon hole-extraction layer via inkjet printing technique for the first time. Ink-jet printing a mixed ink composed of carbon black plus CH3NH3I (methylammonium iodide, MAI) over the previously spin-coated PbI2 layer, they managed to achieve simultaneous formation of the perovskite layer and the carbon electrode resulting in a solar cell with a PCE of 11.60% (by the year 2018, it turned to high value, more than 22% (Gujar 2018)). The inkjet printing technique could not only precisely and controllably print pattern of the carbon electrode, but also improve the interface between the CH3NH3PbI3 (chemical compounds added to the perovskite layer) and C electrodes by the instant chemical transformation.

Furthermore, in another production of OSC by Angmo (2013) by roll – roll inkjet printing printed using an aqueous silver ink onto flexible PET film with a resolution of 600 × 600 up to 1200 DPI. Speed two meter/minute. Layer printing thicknesses and line widths were measured on a Dektak profilometer. OSC device result were tested and the result power efficiency about 1000 watt/meter2.

6: Electrohydrodynamic direct-writing (EHD 3D jet printing)

6: Electrohydrodynamic direct-writing (EHD Inkjet)

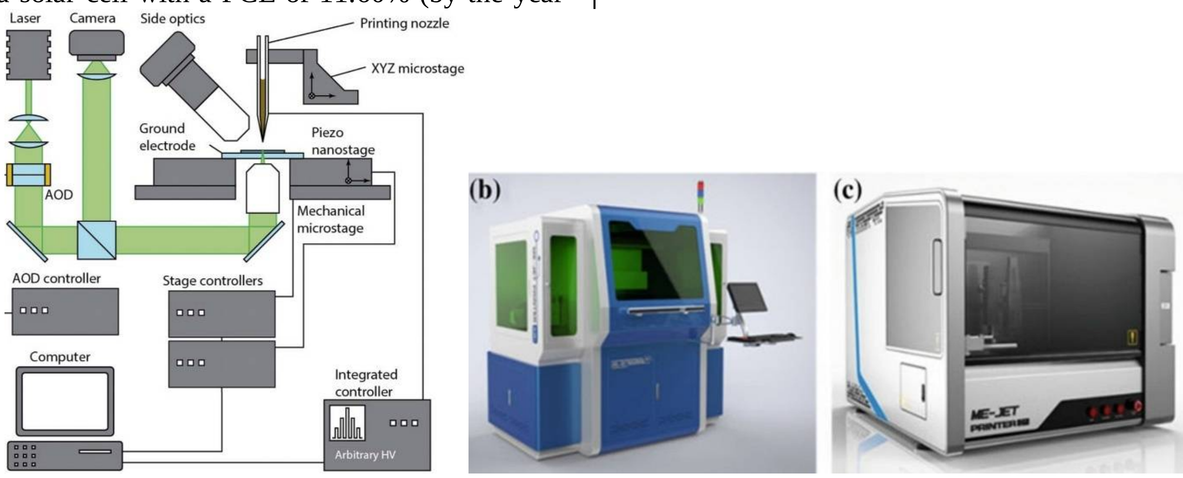

Figure (5): a) Scheme of the printing setup with the stage and voltage controls and the optical access options. Adapted from (Schneider 2015), b) the photographs of self-developed multi-function EHD printer XR1 (Yin 2018), c) and EHD printer D1 (Yin 2018)

There are three kinds of inkjet printing technology depending on liquid ejection, i.e. piezoelectric inkjet printing technology, thermal bubble inkjet printing technology and electrohydrodynamic inkjet printing technology (3D inkjet Nanoprinting). Fig (5)

6.1: The EHD working modes

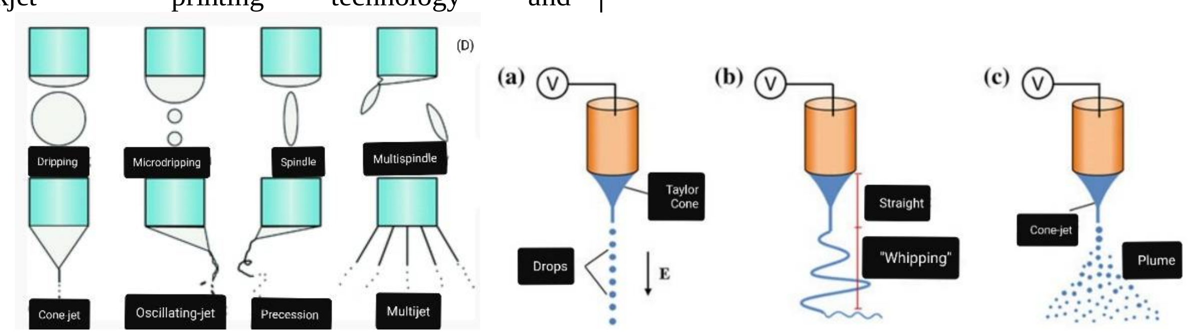

Figure (6): a) Schematic illustration of the E-jet printing, b) electrospinning, c) electrospraying, D) various modes of EHD writing.

There is three types of EHD printing (E-jet printing, electrospinning, and electrospraying) can be realized via a same setup. (Choi 2008)

By carefully adjusting the ink property, the nozzle-to-substrate distance, and the applied voltage, three types of EHD printing (E-jet printing, electrospinning, and electrospraying) can be realized via a same setup.

Table (1): Comparison of the three EHD printing methods. (Yin 2018)

EHD-printing	Mode	Volatge	Electrode distance	Solute	Pattern
E-jet printing	Cone-jet, Microdripping	0.5-3	0.1-1	Polymer, Nanoparticle	Dot
Electrospinning	Cone-jet, Multi-jet	1-15	10-50	Polymer, Nanoparticls	Line
Electrospraying	Cone-jet, Multi-jet	10-30	100-250	Most materials	Thin film

6.2: EHD Nozzles

Nozzles play an important role in improving efficiency, tuning the process parameters (critical voltage, feed rate), and controlling fibers morphology (coaxial fibers, core–shell fibers and diameter). According to various applications, several kinds of nozzles have been developed, such as multi-nozzle, tip-in-nozzle, coaxial nozzle, multi-hole nozzle. The Multi-nozzles can overcome the limitation of low production speed and fabricate low cost electronic microstructures, one of its main applications is to print electrodes of solar cells with high manufacturing efficiency. A parallel multi-nozzle was used for simultaneous printing of a functional material onto the substrate, where the key challenge lies in optimizing the nozzle-to-nozzle distance to improve the integrated level, but with low cross-talk between electrically charged neighboring jets. (Huang 2013). To achieve jetting on demand, an addressable multi-nozzle has been developed, and the jetting is launched by controlling the flow rate, rather than the onset voltage. (Lee 2008)

6.3: Mechanism and Classification of EHD printing

Conventional IJP (piezoelectric and thermal bubble IJP) has various intrinsic problems related to nozzle size (pressure limitation) and nozzle blockage caused by high-viscosity inks, and overheating of organic materials and limited resolution in existing printing devices at high print speeds, resulting in a requirement of high droplet placement accuracy. The need for high resolution with smaller droplets accuracy in the same time with a faster printing speed leads to direct-writing process based on electrohydrodynamics (EHD) inkjet Nanoprinting technology. The main process is to pulls the fluids rather than pushes them like conventional inkjet printing. The ejection is difficult to be achieved in conventional inkjet printing technologies when high viscous ink is used. Instead using piezoelectric or thermal bubble to eject ink, EHD jet printing technology uses the electric field produced by voltage difference between the nozzle tip and the substrate to dispense the droplets or to eject continuous jet from the nozzle. That mechanism makes EHD jet printing technology is able to eject high viscous ink.

EHD jet printing technology is also possible to print higher resolution pattern because the liquid ejected is smaller than the nozzle diameter (Tenggara 2015/ Huang 2013)

6.4: The efficiency of printing solar cells by EHD inkjet 3D Nanoprinting

There is a number of studies through the effect of printing speed into the width and the height of printed lines. The width and the height decreased when the printing speed decreased, (Wei 2013). In another study had been a fabrication of 3d electrode lines using EHD inkjet technology to improve the quality of the printed lines with various number of printing parameters ((silver inks with viscosity 5000 cPs, 8000 cPs and 10000 cPs, A controller inside the machine guided the movement of the nozzle in X- and Z-axis and the substrate in Y-axis. The maximum velocity and the acceleration of the horizontal stage (X and Y) are 2000 mm/s2 and 5000 mm/s2 , horizontal speed of the nozzle and the silicon wafer substrate used to print electrode lines varied from 100 to 500 mm/s., To supply the ink from the syringe chamber to the ceramic nozzle, a micro syringe pump was used (Harvard, NEW PHD ULTRTM Nanomite). The ink flow rate was varied from 0.4 to 1 µl/min, all printed lines temperature fixed on 150C to evaporate the solvent and to connect nanoparticles in electrode lines to conduct electrical current, measurements of printed line morphological and electrical properties: 3D Profiler and SEM images were obtained to observe the profile and dimensions of the line. 3D Profiler NV-1000 model (NanoSystem Co., Ltd) was used to measure the profile of three dimensional lines with height less than 50 µm. The profile of lines with height more than 50 µm were measured using The DektakXT TM stylus profiler (Bruker Corporation). The resistances per unit length were measured with an electrical probe)). the results refers to that direct printing method using EHD jet printing successfully printed high-aspect ratio conductive lines, with aspect ratio up to 350. The important printing conditions were the printing speed, the flow rate and the printing number. In general, decreasing the printing speed, increasing the flow rate and increasing the printing number could increase the aspect ratio of lines. It was observed that by using higher viscous ink, the width of lines became narrower and the height of lines became higher so that the aspect ratio of lines produced by higher viscous ink was higher than the aspect ratio of lines produced by lower viscous ink. It is due to the spreading is higher in lower viscous ink. The resistance of higher aspect ratio lines is related to the viscosity of ink. Higher viscous ink produced lines with lower resistance or high conductance. The high aspect ratio lines conducted by this experimental have great potential to improve efficiency of solar cells. (Tenggara 2015). In another experimental about the efficiency of EHD Nanoprinting to fabricate solar cells, we can explain it through fig. (7)

Moreover, the printing efficiency is as high as 1ms1 (Xin 2012), and the cross-section shape is tuneable, so it is promising to printing electrodes of a solar cell with large aspect ratios and high manufacturing efficiency. The resolution is about 2 orders higher than inkjet printing, and the risk of nozzle jam is significantly lowered. It lowers the difficulty in manufacturing narrow sized nozzles to printing ultra-resolution structures. This technology provides a new solution for the integrated printing of heterogeneous multi-material, multi-scale (macro/ micro-scale) structure. (Zhang 2018)

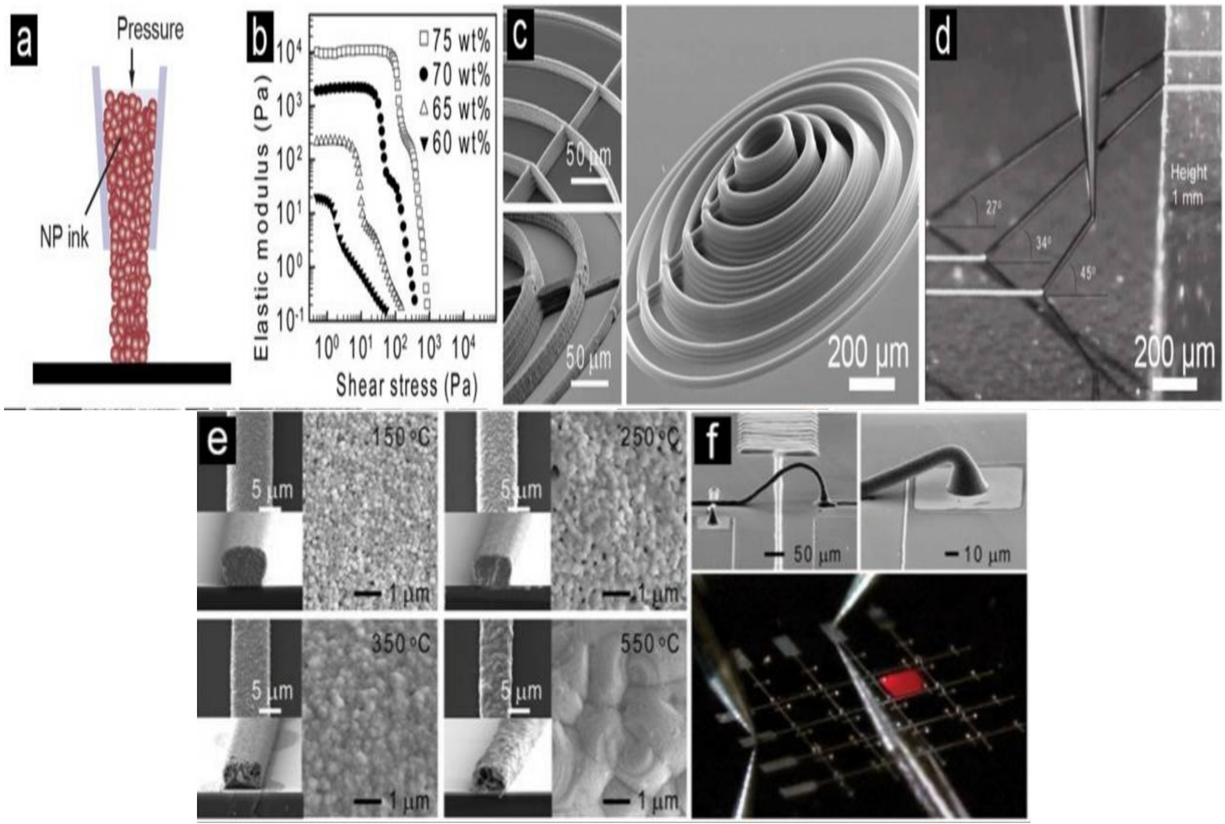

Figure (7): Direct ink writing DIW. a) Principle. A shear thinning silver nanoparticle ink is extruded from a glass micropipette. b) Influence of the particle concentration on the inks' viscoelastic and shear-thinning properties. The elastic modulus increases sharply at low shear stresses. Thus, rapid solidification occurs after extrusion from the nozzle. c) SEM micrographs of 3D silver-structures fabricated using layer-by-layer printing d) the printing process in action: thanks to the high stiffness of the ink in the absence of shear stress, spanning features can be deposited. e) Top view and cross sectional SEM micrographs of silver-lines annealed at different temperatures. The total volume decreases by ~30% due to evaporation of organic content and coalescence of the nanoparticles that form grains of up to 3 µm in diameter. f) SEM images and photograph of DIW- fabricated electric interconnects on micro- solar cell. (Hirt 2016)

7: Process development of shaped and Coloured Solar Cells:

A large efforts has been recorded by several development studies about coloring, shaping , free design of the PV cells, most projects and studies aimed to control the process that affect thickness and hence colour to achieve maximum colour uniformity and reproducibility, as shown by one of them Devenport's and Co-workers (Devenport 2014)

7.1: Cell shaping

A variety of differently shaped cells were produced by reprogramming of the laser, a range of regular polygon shaped cells and cells with curved edges were produced to demonstrate this.

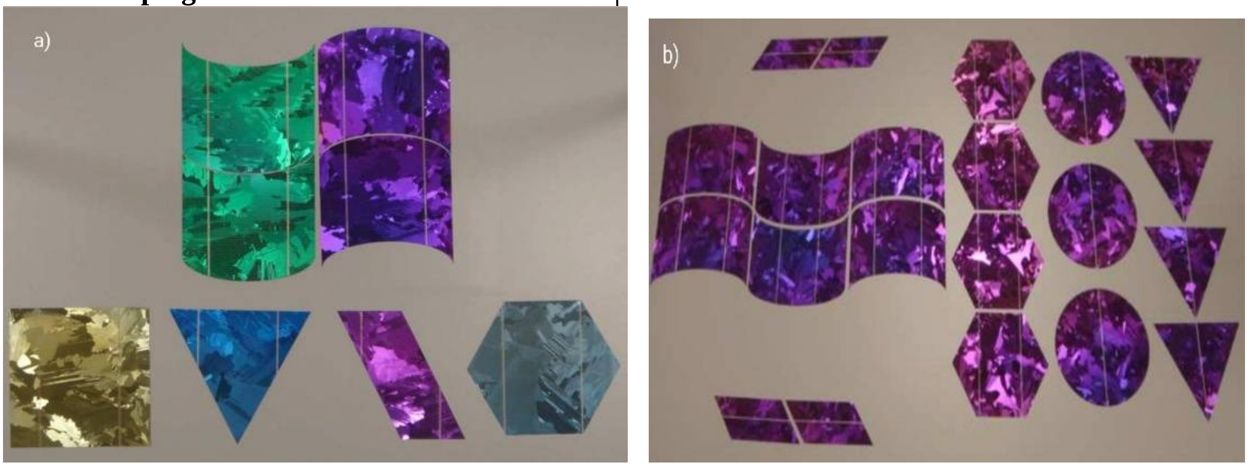

Figure (8): a) Coloured and shaped cells, b) Shaped cells with optimised busbars, copyright of both from the UK Department of Trade and Industry (2014)

7.2: Cell coloring

We can explain it through fig (9)

Figure (9): a) solar cells can be made in different colors by adjusting the antireflective coating. www.lofsolar.com.tw

8: Module design

The design feature of printed OPV is thus not only of aesthetic value but it allows the embedding of a module into an electrical device without limiting the design of the device, the German Federal Ministry of Education and Research BMBF have funded a project to develop the solar trees with first large scale of fully solution coated, degrees of semi-transparent, flexible OPV with a unique design, the new design module has been printed on the PPBTZT-stat-BDTT-8 polymer, producing power conversion efficiency 4.5% (Berny 2016). Another new module has been recorded as a result of a funded project by VTT (Technical Research centre of Finland) demonstrated an energy-autonomous, decorative presence sensor using printed OPV modules. The leaves harvest energy from indoor light to power different types of presence detectors embedded into a 'printed painting', and the system then sends this information wirelessly to control indoor lighting. Organic materials such as perovskite printed increase efficiency fig (10 a,b,c). Välimäk and co-workers (Välimäk 2017) have tested the feasibility of the method by printing leaf-shaped photovoltaic cells. Active surface of a one leaf is 0.0144 m2 and includes connections and a decorative part. Two hundred OPV leaves make one square metre of active solar panel surface that generates 3.2 amperes of electricity with 10.4 watts of power at Mediterranean latitudes fig (10 d,e,f,g). In a new design, OPVIUS have developed an energy-efficient large scale membrane façade of high aesthetic and technical printing quality using the most resistant polymer ETFE (ethylene tetrafluoroethylene) with complete freedom of design, in accordance with the specifications of the client. Fig (10, h)

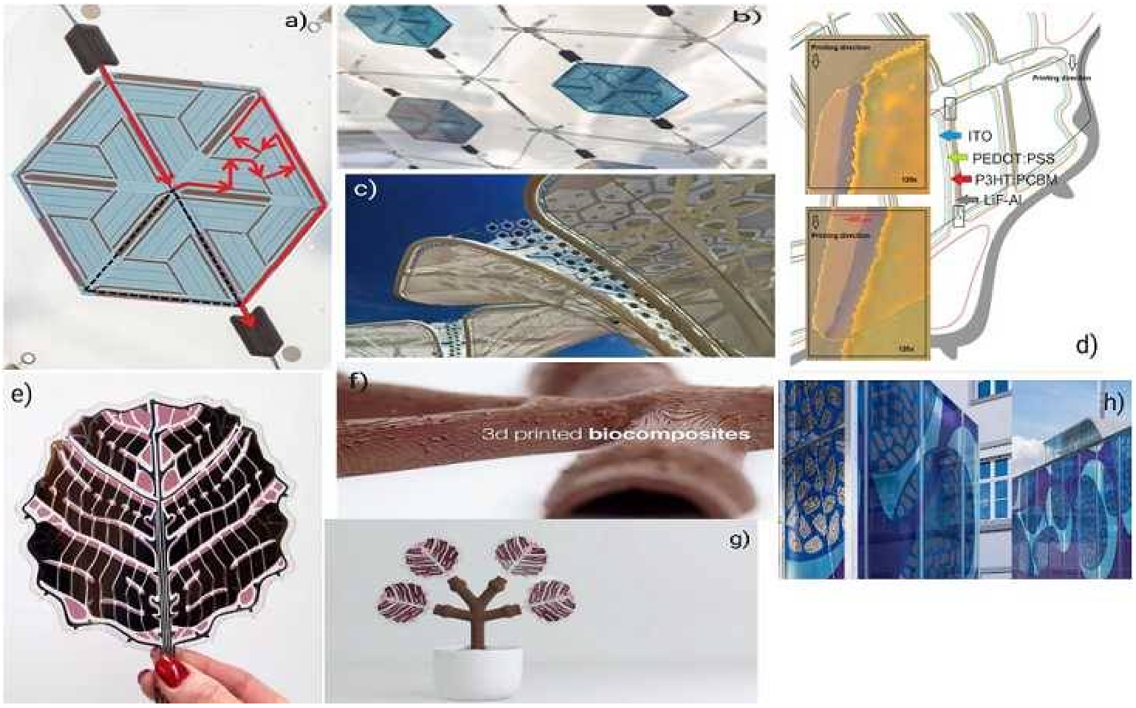

Figure (10): a) Close-up of a small Trigon module installed in an EXPO tree. One of the small blue design modules consists of six submodules, each in a triangular shape (printed dashed line), which are all connected in parallel. One triangular module is made of nine subcells, all connected in series. The red arrow symbolizes the current pathway for one distinct triangular submodule from the anode to the cathode. b) type forming of several printed OPV cells, c) the result of OPV tree, d) Microscopic images presenting printed PEDOT:PSS and P3HT:PCBM layers and their alignment on top of patterned ITO, e) VTT Leaf-shaped OPV modules, f) 3d printed biocomposites, g) both of them forming the printed solar cells electricity harvesting tree, (courtesy of VTT), h) OPV translucent ETFE printed film www.opvius.com

10. Discussion and recommendations

1. Upscaling of organic solar cells asks for alternative technique than spin coating and evaporating which is the traditional method of production, thus these paper studied replacing of the traditional cell production by 2D and 3D IJP layers
2. The study offered a wide range of organic polymer materials and other compounds which could be printed by IJP, in addition to paper which developed in the last few years to enter the green-power electricity field, or integration of the transparent cellulose film (paper fibres) to enhance the performance of in-organic fibre optic temperature sensing technology (GaAs) solar cells. Furthermore, IJP could also print on some inorganic materials like TIO2 and many other wide materials which proved its ability to improve the optimization of charge collection to the OSCs device. IJP ability of INK JETTING organic and inorganic materials will open the door for fabricating environmentally friendly efficient OSCs more than before.
3. Author studied the performance of OSCs inkjet production over similar case studies, the efficiency were at one of them more than 75% due to stable open circuit voltage and fill factor, this is make it a viable technique for large area, with the ability to customise of IJP of OSCs on a wide range of organic materials, furthermore, the paper research continue studied two other case studies of 2 Dimension IJP of OSCs by Wie 2012 and Angmo 2013, both of their results were very satisfied, whereas examination of the device ability to produce power (electricity) where very good. The power is continue its improvement over the years, thus make IJP a promising technology in the field of fabrication OSCs.
4. The paper also highlighted one of the most important factors in jettability of inks of OSCs, also, it appear a case of environmentally friendly (CNTs inks) were utilized for IJP the electrodes for flexible. The developed ink system could print highly efficient OSCs on PET/PEN organic materials. On the other hand the free halogenated ink system has proposed the same idea of green printing. Thus, IJP could turned to be the most effective method in fabricating large area OSCs devices with eco-friendly inking.
5. The study has continue studied inks jetability, rheological properties and coffee ring effect which are the challenges of produce solar cells on several organic material. In addition to many factors affects on inkjet conductivity of

the solar cells 2D printing patterns such as ink composition and the adhesion to substrate, all studies should be concerned while starting any new line IJP of OSCs production.

6. OSCs IJP result quality test inspection by Dektak profilometry either for 2D or EHD 3D printing detected successfully printed normal lines as well as high-aspect ratio conductive lines, another outstanding point that is, these inspections prove the highly developments in a few years and we expect more developments in future.
7. The author studied Electrohydrodynamic direct-writing (EHD) 3D Nano-printing, and its ability module with its high aspect ratio lines conducted which showed through experiments with high resolution, smaller nano-ink droplets accuracy as well as highly speed production. Thus make EHD 3D IJP a great potential to improve efficiency of power as a OSCs devices fabricated method precisely and accurate.
8. The study displayed various freedom designs modules like VTT new aesthetic freedom design leaf-tree shaped OSCs (OSCs harvesting tree), translucent ETFE printed OSCs in Germany and OSCs shade umbrellas. The new designs will alternate the conventional one' in producing an aesthetic OSCs. It became suitable to cover facades of buildings and so many other creative ideas. in addition to the ability to fabricating it in several shapes and colors, this is will go through a new generation of unique and advanced ideas of aesthetic OSCs designs.

As a conclusion of our paper, the author recommended The Ministry of Electricity and Renewable Energy in collaborate with Ministry of Military Production and Ministry of Housing and Urban Communities to start fabricating aesthetic freedom designs OSCs with 2D and 3D IJP, this active, eco-friendly and innovative technology will turn the Egyptian electric energy field, also it has succeeded in decorating streets by OSCs trees, buildings and public & private facilities instead of traditional building faces designs.

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List of abbreviation:

N-Methylpyrrolidone	NMP
o-xylene	XY
Organic Solar Cells	OSCs
Inkjet Printing	IJP
Roll – to – Roll printing	R2R
Organic Photovoltaic	OPV
Electrohydrodynamics	EHD
Direct Ink Writing	DIW
Indium Tin Oxide-	TIO2
Polyethylene Glycol solution	PEG