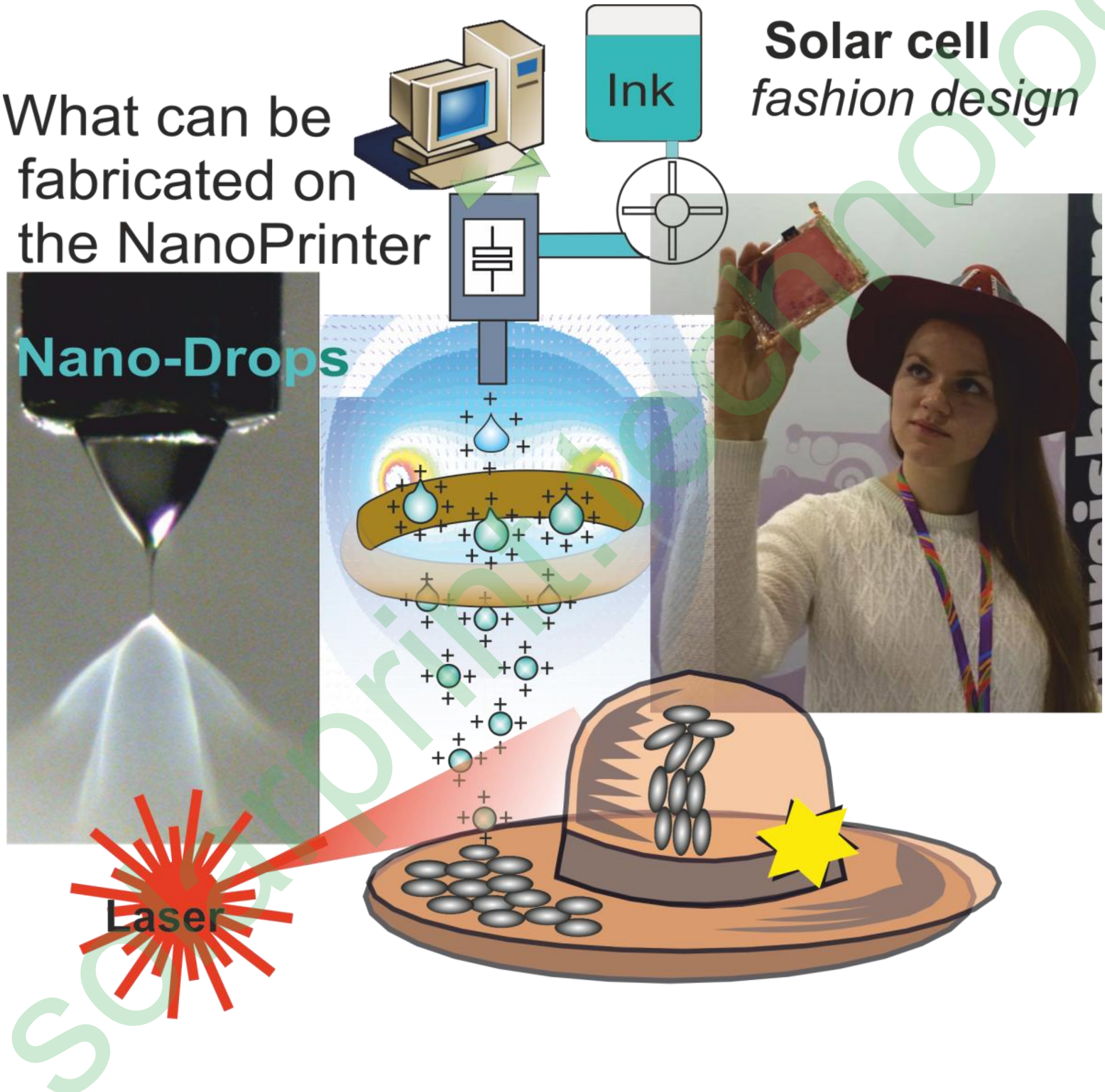
SolarWindow NanoPrinting



1. **Excellence**
2. NREL – independent test of efficiency and spectral charactericrtic of the transparent solar cells
3. California Institute of Technology Caltech, Lawrence Berkeley National Laboratory – manufacturing help and
4. San-Diego CleanTech – tests transparent solar cells in city objects in real conditions, local investments

1.1 Objectives

Short description

The smart printer depositing ionized nano-drops of solar cells materials, and in real time, digitally recognizes image of layers and corrects mistakes, like a sculptor

Problem

Current printing technology of nano-layers and 3d printing has some drawbacks that prevent their spread.

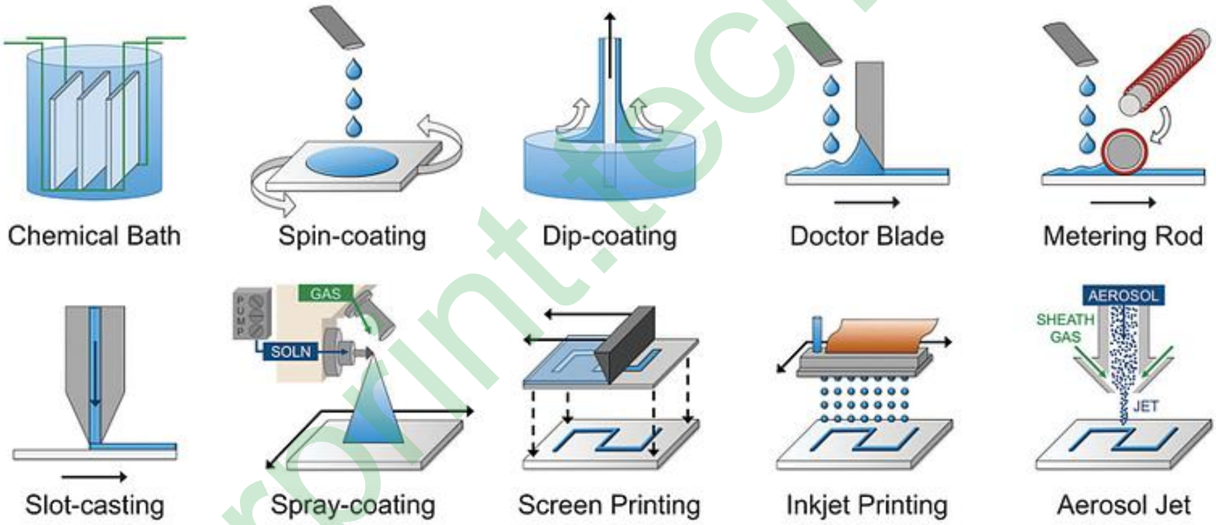


Figure 1. Current non-vacuum layer deposition methods

Printers for high-precision printing are blind, can not recognize errors, control thickness, besides there are difficulties for printing on three-dimensional objects due to runoff and uneven heating. The printer is not equipped with a depth learning system. Bad adhesion between layers and the appearance of cracks and delaminations.
Ink for nano-printing is expensive, particles of a material decrease in size, their cost greatly increases, from 100 to 500 times with a decrease to 10 nanometers

Many methods are usually used for surface modification. All these methods can be divided into vacuum and vacuum-free. All these methods can be divided into vacuum and vacuum-free.
Vacuum-free methods include:

- layer-by-layer (chemical bath) – it does not allow to regulate the thickness and percentage of the modified surface;

- spin coating allows to adjust the thickness, but not the percentage of the modified surface, the covered area is quite small;
- inkjet printing allows to adjust the thickness to within 10 microns and filling of the surface. The disadvantage of this method is low speed, the complexity of full filling of the surface without gaps less than 5 microns;
- ultrasonic spray deposition has a high print speed, allows you to control the thickness and percentage control of the filling from the time of spraying. There is a disadvantage: the impossibility to print small objects;
- aerosol jet has a high printing speed, control of thickness and surface filling.

The general disadvantages of vacuum-free methods include the absence of the emergence of chemical bonds between layers (covalent, ionic, hydrogen, van der Waals).

In turn, such vacuum methods as Chemical vapor deposition (CVD), Plasma enhanced vapor deposition, Plasma etching allow to create chemical bonds.

Disadvantages of these methods:

- limited set of substances, selection of precursors and monomers;
- impossibility of applying complex organic molecules, especially of biological origin;
- part of the reagents settles on the walls of the reactor;
- limited sprayed area by the working chamber;
- the difficulty of creating a continuous conveyor process;
- difficulty or impossibility to regulate the filling of the surface;
- high cost of equipment.

Our technology allows us to achieve a high degree of uniformity and adhesion due to the small size of the droplets. Electrical activation droplets and nanoparticles allows achieving adhesion layer to a wider class of substances, so that the product can be printed in full cycle. Elements of artificial intelligence and neural networks in digital recognition and printing control can reduce the amount of rejection to zero.

Our solution

We develop the technology of smart manufacturing, like a printer, while layers are deposited of surface electro-activate nano-droplets, that allows to achieve the accuracy of the layer thickness of 50 nm and a controlled porosity. The printer no longer blind, and can scan and correct their mistakes, like craftsmen. Applications is the individual manufacturing for flexible, different shaped, textile integrated electronics, solar cells, batteries, bio-inspired membranes We can form a very small droplet size of less than a micrometer and compress their flow, but due to the activation of the surface, they do not stick together. High Definition Camera and sensors scan the surface and digital recognize, and comparing the recognized drawing with the original, you can avoid mistakes

This is a fabrication technology for perovskite solar cells, where the thickness of the layers is important. Due to the ionization of the droplets, the layers are homogeneous, which increases the efficiency, and the determination of the layer thickness in the printing process reduces the mistakes rate and reduces the cost.

Unlike combined-vapor deposition methods, the size is not limited by the chamber and the percentage of substances used approaches 95 percent, does not require high temperature.

Also, with this printer, we have developed a transparent solar battery, where special printed multi-layer mirrors redirect infrared light from the sun to the solar panels, and visible light passes inside.

This way to modern research of solar cells, batteries, fuel cells, membranes in universities and companies require rapid prototyping of different design options. This would speed up the research process. Therefore, we believe that no less than 1,000 laboratories could buy our printer.

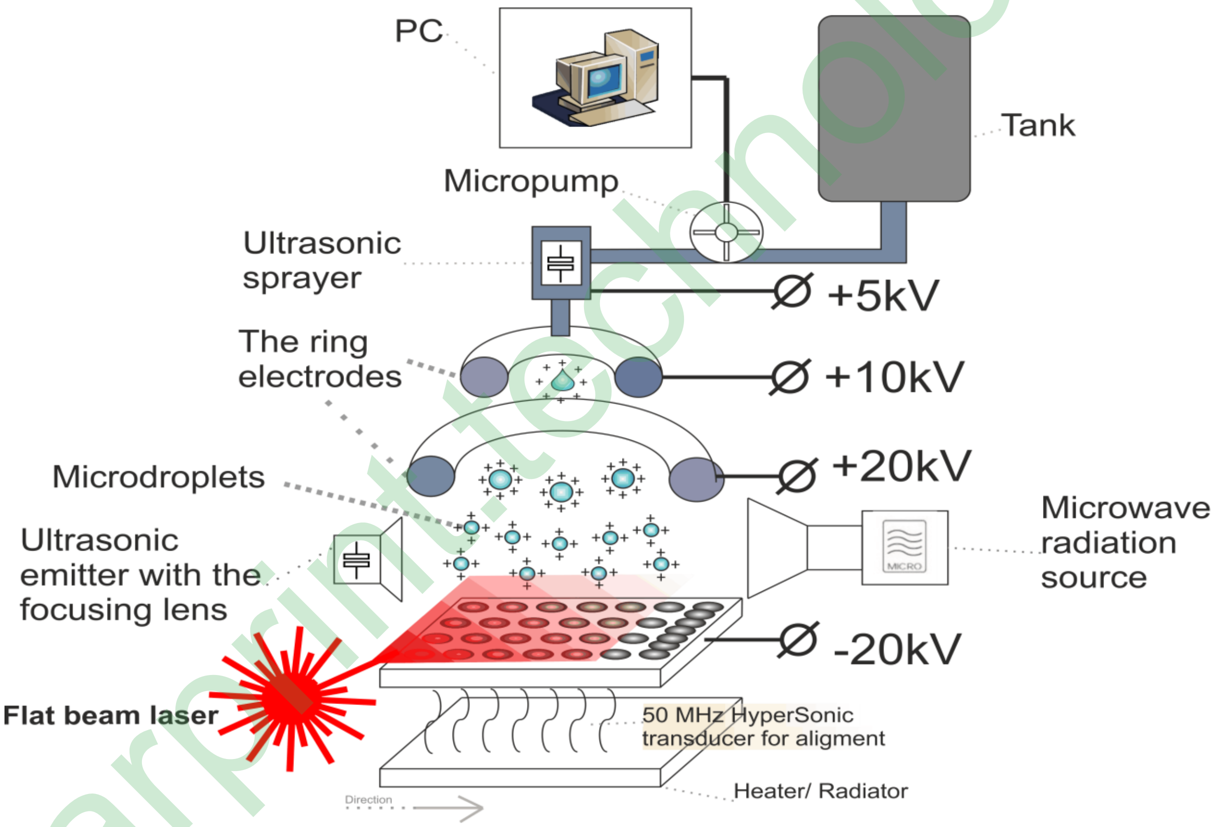


Fig 1. Solar 3d printer concept

Your computer is inserted into a pattern of future products and materials selected for each layer. The printer cartridges are inserted with the correct materials. The printer attached storage, which will be printed materials. Turn on the scanner and it digitizes its shape. Next on the computer selected location on a digitized workpiece where printing will occur. During printing, the scanner compares the printed object with a pattern and displays percentages. If the discrepancy is strong, then the printer head back and corrects

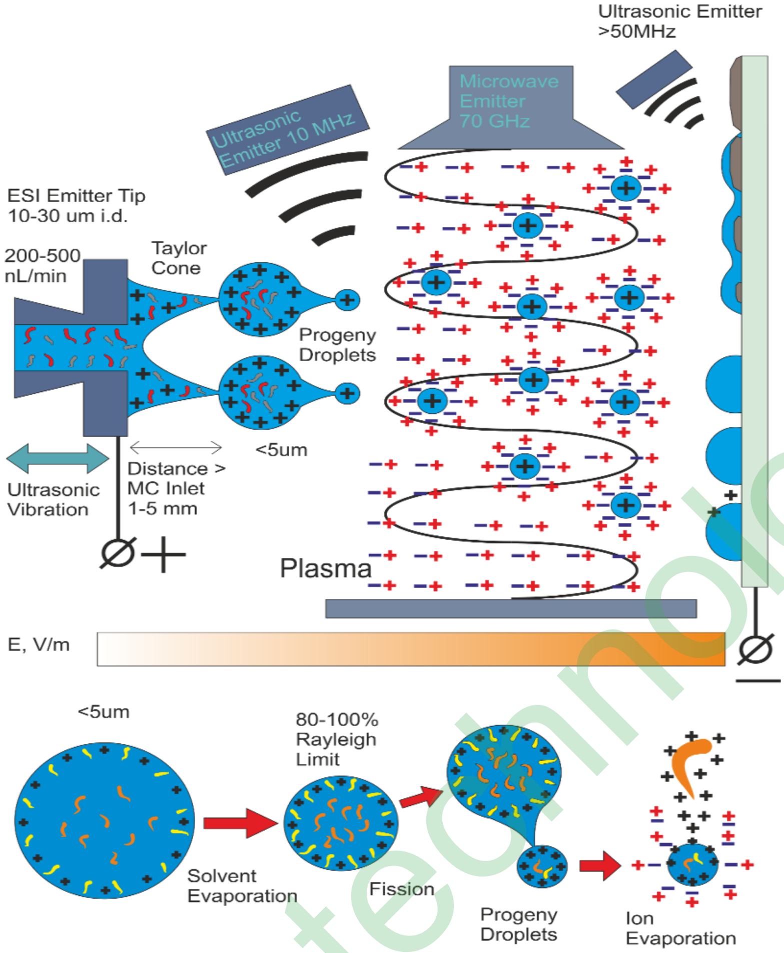


Fig. 2. How to print nanomaterials on solar cell

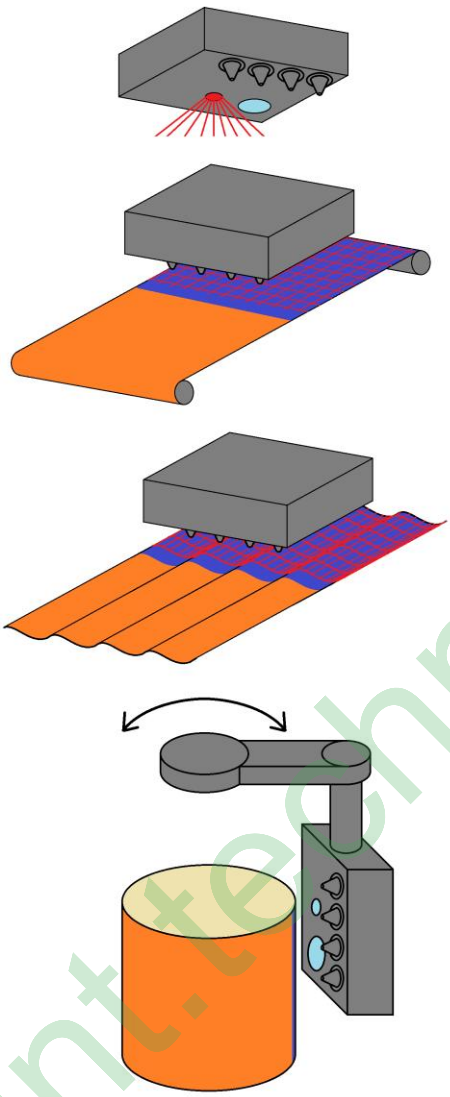


Figure 2. Scan the surface and recognise

Figure 3. Software for layers tests

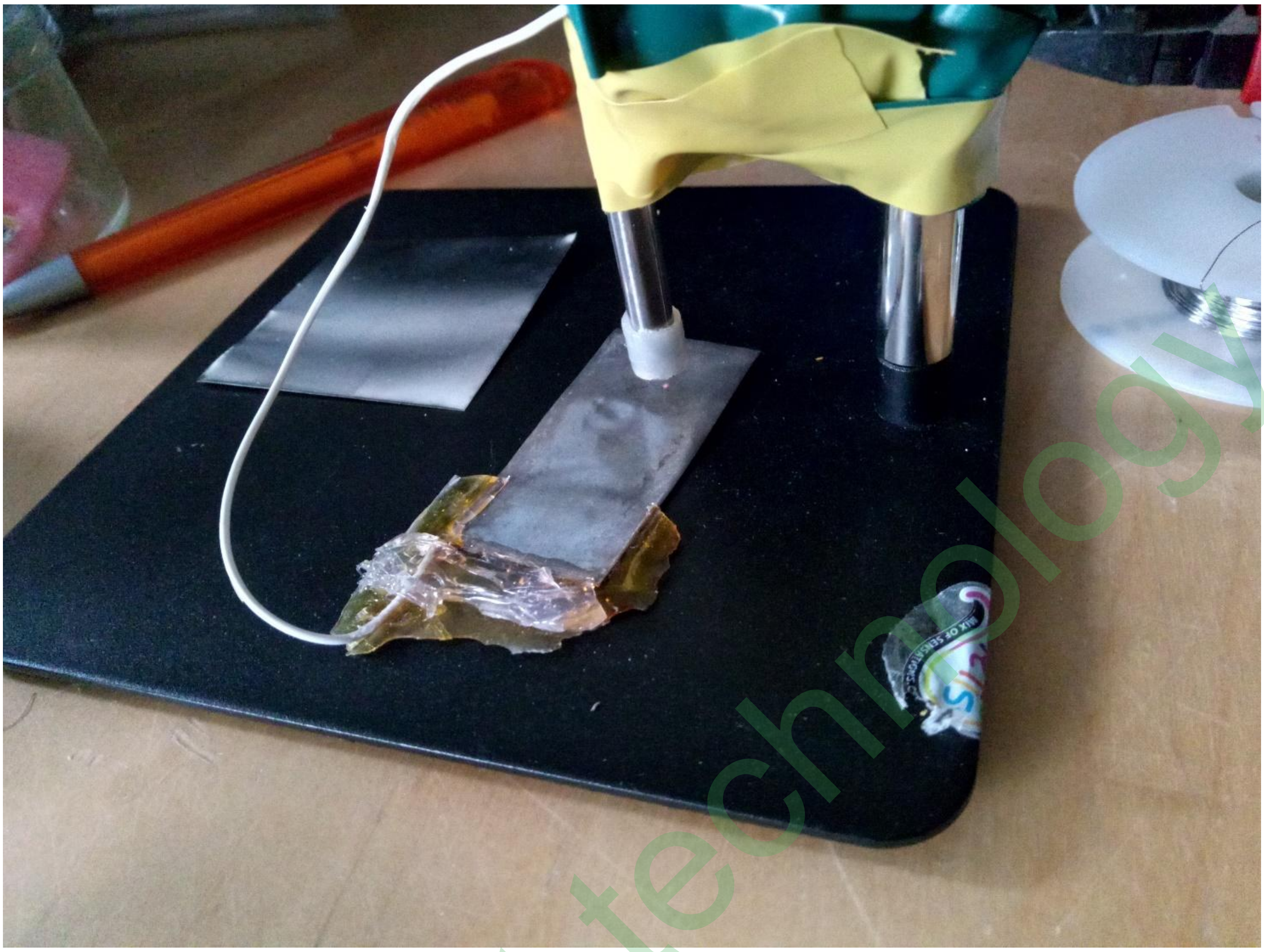


Figure 4. Thickness measurement

Product

Smart printer with focused nano-drops and deep learning via sensors for digital recognition - decrease mistakes for programs full cycle nano-printing perovskite solar cells , optical concentrators, membranes, millimeter waves antennas, batteries. Our technology allows us to achieve a high degree of homogeneity and adhesion due to the small size of the droplets with oxides (transparent conductive oxides), metals, nitrides, graphene. Electro-activation and acceleration of droplets, nano-particles and ions allows to achieve adhesion and chem bonds between layers of a wider class of substances, so that the product can be printed in full cycle. Elements of deep learning and thickness control gives feedback. High solvent variants -20 + 150 degree boiling, 1-60 cp viscosity, with recycling. Printing accuracy 5-10 nm, sensors accuracy 1-2 nm, optical and other scanning parameters.

Additional reactor for nanoparticles cheap ink preparation. Inks for printer with different materials and service for development customer inks .

Who are your competitors? What distinguishes you from them?

Fujifilm Dimatix 75000 $ http://www.fujifilmusa.com/products/industrial_inkjet_printheads/

Advantages

3. Very similar to office inkjet printer

4. Use Graphical user interface

5. Pre loaded pattern templates

6.Operator can control the printing process from camera

7. High accuracy 25 µm

8.Self cleaning printer head

Disadvantages

1. Low speed– small area. Good only for small area

2. Can only these ink , low choice of materials. Used solutions of organic materials, suspensions. Cannot print oxides, metals

3. Low adhesion between layers

4. Slow dry of solvent

5 No feedback. No digital recognition of printed area. Cannot recognize crack , return and repair .

6. Miss print, leaving lines . Gaps and holes between the drops

7. Droplet size is very large . More 15 micrometers.

8. Cannot print layer lower than 1 micron at thickness. Low uniformity.

9. Can make only simple layer. No porosity controlled layer. No 3D textured layers (nanorods, nanotubes array, nanowires structures)

10. Cannot print on curved surfaces

11. No have sensors channels for express control

Optomec, Medium price 300000 $ https://www.optomec.com

Advantages

2. Aerosol jet have more accuracy that inkjet

3. Can print metals (licensed Laser engineered net shaping (LENS) from Sandia National laboratory)

Disadvantages

1)Low adhesion, only mechanical

2)No have sensors channels for express control of thickness and missrd lines

3) Low ink usage efficiency (50-60 %)

We have advantages to comparison with competitors for 3-6 month for exit to market (Fujifilm Dimatix, Optomec, Sono TeK, Ultraspray, 3D bioplotrer) – digital recognition feedback, better accuracy, better adhesion via ions, more materials, more speed, curved surfaces

Ions in our printer like a cement, increase adhesion, comparison

We have advantages comparison with competitors (Fujifilm Dimatix, Optomec, Sono TeK, Ultraspray, 3D bioplotter) – digital recognition feedback, better accuracy, better adhesion, more materials, more speed, curved surfaces for 3-6 month for exit to market

Example

Dimatix

Advantages	Disadvantages
1.No Competition. Practically no choice for lab usage	1. Low speed– small area. Good only for small area
2. Medium Cost 75000 $	2. Can only these ink , low choice of materials. Used solutions of organic

	materials, suspensions. Cannot print oxides, metals
3. Very similar to office inkjet printer	3. Low adhesion between layers
4. Use Graphical user interface	4. Slow dry of solvent
5. Pre loaded pattern templates	5 No feedback. No digital recognition of printed area. Cannot recognize crack , return and repair .
6.Operator can control the printing process from camera	6. Miss print, leaving lines . Gaps and holes between the drops
7. High accuracy 25 µm	7. Droplet size is very large . More 15 micrometers.
8.Self cleaning printer head	8. Cannot print layer lower than 1 micron at thickness. Low uniformity.
	9. Can make only simple layer. No porosity controlled layer. No 3D textured layers (nanorods, nanotubes array, nanowires structures)
	10. Cannot print on curved surfaces
	11. Small sensors channels for express control

Optomec

Advantages	Disadvantages
1. Medium price 300000 $	Low adhesion, only mechanical
2. Aerosol jet have more accuracy that inkjet	No have sensors channels for express control of thickness and missrd lines
3. Can print metals (licensed Laser engineered net shaping (LENS) from Sandia National laboratory)	Low ink usage efficiency (50-60 %)

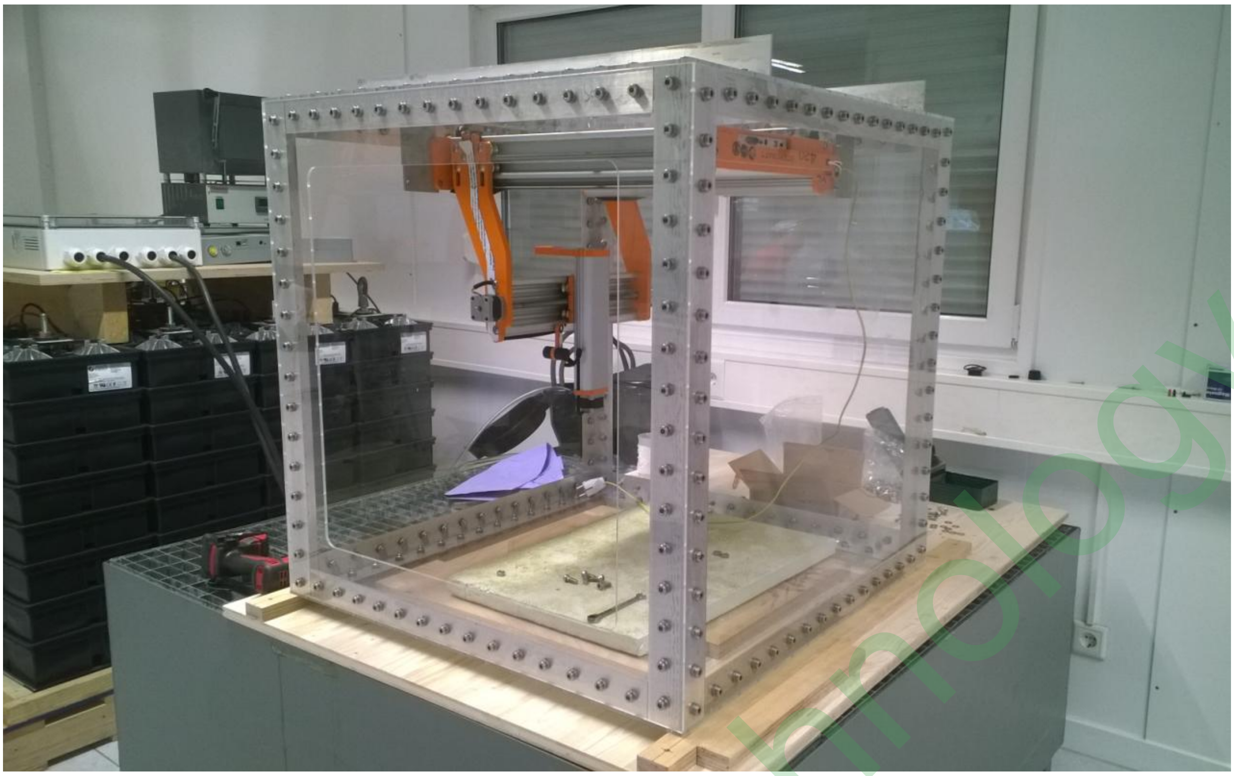
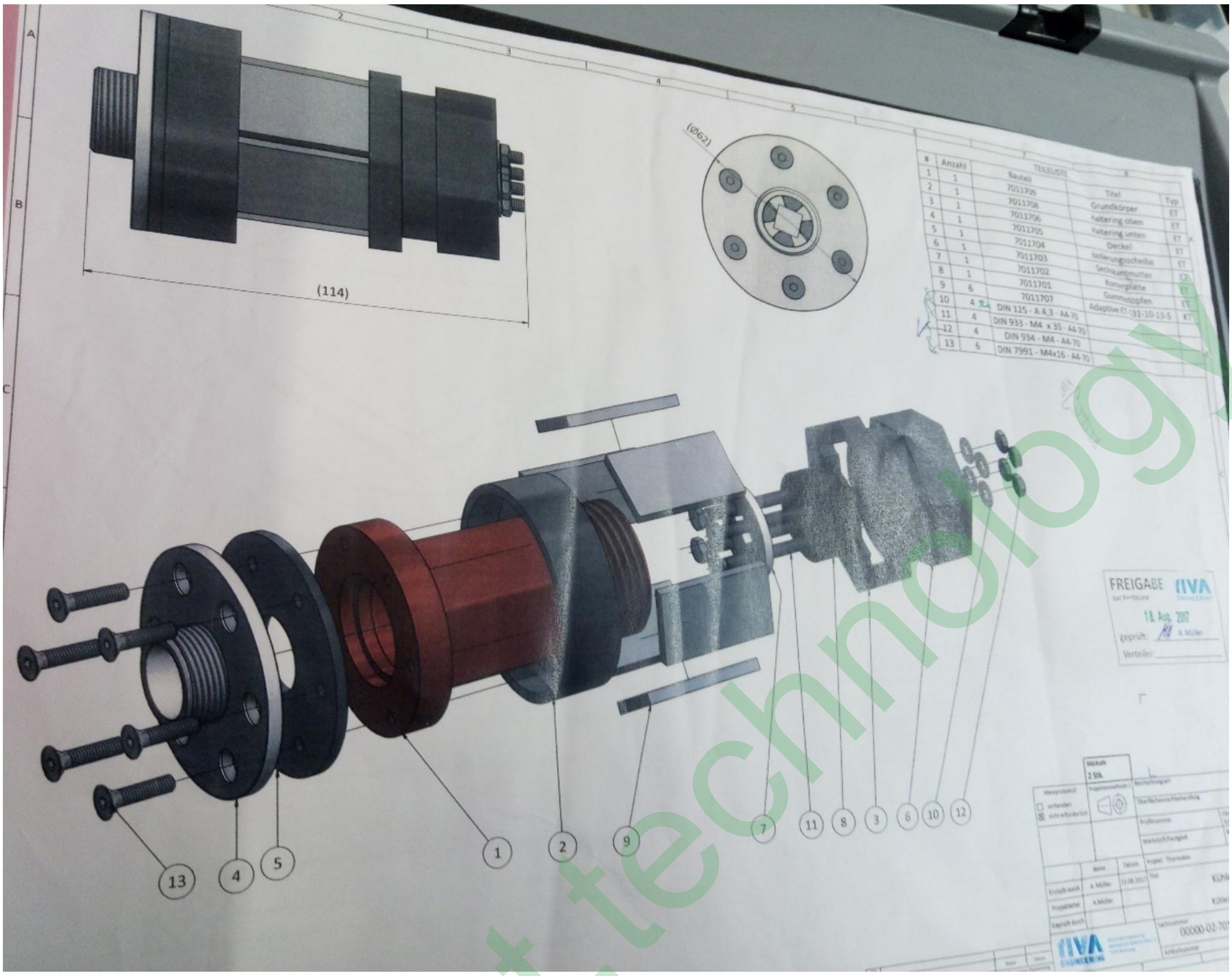


Figure 5. Nano-Printer prototype in RIVA container lab



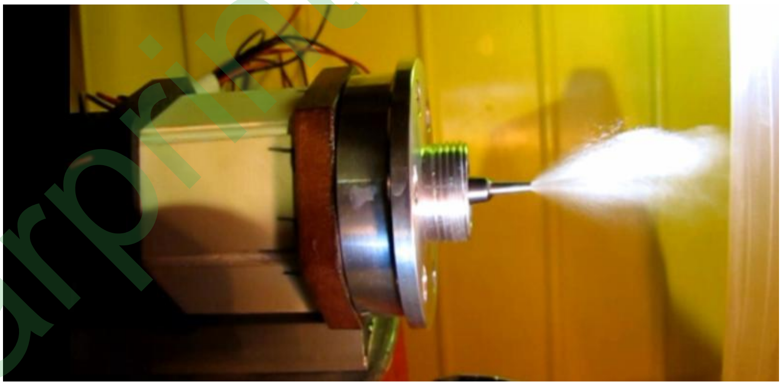


Figure 6. Printer head assembly and test

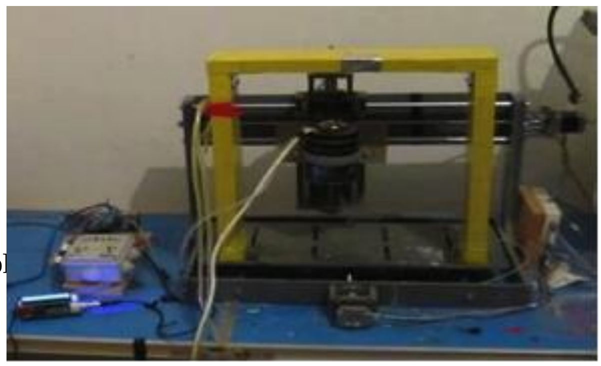
EXISTING PROTOTYPE STATUS (In Russia):

SPECIFICATIONS

Minimum line width	100 µm
Single Pass Layer Thickness	Min 500 nm max 500 mkm
Print Speed	40 mm/s normal , 200mm/s max

Mechanical shutter	Response time 2 ms
Ink Viscosity Range	1-50 cP
Atomizer temperature control	Controls ink temperature, 25-60°C, Oil cooling
Inks stirrer	Ultrasonic stirrer /reactor, viscosity dependent.
Area of print	300 mm x 300 mm; temp control up to 150°C Freezer
Platen (Optional)	Robot arm for print on 3d curved surfaces
Laser (Optional)	2 W blue/UV 300-450nm laser 10 W 1500 nm IR laser
Droplet size	0,5-2 µm
Stand-off height(size between head and surface)	1-5 mm
Electrical field intensity	4-8 kV/cm
Ultrasonic frequency	100 kHz - 10 MHz
Motion accuracy	+/- 10 µm for each axis
Motion repeatability	+/- 2 µm for each axis
Dimensions	300 mm x 400 mm
Electrical / Utilities	220 v

Demonstrable setup for printer:



Advantages	Disadvantages
High adhesion between layers and substrate, enhanced by electrically charging drops and plasma ionization	Used licensed software. Software used need advanced abilities, will be changed and modified
High speed print on big area	Not finished the automation
It can print on the 3d curved surface. Ultrasonic alignment of layer	Wide line , need to decrease 25 um Big thickness, necessary decrease to 100 nm.
	Not have air filtering from particles, water vapor. Necessary put printer inside the transparent, hermetically opened box

Business model

Sell printer and ink to it, as well as drawings pattern files with the possibility of printing the finished product. Initial users - laboratories in universities, in the future as the production technology. Printer Cost of not more than 10,000 USD, competitors are more than 70,000 USD. Possible production model integrable with the sale of solar cells, membranes, electronics. We can print solar cells based perovskites (10USD / sqr.meter) and CIGS, in the development of printing GaAs and silicon tandem increased efficiency for mobile devices and printed solar concentrator We also can print porosity control membrane for water desalination with the ability to control Ph and reduce the power consumption, which failed in the manufacture by conventional techniques. In this case it is possible to cheaper materials and with a strong economy expensive materials. All this can be the basis for printing smart and energy-efficient clothes

Planned reached parameters

Basically , what s printer can input file with pattern template in computer, input inks in to the printer , , control process of print with camera and sensors.
This task we can made for 3-6 month

Basic advantages:

- High adhesion between layers and substrate, enhanced by electrically charging drops and plasma ionization
- High speed print on big area
- It can print on the 3d curved surface. Ultrasonic alignment of layer

Features

Minimum line width	15 µm
Single Pass Layer Thickness	Min 100 nm, max 500 mkm
Print Speed	40 mm/s normal , 200mm/s max
Mechanical shutter	Response time 2 ms
Ink Viscosity Range	1-50 cP
Atomizer temperature control	Controls ink temperature, 25-60°C, Oil cooling Optional freeze of ink under -20 C with Peltier friezer
Inks stirrer	Ultrasonic stirrer /reactor, viscosity dependent.
Platen (Standard)	300 mm x 300 mm; temp control up to 150°C Freezer
Platen (Optional)	Robot arm for print on 3d curved surfaces
Laser (Optional)	2 W blue/UV 300-450nm laser 10 W 1500 nm IR laser
Droplet size	0,5-2 mkm
Stand-off height (size between head and surface)	2-5 mm
Motion accuracy	+/- 10 µm for each axis
Motion repeatability	+/- 2 µm for each axis
Stand alone system dimensions	
Stand alone system weight Electrical	
Utilities	

Medium recommended advantages :

- Original software, select material / ink profile in computer
- Digital recognition of printed area, feedback, return to missed lines, repair. Many sensored parameters.
- Multinozzle

Can be reached on 4-8 month

Hard reached advantages:

- Less than 5 mkm line size
- Less 30 nm minimal thickness

Can be reached on 7-14 month

Nano-Inks –, Nano-suspensions, Nano-Particles, Nano-wires

The secret of good printing of electronics is in the creation of nanoparticles. Of these, as a brick, you can make a material, while the layer is durable due to van der Waals forces, those that hold a gecko on the glass. These forces act, if the particles are brought closer together, to less than 100 nanometers, and the particles must be smaller than this size.

When the dimensions are reduced, many properties of the substance change, for example, the melting point

And, finally, as the particles of a substance decrease, their cost greatly increases, from 100 to 500 times with a decrease to 10 nanometers. This is due to the separation of smaller particles from large particles during centrifugation. In ink usually leaves less than 5% of the original substances, which is reflected in the price

Our team developed the technology of nanoparticle preparation and a device that allows to significantly increase the efficiency of production of nanoparticles

We also developed a computer model and a profile of each material that allows us to predict its properties and choose the best way to deposite it to the mold.

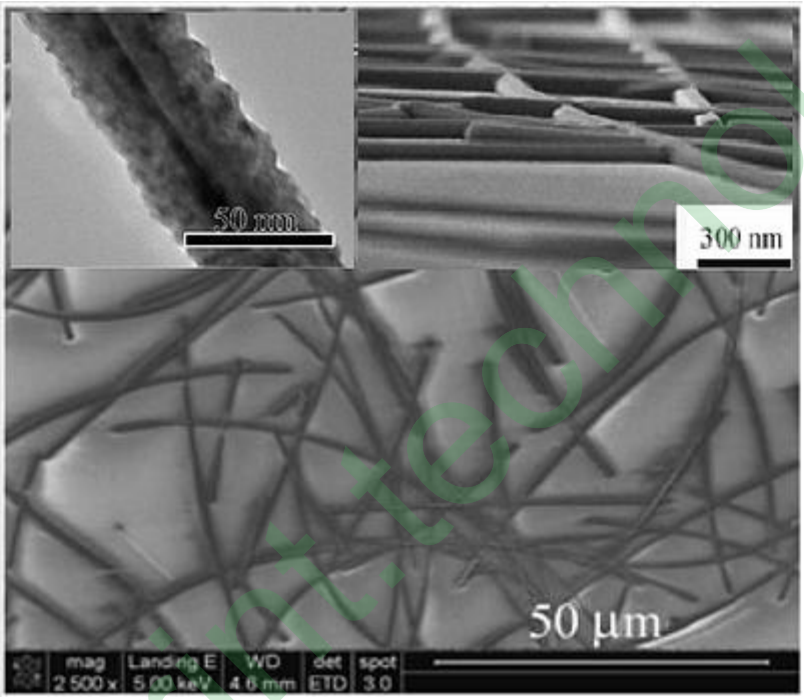


Figure 7. Printed nano-wires

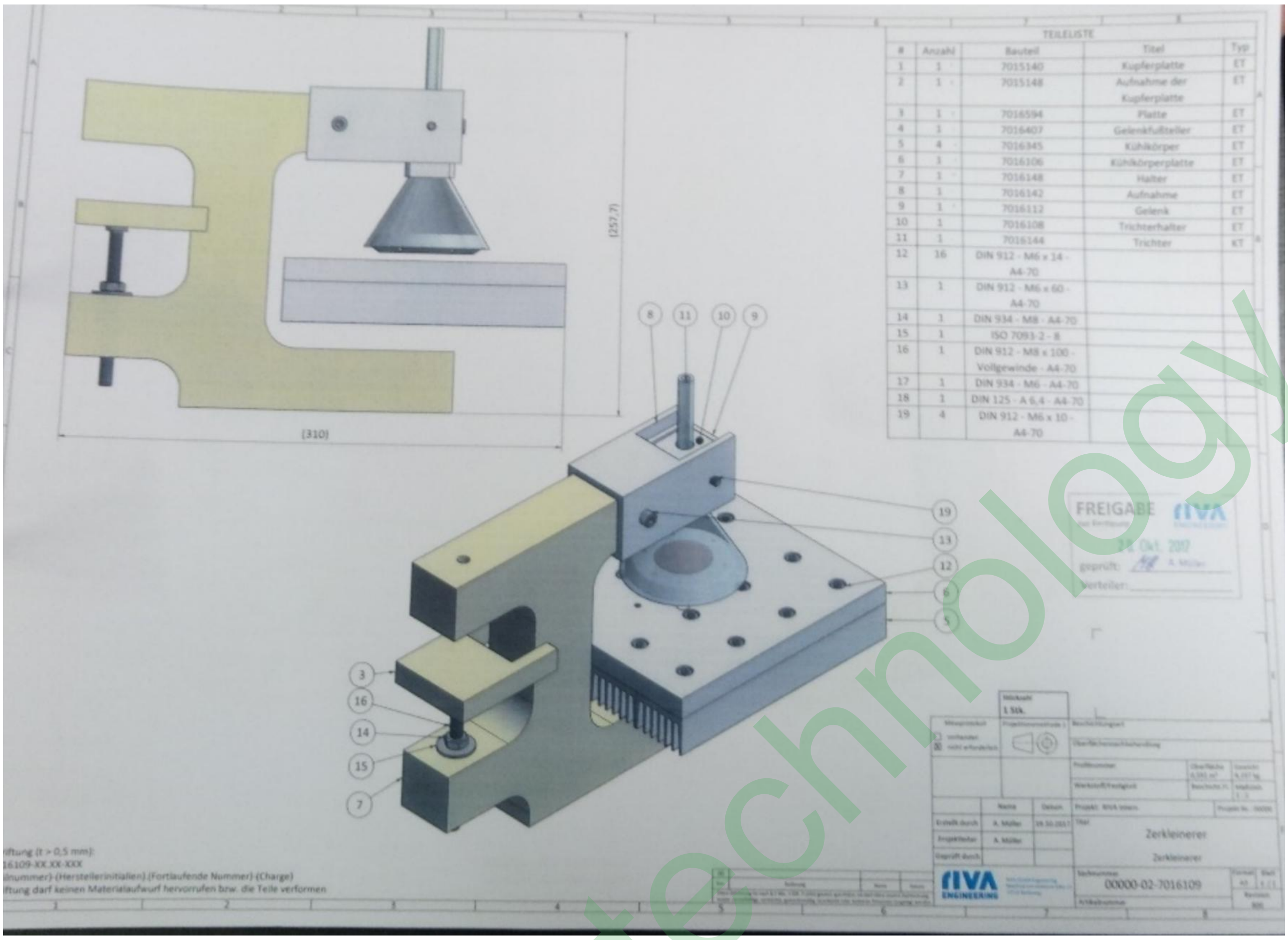


Figure 8. Nanoparticles preparation machine drawings

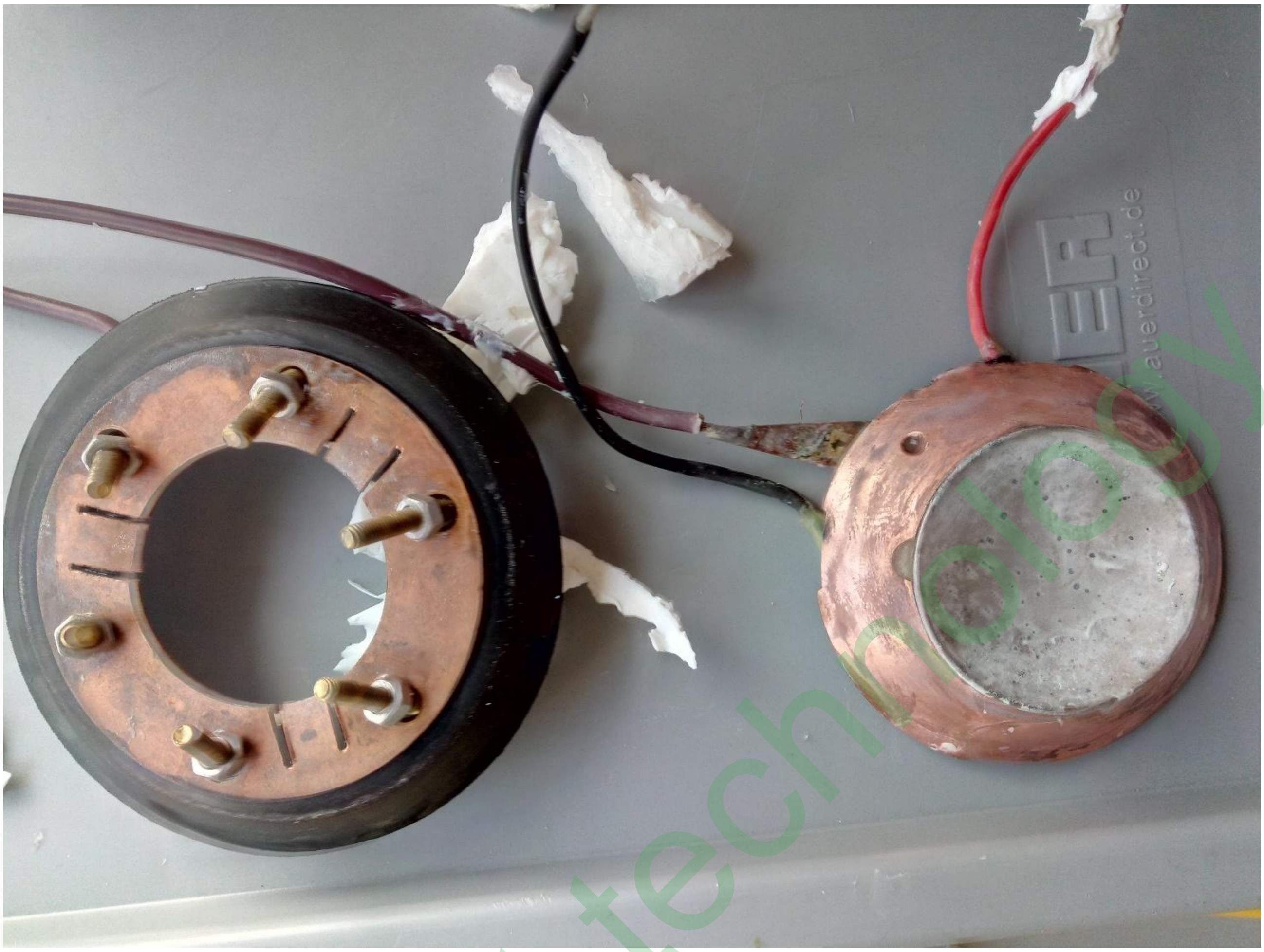


Figure 9. Focused transducer with radiator

Figure 10. Carbon nanotubes preparation

Applications

The smart materials printer that can scan the printed section and digital recognition. This allows you to correct mistakes and print are not blind. Print technology is also applicable to metals and organic materials allows you to create electronic circuits on any surface, provides high adhesion. Special prepared inks for printer (nanotubes, graphene, transparent conductive oxides, metal nano wires)

Printed customer products- solar cells, membranes, batteries, electronics. We was tested our solution in this applications.

Perovskite solar cells on metal foil with printed transparent conductive layer. Primary cost of 17 % efficiency solar cell 10 USD. Now we are try print tandem perovskite solar cell.

Also, high resolution of printing can be used in printed optics We use nanoparticles and ultraviolet photopolymer for printing micro-electromechanical (MEMS) solar concentrators with liquid lens for cars and aeroplanes

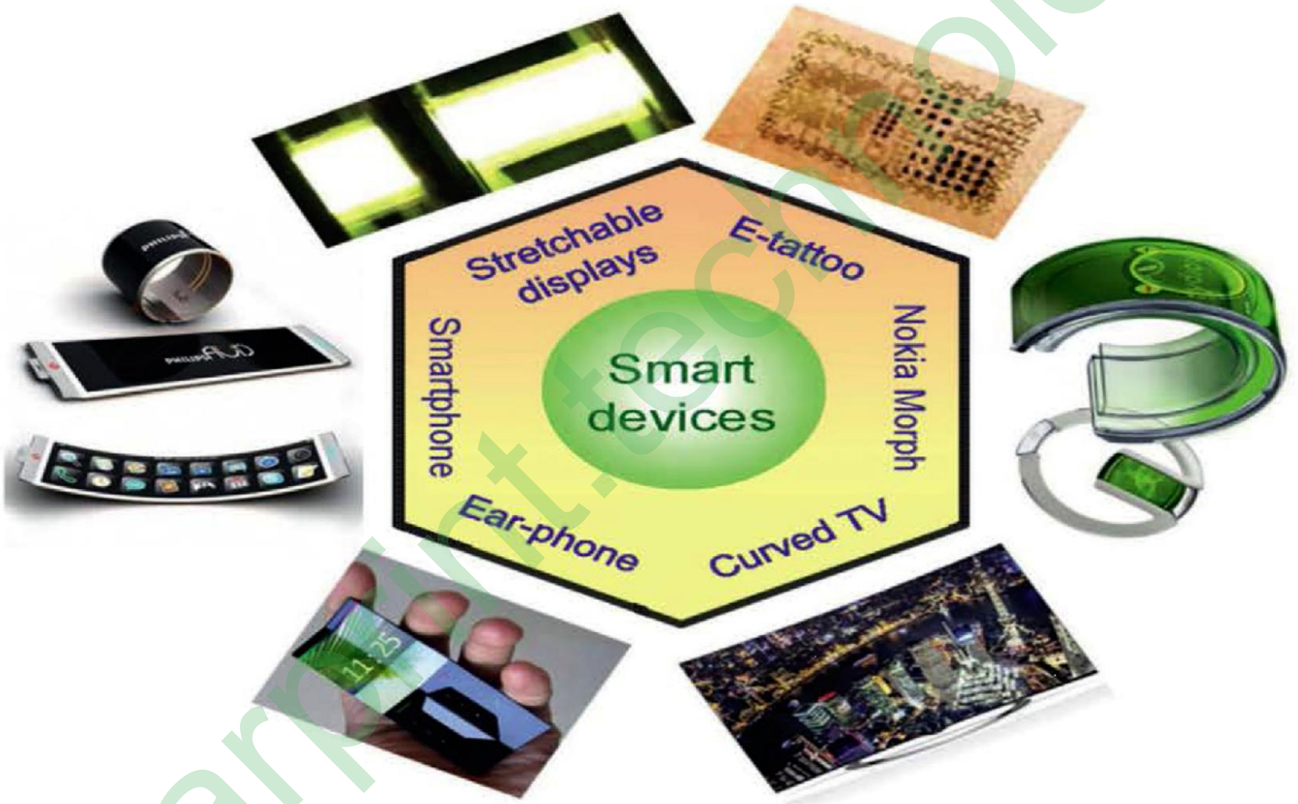


Figure 11. Applications of printed electronics

Also, we can print membranes or change their physics-chemical characteristic. We can modify of the ion exchange membrane by spraying of nano-drops with porosity control. This has fetch to a change in the morphology of the membrane surface, therefore - to changing the value of electro convection. Modifier helps increase energy efficiency by 35% and there is no need for additional reagents in the system during the desalting. Modified homogeneous ion-exchange membranes for purification of aqueous waste effluents, wine and wine products, juices and dairy products, as well as methods of their manufacture. Electrodialysis installation will become more mobile. We want to desalinate sea water through solar cells energy and direct in a dry place where there is no a constant source of fresh water (desert near the sea). Also we was testing a modification ultrafiltration membranes

Other possible applications

1.Solar cells a)Tandem solar cells with bottom silicon,b) CIGS Roof shape solar cells c) Metal-surface solar cells d) Porouse textile clothes with integrated flexible solar cells e) Integrated solar cells with OLEDS Metal print back electrode and contacts Nonlinear optical plastics : flat solar concentrator

2.Membranes a) Electrodyalysis membranes, nanoporosity control membranes Desalination, selection cleaning food processing industry, milk, jus, wine b) Ultrafiltration membranes c) Fuel cell proton exchange membranes d) Membranes for accumulator batteries, redox electrolyte batteries e) Bio-inspired medical membranes (hyaluronic acid,) Hemodialysis, artificial kidney.

3 **Transparent conductive oxide** (laser plasma cold deposition) a) Silicon solar cells covering - increase efficiency 2-3 % , because decrease resistive losses b) OLEDs Screens, different shapes, flexible c) Smart window glass (electrochromic)

4. **Electronics** a) Different shape electronics printed circuit board b) Multi layers printed circuit board c)Transparent electronics components d)Flexible, textile integrated electronics e) Printed metal conductive lines k) Printed resistor, capacitors l) Printed diodes, transistors , logic (low repeated parameters)

5. Accumulator batteries a) Al-air batteries b) Zinc-air batteries c) Li – ion electrodes with control porosity,d) membranes for electrolyte separation graphene batteries

6.Printed composite advanced materials a) Aerospace: smart materials withsensors integrated, b) Self cleaning, self healing c) Meta-material, multiferroic printing.

Printed products

Printed CIGS , perovskite solar cells on curved surfaces.

Fabrication of thermally stable and long lasting perovskite solar cells:
Organometallic perovskites are one of the most promising materials for photovoltaics. They consist a lead halide compound and an organic positive ion. The most well-known structure is CH3NH3PbI3.

Problem1:

Based on perovskites the solar cells now can reach 19.7% efficiency in a laboratory, but it has low stability and scattered parameters because they are highly hygroscopic due to loss of seal at which they reversely decay. The main reason is reaction with water vapor, and it happens in places of defects and cracks as a result of the efficiency of elements mostly falls from 19-13% to 1-3% per month.

Strategy1:

a. Use of high purity original components (99.999%) to avoid the defects, in this case methylamine salt sublime.

b. Using fullerenes, antimony sulfide and molybdenum oxide for covering cracks and pores. These materials also serve as protectors of the decay. It is experimentally shown that this method allows to increase the stability and reduce the hysteresis with the addition of fullerenes about 1%.

Fullerene has roughly the same energy levels as a perovskite. The energy levels of the perovskite can be extended using double layers with different chemical compositions

The addition of semiconducting polymers with the adjacent energy levels in the amount of 15-30% and 1-5% of fullerenes can afford to use them as a protector from disintegration and mechanical stabilization. This can be called plasticization of perovskite.

c. Using special additives, blocking methylamine ions or formadimina in their positions. In a simplified form it is ammonium chloride, in a more complex form it is butylphosphonic acid 4-ammonium chloride (4-ABPACl)

d. Using nonporous layers of metal oxides to prevent degradation.

One of this methods is spraying metal oxide ion-beam method, but then need to regulate the flow of ions bombarding the target while spraying. Thus there is a decay of the applied substances into ions that may lead to a significant performance improvement - the reaction between components take place more completely in the crystallization, hence smaller defects will lead to smaller pores and micro-cracks, and improved adhesion and electrical contacts. This can lead to improved efficiency and lifetime of this type of solar cell. But there is the opposite effect, as if backward organic compounds can be problematic. The articles and patents in the world such a method of making this type of solar cells has not been described, so you can get new results.

e. Using pseudo halides instead of halogens:

Examination of various organic radicals as replacing methylamine CH3NH3 +, for example HC (NH2) 2+, and other similar radicals

f. Crystallization with minimum defects:

The use of an electric field, ultrasound, laser radiation upon crystallization allows to intensify the reaction

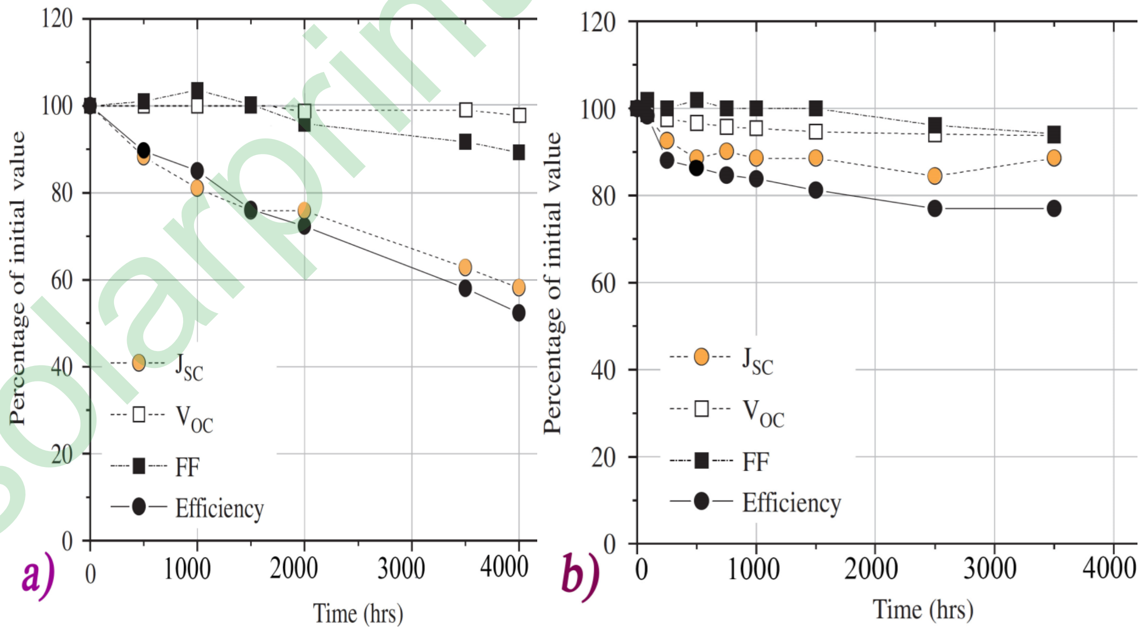


Fig.8. Degradation of perovskite solar cells average main characteristics at encapsulation and light intensity of 1 sun: J_{sc}- the current density, V_{oc} –open circuit voltage, and FF - fill-factor. a)

deposition layers from the solutions, efficiency fall on 37,5 % for 3000 hours; b) thermal vacuum deposition, efficiency fall on 21,7 % for 3000 hours.

Problem2:

As the layers used are quite expensive hole conductor- SPIRO-OMETAD and PTAA, priced around $ 200-300 per gram, and for 1 square meter area, the required amount is about 0.1-0.05 grams (a layer of about 100 nm). Additional charges come to increase conductivity by using organic lithium salts to overcome the issues related to their hygroscopic nature and increased the corrosion of the metal electrode and perovskites.

Strategy2:

1) Here we will use, as a hole conductor, a composite of nickel oxide and multiwall carbon nano-tubes. This will lead to the reduced cost and increased stability of the hole conductor by using multiwall carbon nanotubes with a gradient impurity of 15 to 5%, from one side of the pair PEDOTT: PSS and polyaniline or P3HT and TTF-1, on the other hand, nickel oxide.

Problem3:

The current anode for all the laboratory samples worldwide is silver or gold owing to their low corrosivity, high adhesion and low work function of the hole but it can not be used in the industrial embodiment due to high cost.

Startegy3:

Replacing the gold electrode with an energy level of 5.1 eV carbon Nickel 5.04 eV to 5.9 eV, selenium layer (anode) and titanium-aluminum (cathode)

Problem4:

Low absorption in the near infrared range, which is about 40% of light energy

Startegy4:

This drawback can be overcame by combined water heater element as a coating. This can also be solved by creating a tandem perovskite-silicon cells.

Another method could, possibility be, the introduction of quantum dots as hole conductors, with a lead sulfide infrared light absorption to 2 micrometers, instead of using nanotubes.

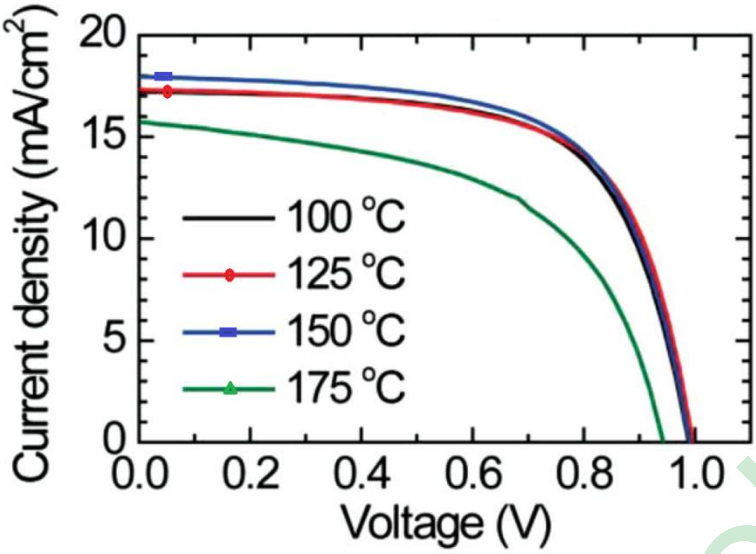


Fig 9. Current-voltage characteristic of solar cell at different temperatures.

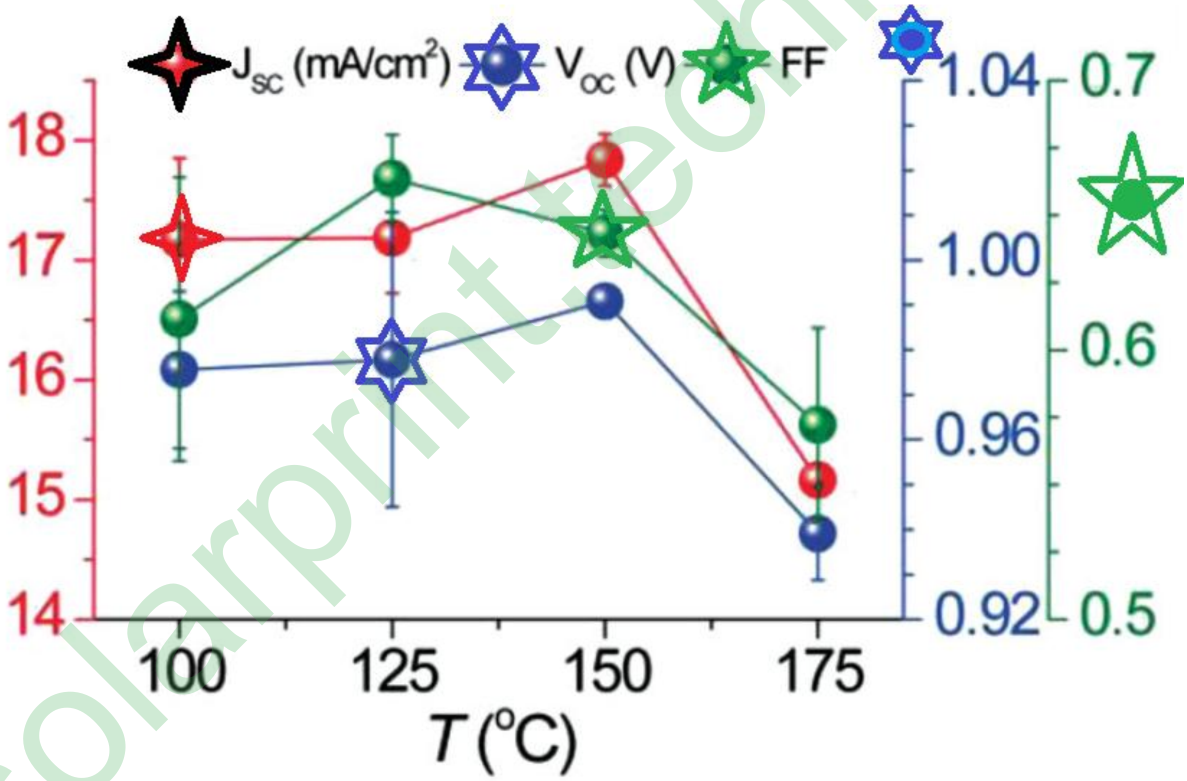


Fig. 10. Main characteristics of solar cells at different temperatures: Jsc- the current density, V - voltage and FF - fill-factor)

Problem5:

Perovskite layer is limited to a maximum thickness of about 3 micrometers. Above this value, efficiency is reduced due to the limit of free path of electrons and holes. This means that the solar cell will be translucent and will not absorb all the light.

Strategy5:

To increase the effective thickness we use nano-tubes of titanium dioxide as an electron conductor. Nano-tubes of titanium dioxide and zinc oxide are one of the elements of the semiconductor heterojunction to create three-dimensional structure for light absorption and to yield improved work in the slanting rays.

Expected results:

Production of stable organometallic perovskites with a maturity of more than a few months, and further expansion of working hours to years.

Available samples:

DESCRIPTION	SIZE	DATE Year month	EFFICIENCY % When It made	CURRENT STATUS	PHOTO
Glass/ITO/TiO2 100 /TiO2 porouse 2000 nm/C60 /perovskite 2000 nm/spiro/ Carbon nanotubes/Copper foil fully printed	100x100 mm	2015 - 01	12 % 850 mV 15 mA/sq	6,5% 450 mV 10 mA /cm2	

Material Cost Estimates:

Cost estimates solely depend upon the amount and purity level of the materials used. If the thickness of perovskites is 200-600 nm, the thickness of the transparent conductive coating 200 nm, multi-wall carbon nano-tubes doped organic conductors as 150-300 nm, porous and nonporous oxide of zinc, zirconium, aluminum, nickel and titanium as 150-200 nm and graphene and fullerenes C60 as 30-40 nm, that is, the total thickness of 800-1300 nm with an average density of 1.5 g/cm^3 bulk propellants will be from 0.35 to 0.7 grams, on average, about 0.5 grams, while also spent solvents weighing 20-30 grams, but they can be recycled, by means of a refrigerator. And the cost will be around 11-19 dollar per square meter as shown in Table 1.

TABLE I. CALCULATION OF THE PRIME COST OF 1 SQUARE METER OF PEROVSKITE SOLAR CELL

Weight, g	***wholesale price $***	***retail price $***	***material/source***
1000-8000	3-4	5-8	Ni-Al surface , plastic encapsulate
0.15	0.6-2	5	Perovskite (sintered)
0.1	2	5	Copper nanowires + indium tin oxide
0.1	0,8-1,9	2,5-5	Doped carbon nanotubes (30 nm)
0,04	1-3	2-6	Graphene+C60
0,12	0.6-3	2-5	Meso-porous oxide
30	0.4	0.7	Solvents (recycled)
-	~1-3	~3	Energy cost
-	~1-2	~5-10	Labor cost
	~10.6-18.5 $	~30,5-47,7	Summary

Microcell liquid lenses solar concentrator

One of the pilot uses of the nano-printer is solar cells for cars based on microlenses. The use of solar cells for specially designed vehicles has already become a reality. There were also gliders and cars, powered from the sun

The main problems are a limitation in size, which is why it is necessary to use solar panels of maximum efficiency and a change in the direction of incidence of the rays due to traffic,

The maximum efficiency at the current time have arsenide gallium batteries, serial samples of about 30-35%. However, their cost is tens and hundreds of times greater than silicon batteries. Therefore, they are usually used together with concentrators. For concentrators, a tracking system is needed, otherwise, when the focus is shifted, their effectiveness decreases. Until recently, there was no tracking system that could be installed on a moving object

In the case of an efficiency of 30%, you can get about 300 watts per square meter. In the case of an average electric vehicle, we have at least 3 square meters, which will give about a kilowatt of power. The electric car itself consumes an average of about 20 kW. The battery capacity of the Tesla Model S is 85 kWh, while on one charge it can travel 426 km. Thus, for 10 hours of parking in the sun of an electric vehicle, it can be charged for 10 kWh or 50 km of travel.

Also, solar panels must be made with a curvature of the surface, which repeats the curvature of the vehicle

As for aircraft, the weight of the solar battery is of great importance here

To spread solar panels using concentrators there are several problems. First, using traditional Fresnel lenses results in a large focal distance between the concentrator and the solar cell with the consequence of the large size and weight.

The second problem is the need for tracking the sun, because even a sun offset by a small angle causes a significant shift in the focal zone relative to the concentrator.

We propose the following solution:

Our concentrator would consist of two parts. The first one collects sun rays inside of an optical fiber, then inside of a two-dimensional waveguide where they are reflected from both sides to confine in the center at the solar cell location. The lens consists of several segments filled with a liquid gel. When the sun moves, the gel inside the lens moves too to always let the sun rays fall down perpendicularly on the solar cell for all sunlight hours in a day. This eliminates the need for a tracking device and makes the concentrator efficient for most acceptance angles.

In the area of concentration of the sun rays, we plan to investigate the perovskite solar cells, which we will make and compare their efficiency to the existing silicon and gallium arsenide panels.

Further, the necessary passive and active cooling methods will also be investigated, with the option of combining the electrical supply with heat pumps and water heaters. Solar thermal storage using this Perovskite battery will also be investigated.

The combination of printing manufacturing techniques of the optical waveguide concentrator made of plastic and gel with different refractive indices, and tracking of the sun by means of liquid lenses are novel aspects of this work and have not been previously reported in literature.

The result of this work is an efficient printed concentrator backed by theoretical and experimental data. The practical significance lies in the possibility of the emergence of high-performance all-day solar water heaters, that are modular and that can be maintained while operating.

Development of microcell liquid lenses Solar concentrator

Solar concentrators have the potential to decrease cost associated with solar cells by replacing the receiving surface aperture with cheaper optics that concentrates light onto a smaller cell aperture. However a mechanical tracker has to be added to the system to keep the concentrated light on the size reduced solar cell at all times. The tracking device itself uses energy to follow the sun's position during the day.

Concentrated PhotoVoltaics (CPV) focuses on increasing the yield of solar cells. Traditional CPV has two major challenges. First is the relatively large distance between concentrator and solar cell with the associated large size and weight of the structure, and second is the need to track the sun in order to provide large concentrations required.

The current project proposes a solution that addresses both these challenges. The size and cost of material of the concentrator is to be significantly reduced by manufacturing it in two parts. The first one collects sun rays inside of an optical fiber, then inside a 2D fiber where they are reflected from both sides to concentrate in the centre. The lens consists of several segments filled with a liquid gel. When the sun moves, the gel inside the lens moves too resulting in a perpendicular incidence on the solar cell for all sun angles or times of day, eliminating the need for tracking. The use of perovskite solar cells to concentrate the sun's rays will be investigated. The necessary passive and active cooling methods are to be investigated, with the option of combining the electrical supply with heat pumps and water heaters. Solar thermal storage using this Perovskite battery will also be investigated. The combination of printing manufacturing techniques of the optical waveguide concentrator made of plastic and gel with different refractive indices, and tracking of the sun by means of liquid lenses are novel aspects of this work and have not previously reported in literature.

We develop the technology of smart manufacturing, like a printer, while layers are deposited of surface electro-activate nano-droplets that allows to achieve the accuracy of the layer thickness of 50 nm and a controlled porosity. The printer no longer blind, and can scan and correct their mistakes, like craftsmen. Applications is the individual manufacturing for flexible, different shaped, textile integrated electronics, solar cells, batteries, bio-inspired membranes.

1.2

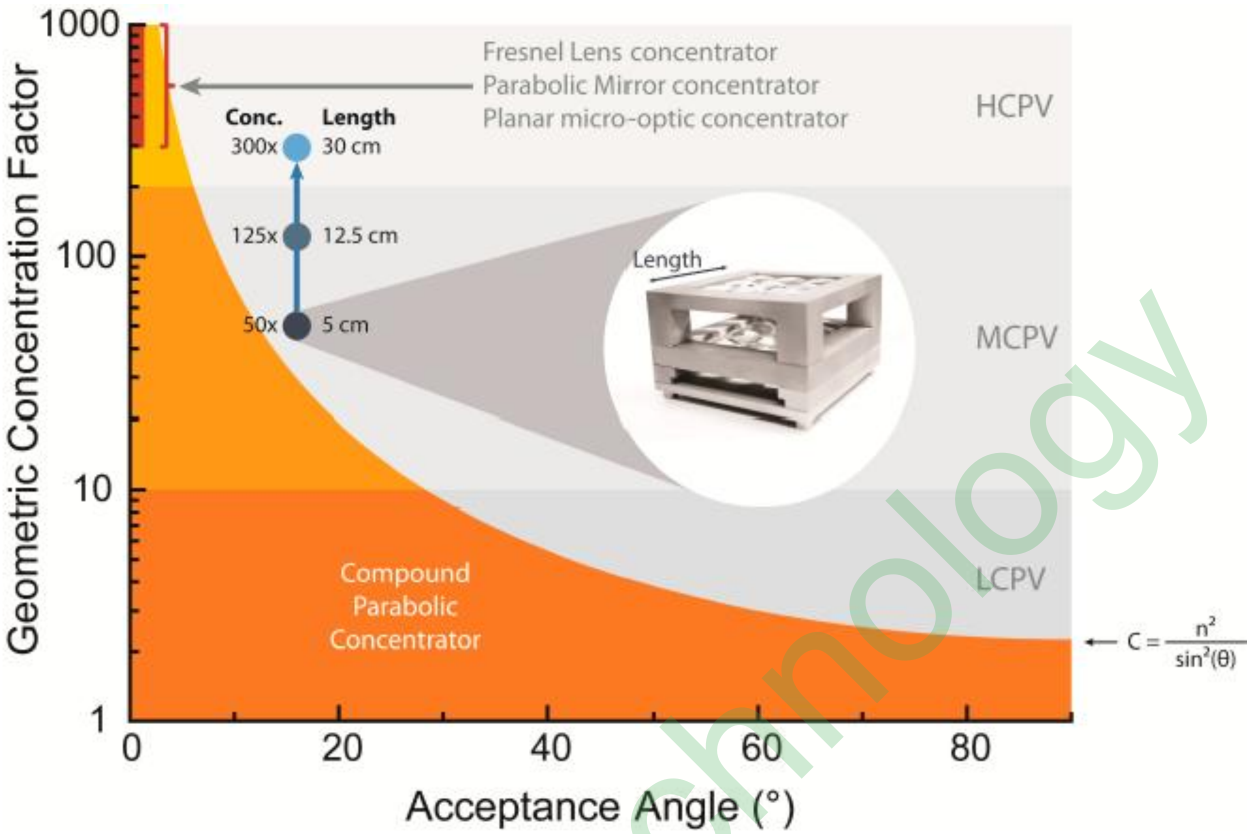


Fig. 3. There is a trade-off between concentration factor and acceptance angle. For any given acceptance angle, there is an upper limit of possible concentration (orange area, n = 1.5). Due to this the field of CPV technologies is divided into three categories: High, medium, and low CPV. Our approach has a concentration factor that is to the right of the curve due to its self-tracking mechanism, capable of reaching 300x geometric concentration with ± 16° acceptance angle (dark spot).

Due to the high cost of solar cell materials, CPV aims to decrease the amount of photovoltaic cell materials by using less expensive optical elements to concentrate sunlight onto a smaller solar cell. This has the potential to decrease the cost per watt. Any CPV module, regardless of the technology used, has a certain acceptance angle and a concentration factor. The acceptance angle describes the part of the sky the concentrator is looking at and the concentration factor describes the relation between an incoming aperture and the exiting aperture, in this case a solar cell. It is fundamentally not possible to achieve both a high acceptance angle and a high concentration factor as can be seen in Eq. (1) where theta-max-in is the half angle of acceptance.

$$C \leq C_{max} = \frac{1}{\sin^2(\theta_{\text{max,in}})}. \qquad (1)$$

Due to this tradeoff, we can identify three classes of concentration systems: low, medium and high concentration systems. Low concentration systems (<10x) have a large acceptance angle to be operated in a fixed position (no tracking). On the other end, high concentration systems (100x – 1000x) operate with very narrow acceptance angles and require precise mechanical tracking. These sun trackers are active mechanical systems, which consume energy in order to function, thereby reducing the overall efficiency of the system. Commercial CPV systems are of typically large area, high concentration which results in large form factors. Hence HCPV systems are mostly used in solar farms. The middle ground, medium concentration, (10x –200x) is not as common. The drawback of MCPV is that it still requires accurate track.

Proposed working of concentrator:

Figure 3 shows a classical waveguide concentrator with no self-tracking. This basic concept is refined to include self-tracking in this project.

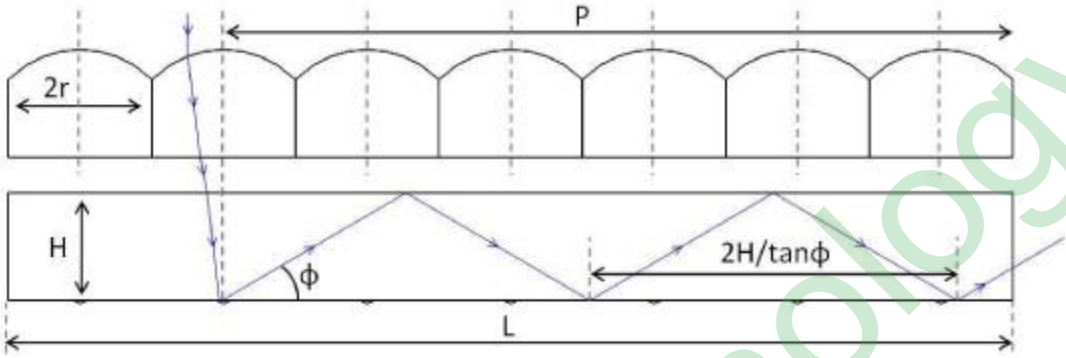


Fig 4. Classical solar waveguide concentrator

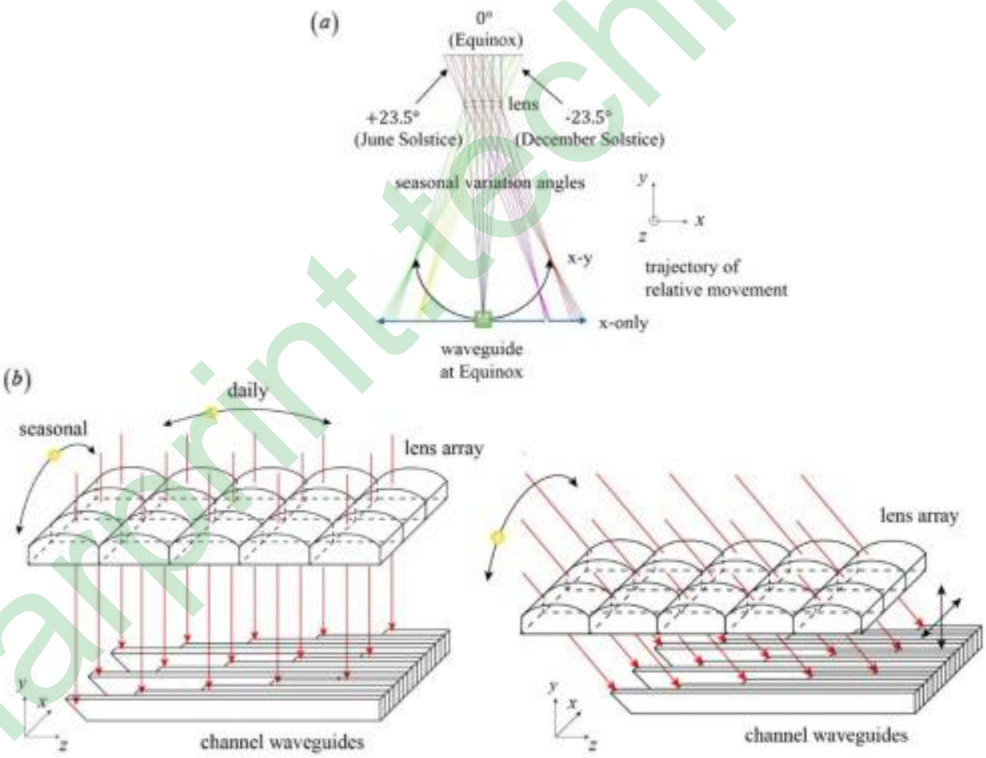


Fig 5. Micromotion solar waveguide concentrator tracking

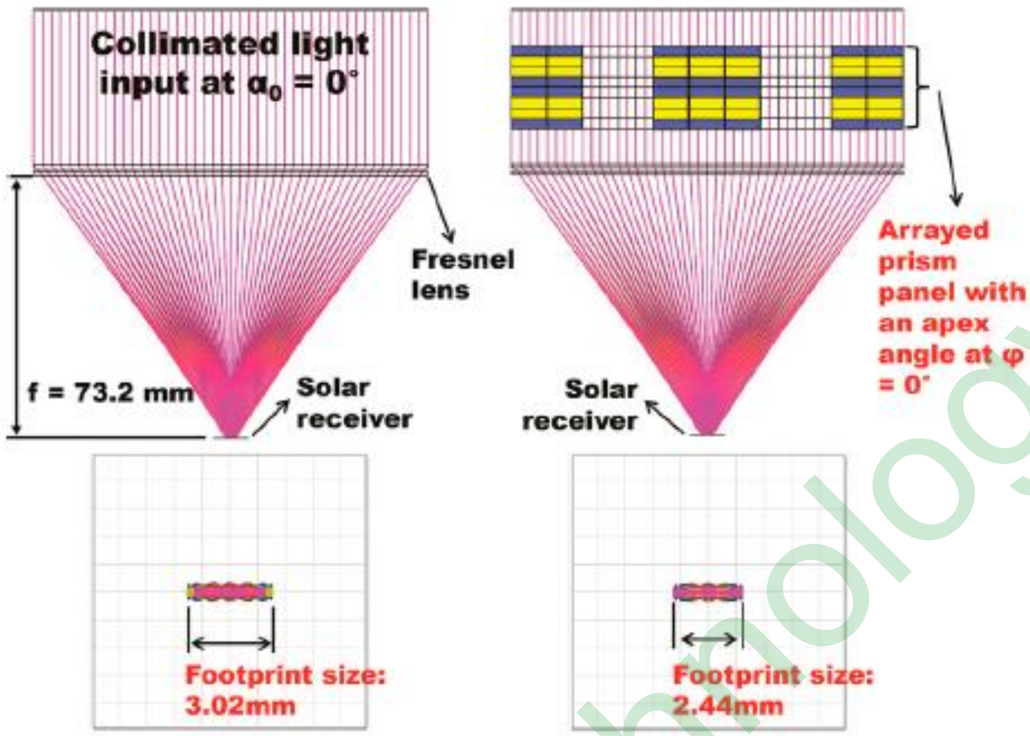
Figure 4 shows an illustration of x-y and x-only movement of the translation stage using a lens-waveguide pair in XY plane (looking into the waveguide). When the incident angle is large, field curvature and astigmatism become significant; focal points are not located in the same plane. If the relative movement is x-only, large spot size at oblique angles would lead to efficiency decrease. Therefore x-y movement is important to compensate for the increased spot size. In Fig.4(b), a brief 3D view of the proposed tracking scheme is provided. Only chief rays are shown. At the Equinox, the lens array and the waveguides are aligned in all three dimensions. The system is placed so that the Sun travels in the YZ plane at this time of the year. Departure from the Equinox, the single-axis mechanical tracker (x-axis in this figure) rotates the whole structure daily to ensure that the lens array and the channel waveguides are always aligned in z-direction. Relative movement by the translation stage happens only in x-axis and y-axis.

Previous work

Previous works on self-tracking concentrators have shown the potential of the concept, but viable candidates for the adaptive mechanism remain a challenge. Towards the goal of an effective self-tracking mechanism, we have presented a proof of principle demonstration of a reversible in-plane Photovoltaic Concentrator Material (PCM) actuator activated by focused sunlight, and described a concept for its use as a self-tracking mechanism in a planar solar concentrator. Experimental results suggest that when combined with a tuned-angle dichroic facet array and a two-element lens array, the in-plane PCM actuator can be used for high efficiency coupling over ± 23.5° with a lens Focus F<2x, and could be used in combination with coarse single axis tracking for a simplified and potentially low-cost solar concentrator.

As with any solar concentrator technology, cost benefits are critically important. At the early stage of this work it is difficult to accurately predict the manufacturing costs of such a device, but we can describe a basic hypothesis for a cost advantage. We suggest that cost savings from 1) reduced PV material due to moderate levels of concentration and 2) the reduction from accurate two-axis tracking to coarse single-axis tracking outweigh the additional costs incurred from materials, parts, and complexity of manufacture.

Each of the liquid prism modules is implemented by a microfluidic (i.e. non-mechanical) technology based on electrowetting for adaptive solar beam steering. Therefore the proposed platform offers a low-cost, lightweight and precise solar tracking system while obviating the need for bulky and heavy mechanical moving parts essentially required for a conventional motor-driven solar tracker. In this work, various liquid prism configurations in terms of design (single, double, triple and quad-stacked prism arrays) as well as optical materials are considered and their impact on optical performance aspects such as solar beam steering, reflection losses and beam concentration is studied. Our system is able to achieve a wide solar tracking covering the whole-day movement of the Sun and a reflection loss below 4.4% with a Rayleigh’s film for a quad- stacked prism configuration. Furthermore, an arrayed prism panel is proposed to increase the aperture area and thus allows for the collection of large amounts of sunlight.



(a) (b)

Fig 6. The optical layout and the footprint of the focused light at normal incidence (a0 = 0) (a) without and (b) with our arrayed microfluidic prism panel, which consists of arrayed 11x1 quad-stacked prism modules.

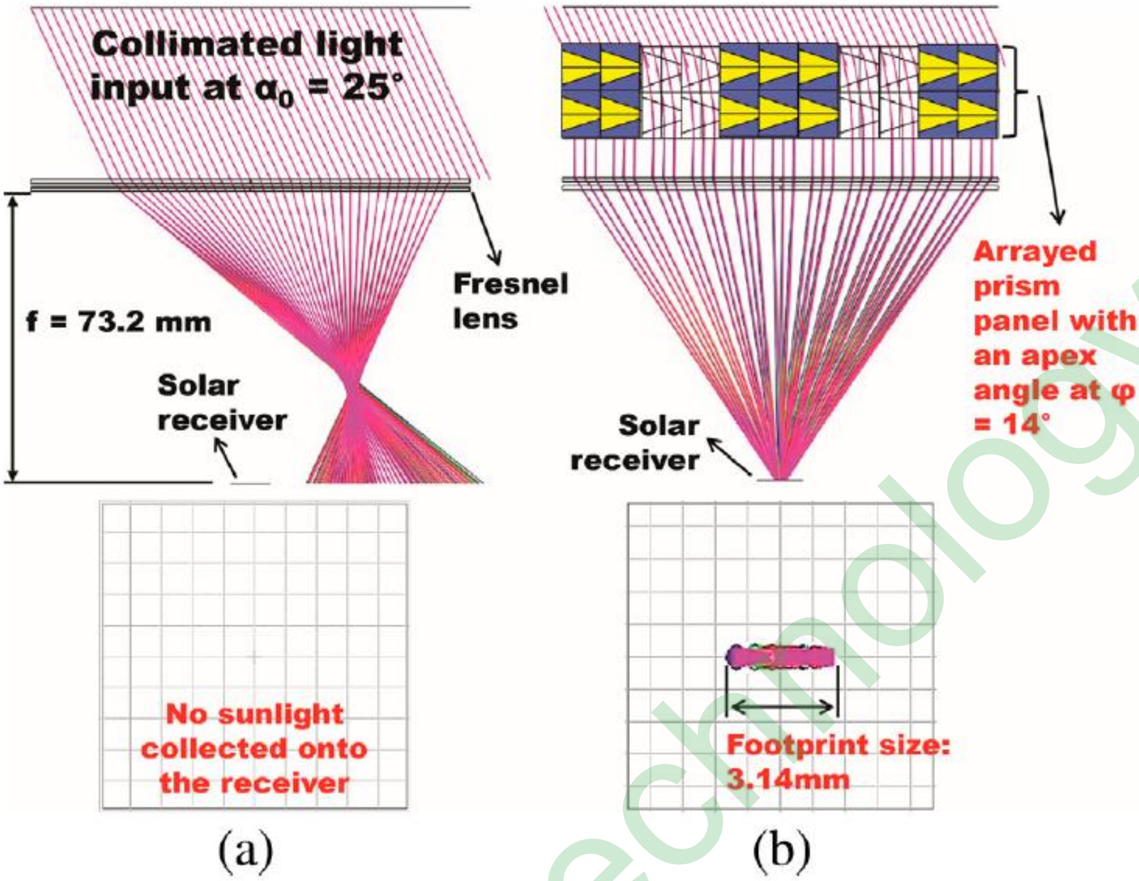


Fig 7. The optical layout and the footprint of the focused light at oblique incidence ($a0$ = 25°) (a) without and (b) with our arrayed microfluidic prism panel, which consists of 11 x 1 arrayed quad-stacked single prism modules.

Fig. 5(a) shows the optical layout without the arrayed prism panel. Input collimated light directly irradiates at normal incidence (a_0 = 0°) and focuses onto a solar receiver through a concentration optics which creates a focal plane at f = 73.2 mm away from it. As concluded previously, the simulation while considering a 110 x 10 mm^2 linear aperture for simplicity can be extended to 110 x 110 mm^2. Consequently, the input light with an aperture size of 110 x 110 mm^2 can be concentrated onto the receiver as small as 3.02 x 3.02 mm^2, which indicates the minimum footprint size required to collect 100% solar input. This area reduction leads to a high concentration ratio.

Further studies were conducted to observe the effect of solar concentration with an oblique incidence, which represents the variations in the Sun's position throughout the day. Incoming light illuminates at an incident angle of a0 = 25°. Without the liquid prism panel, incoming rays are refracted out of focus and miss the solar receiver located at the center of the system (see Fig. 6 (a)). Consequently, none of the solar energy input can be collected onto the receiver just with the concentration lens. Another simulation study was run with our prism panel. The prism apex angle is tuned at u = 14° to adaptively steer an oblique incidence at a_0 = 25°. As a result, all the incoming rays can be focused onto the solar receiver with the minimum footprint size of 3.14 mm (see Fig. 6(b)). The concentration ratio can be estimated to be 1227x even for a_0 = 25°.

<u>Materials research</u>

Further, we can consider the materials used for our concept device. Paraffin wax is an inexpensive and common by-product of the petroleum refining process. Similarly, carbon black is also a common and inexpensive material produced by combustion of heavy petroleum products and also more recently from recycling of rubber automotive tires. Polydimethylsiloxane (PDMS), the elastomer we currently use is extremely convenient for prototype fabrication, but it is not common for industrial applications and would likely be substituted by another transparent and flexible polymer in a commercial device. Finally, of the components required by our concept, the dichroic mirror coating is the most likely to be considered too costly, as it is often deemed too expensive for other solar concentrators. However, there are reasons to believe that multilayer coatings are not out of reach. Further, its multilayer design is similar to that required for our application, since it reflects useful light for Silicon PV and transmits the heat producing mid-infrared and UV light. Although it's unclear if this material could be processed for our device, its existence suggests that we should not discount the possibility of inexpensive multilayer coatings suitable for solar spectrum splitting

Fabrication

We are using flexible PDMS optical waveguide sheets that act as large area light collectors (concentrators) and illuminators (diffusers). The performance and efficiency of these optical sheets are determined by the position and geometry of micro-optical features embedded in the sheet or imprinted on its surface, thickness and shape of the waveguide, core and cladding refractive indices, and wavelength of the incident light source. The critical design-for-manufacturability parameters are discussed and a scalable method of fabricating multi-layered PDMS optical waveguides is introduced. To illustrate the concepts a prototype waveguide sheet that acts a combined light collector and illumination panel is fabricated and tested. The region of the waveguide sheet that acts as the light collector consists of two superimposed PDMS layers with slightly different indices of refraction. The top layer is patterned with micro-lenses that focus the incident light rays onto the micro-wedge features that act as reflectors on the bottom of the second layer and, due to total internal reflection, redirect the light rays to the light diffuser region of the waveguide sheet. The bottom face of the diffuser PDMS layer is patterned with angled triangular wedge micro-features that project the light out of the waveguide sheet forming an illuminating pattern. The proposed fabrication technique utilizes precision machined polymethylmethacrylate (PMMA) moulds with negative patterned PDMS inserts that transfer the desired micro-optical features onto the moulded waveguide.

printed concentrators with high efficiency, which can track the sun while staying stationary (Fig. 12).

These concentrators allow to use small area solar panels with high efficiency. Because of this the cost increases in 1.5-2 times as compared with silicon solar cells at the cost of increased efficiency. With this technology, upto now we could not fully reproduce the results in the morning and in the evening, but the increase in efficiency is possible (Fig. 13). In the first step of the work we have to determine, as far as possible to approach to the two axial concentrators in the morning and in the evening, and a prime cost.

This technology became interesting for AUDI for use in electric vehicles powered by solar panels on the roof.

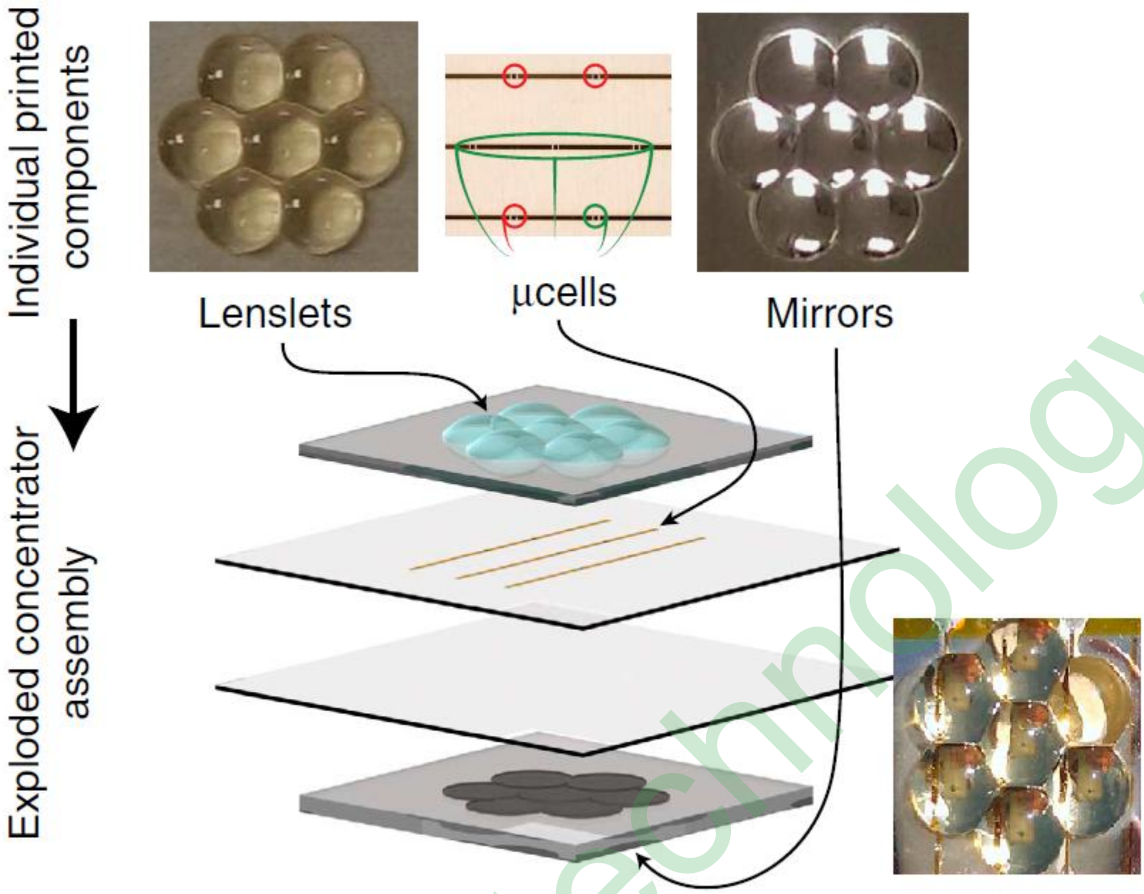


Fig 12. Planar printed concentrator

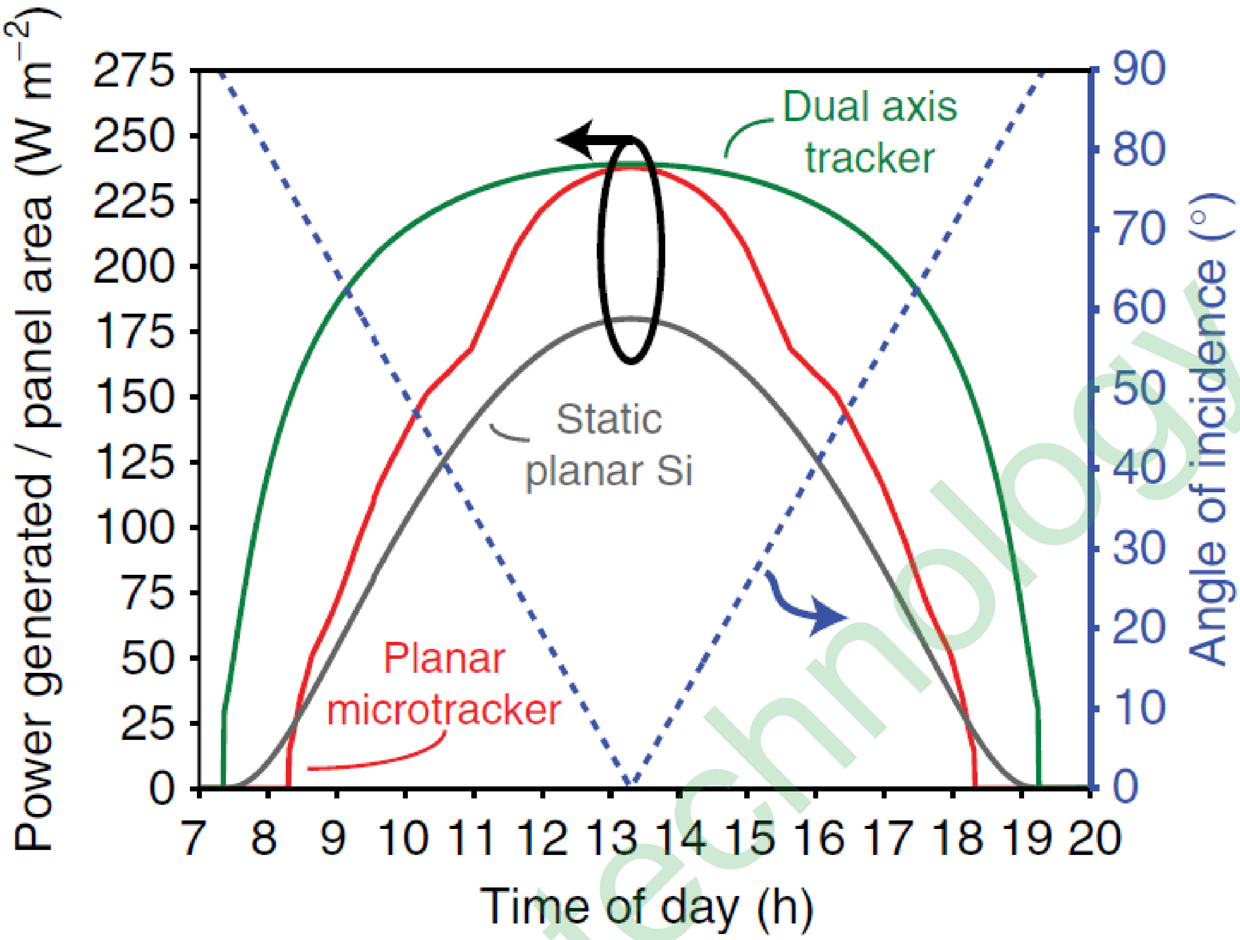


Fig 13. Power generation per day, comparison silicon, dual axis tracker, printed planer microtracker.

Printed transparent solar cell for skyscrapers roofs and windows

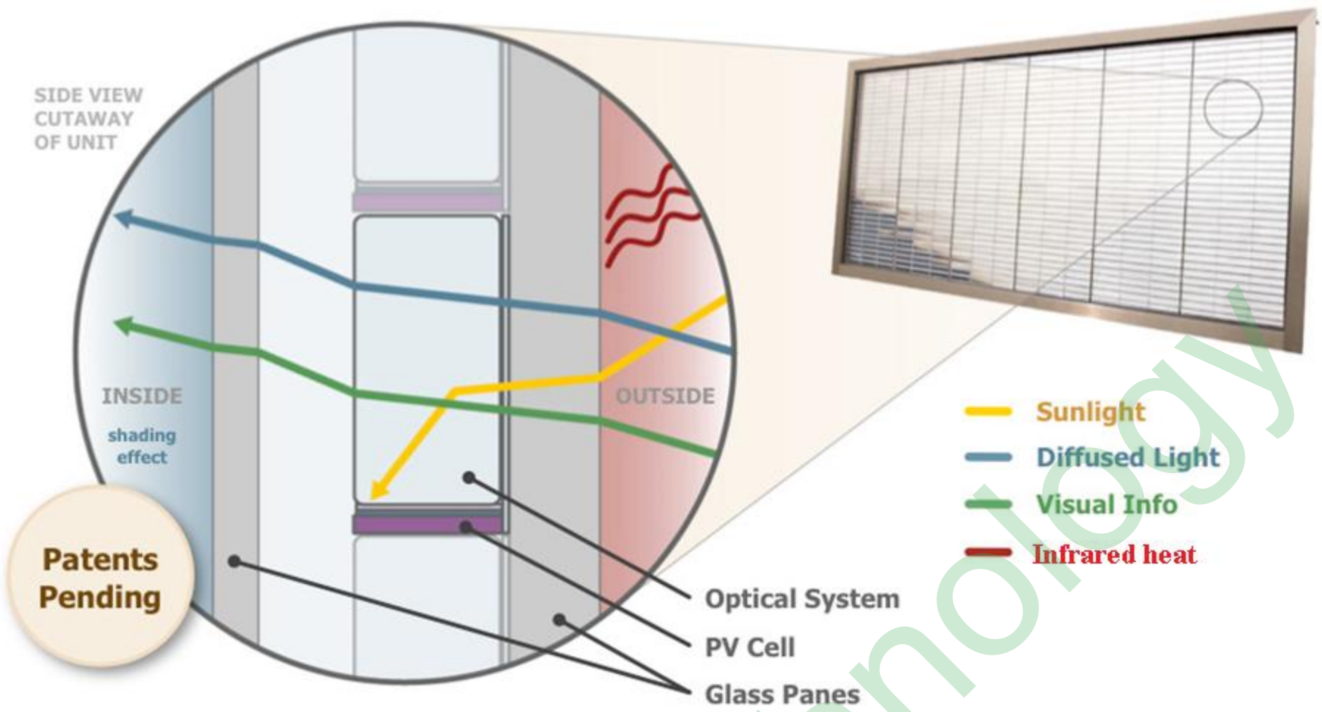


Figure 12. Solar window concept

We have developed a way to print windows with built-in solar panels. Solar light is 53% composed of infrared light, which we do not see, but feel like heat. This infrared light is separated from visible light when it enters the window and is directed to solar panels, located as blinds inside the window. Visible light passes inside. The optical system practically does not distort light, distortions can be minimized

In this case, an optical system is used to divide and redirect infrared light and solar cells with enhanced absorption in the IR region.

Measurements of power versus angle were also carried out, at angles of about 20 degrees the power drops by 15%

The conversion efficiency of infrared light is 11%, it can be increased to 16-17%. This is about 110 watts per square meter of double-glazed windows. Transparency for visible light is 90.5% perpendicular, and about 78% at an angle of 45-60 degrees, the window changes its color from blue to burgundy at an angle. You can make a drawing that will not be visible at small viewing angles to the window, but visible on reflection when looking obliquely at the glass. In the future, we plan to increase transparency for visible light.

If we take the area of Burj El Khalifa, an area of 334,000 m², then, considering that on average only half the building, then 110x334000 / 2, there will be 18.37 MW, and for the light day there will be 367.400 kWh.

The peak consumption of the tower is 30-50 MW, that is, the window can provide up to 50% of the energy of the glass building.

The usual cost of a solar battery is about 80-100 dollars per square meter, about the same cost have energy-saving windows

There are developments of a similar orientation, it is possible to mention translucent batteries based on dyes (due to sensitized solar cells), brown, red, yellow and green colors that can be used similar stained glass windows. They assembled a group of Michael Gratzel from the Lausanne Polytechnic School. The efficiency of such batteries is about 5-7%. They absorb a part of the visible light, and the other part is passed. In this case, the infrared part is captured only partially

There are also solar cells on quantum dots that absorb mainly the infrared part of the light, but the

efficiency of such batteries is only about 3-4%.
Also, there are batteries based on phosphors, where the light falls on the phosphor and is re-emitted to solar batteries along the perimeter of the window. The efficiency of such systems also does not exceed 3-5%.
Also there were windows where the lens is built, but they distort the visible picture.
It should be noted the Spanish Onyx Solar and American ubiquitous energy. Ubiquitous Energy states that its UV-absorbing solar panels are 3% of the total energy of light and infrared, 53% of sunlight, can have an efficiency of up to 10% and transparency for visible light of about 90%.
Specific values of efficiency can not be found, but in the latest publication, where a 150 nm thick titanium oxide oxide (ITO) oxide is used. Then 20 nm of molybdenum trioxide (MoO_3), 15 nm of chloraluminium phthalocyanine (ClAlPc), 30 nm of Buckminsterfullerene (C_{60}), 7.5 nm of batocuproine (BCP) and 100 nm of Ag cathode are added via thermal evaporation. The efficiency was about 2.5%.
Thus, the market now does not have solar panels for windows with acceptable conversion efficiency and minimally disruptive windows function.

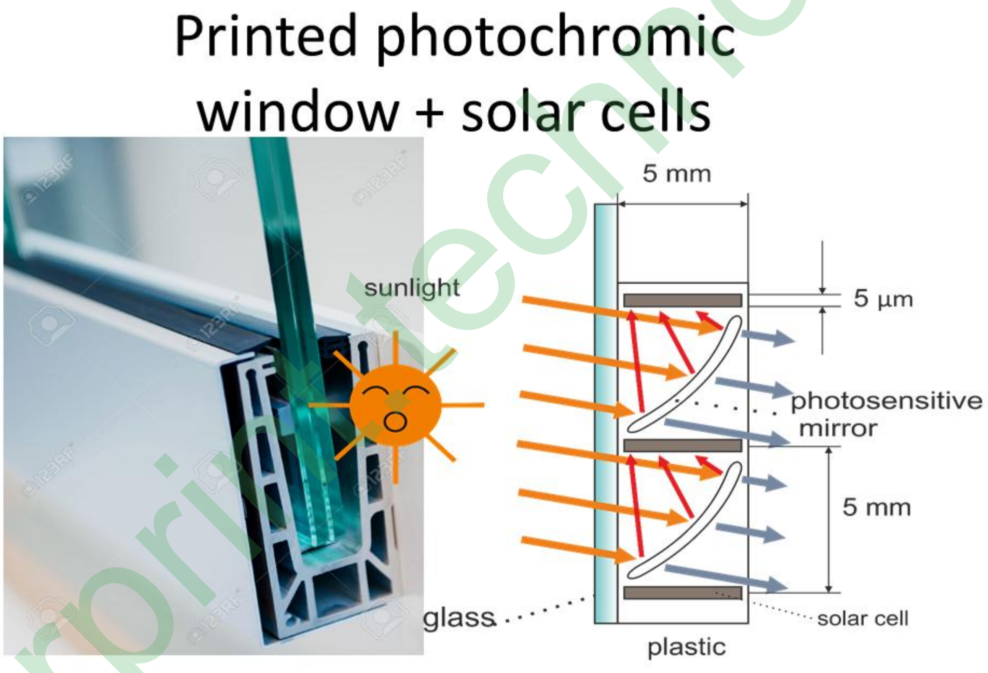


Fig 11. Window integrated solar cell concentrator. Photo-sensitive mirror always concentrate infrared on solar cells, visible light depends on intensity of light

Figure 13. Solar window with double sided solar cell

PLANNED REACHED PARAMETERS FOR TRANSPARENT SOLAR CELLS ARRAYS:

Efficiency: 12-16 %

Transparency:

a) Sun direct light
   - i) invisible (ultraviolet + visible + infrared) 20-40 %
   - ii) visible 50 %

b) Cloudy weather, shaded area
   - i) invisible (ultraviolet +visible +infrared) 60 %
   - ii) visible 75-85 %

So by adopting the said technology, the output power yield is expected upto 150 W on maximum lighting from 1 sqr . meter panel.

Comparing these with current development products, we can see that semi transparent solar cells based on dye-sensitized technology yield 5-8 % efficiency (EPSL, Switzerland). However they are in green and red colors only making them less attractive.

On the other hand, Quantum dots based cells show 1-3 % efficiency, which could be made selective to absorption in infrared spectrum.

At the end of development, we should get a clear transparent sheet of large area in which is built-in an array of reflectors directing sunlight into an array of solar panels (Fig. 6). The array of reflectors, and solar cells must be manufactured in a single process using additive manufacturing. The degree of reflection will depend on the intensity of sunlight: the more light passing inside reflects more infrared light. *Hence, semi-transparent solar panels can be used instead insulating glass in skyscrapers.*

Future work involves the experimental study of heat distribution in concentrator, made by Russian group.

Figure 14. Concept of transparent window

TEAM and previous work

Technology is primary developed in Russian company PhotoChem Electronics and German company RIVA GmbH Engineering. We are creative friendly international team of including chemists, physicists, engineers, programmers. its CEO, inventor Dmitry Lopatin chief engineer Oleg Baranov (CTO) chemical engineer Elizaveta Korzhova, she research membranes, modified on printer, in University of Franche-Comte.

Our investor and partner is Hermann Puettmer, CEO and owner of RIVA GmbH Engineering-

Key publications:

(WO2017176163) MODIFIED ANION-EXCHANGE MEMBRANE AND METHOD FOR MANUFACTURING SAID MEMBRANE

https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2017176163

We have Russian patent applications for:

1) “Method and device for additive manufacturing nanostructured materials”

(November 2015) Title of the Application: RU2015113324A

2) Solar cell and manufacturing method thereof (November 2015)

3) Solar cell concentrator and manufacturing method thereof (April 2016)

4) Semi-transparent solar cells array and manufacturing method thereof (June 2016)

Science articles

Lopatin, D., Baranov, O., Korzhova, E., Kozbaev, K., & Samarskiy, D. (2015, July). Perovskite solar cells: a comparison at ultrasonic spray and vacuum thermal deposition methods. In *Nanotechnology (IEEE-NANO), 2015 IEEE 15th International Conference on* (pp. 405-408). IEEE.

http://ieeexplore.ieee.org/abstract/document/7388622/

Korzhova, E., Pismenskaya, N., Lopatin, D., Baranov, O., Dammak, L., & Nikonenko, V. (2016). Effect of surface hydrophobization on chronopotentiometric behavior of an AMX anion-exchange membrane at overlimiting currents. *Journal of Membrane Science*, *500*, 161-17

http://www.sciencedirect.com/science/article/pii/S0376738815303185

Video about this project

https://www.youtube.com/watch?v=EkOL5ijrh9g

https://www.youtube.com/watch?v=dUS2EquBo4k

Yearly Work Plan:

1st Year plan:

Russian group in conjecture with German partners will work on the manufacture of plastics and printing technology and gels with different refractive indices, as well as integration with solar panels.

2nd Year Plan:

Experimental study and theoretical/modelling simulation of the different design concentrators.

The mode of cooperation would be to provide interaction between the different groups through:

1. Exchange visits of researchers and students.

2. Skype meetings to discuss progress
3. Joint preparation of research publications for journal publications and presentation at conferences.

Relation to the work programme

The Russian partner team PhotoChem Electronics LLC will focus on the 3D printing techniques of the solar cells and concentrator. Also group will focus on the simulation of optical properties and of the optics and thermal behaviour of the components, complemented by experiments. German Riva team focused to making semi-industrial printer for additive manufacturing solar cells and concentrator.

- Russia Researchers in Research Team

Name	Organization, Division	Title	Degree	Speciality
Oleg Baranov	PhotoChem Electronics LLC	CTO	M.Eng	Optical engineering
Dmitry Lopatin				
Dr Andrey Sitnikov	Solar Wind LLC	Consultant, industrial partner	D.Sc	semiconductor
Dr Grigory Yurko	JSC «Saturn»	Consultant, industrial partner	D.Sc	aerospace
Dr Vinay Gupta	National Physical Laboratory, India	Visiting scientist	PhD	Solar cells

Russian side plan

Dates	*Descriptiion*
08/2017 *10/2017*	*Development the printer head and different deposition modes.* *Calculation and modeling nano-drops in printer head in change focusing area*
11/2017 *01/2018*	*Testing the printer modes for different materials for solar cells and optical devices. Assembling printer head with change focusing area size*
02/2018 *07/2018*	*Developing the automation software for printer head. Developing the smart feedback in printing process. Testing the uniformity of layers*
08/2018	*Comparison for printed layers with inkjet and aerosol jet printers and with vacuum*

02/2019	*and vapour deposition methods*

German side plan

Dates	*Descriptiion*
08/2017 *10/2017*	*Development and assembly of printer for additive manufacturing solar cells and solar concentrators.* *Test the horizontal and vertical accuracy of printed area*
11/2017 *01/2018*	*Printing of prototypes of translucent window solar concentrators. We plan this as a main product because it is very close to the main profile of the company.*
02/2018 *07/2018*	*To determine the extent of absorption in the reflective material along with total power efficiency.* *Calculation of the optical beam path tracking.*
08/2018 *02/2019*	*To determine the primary cost of manufacturing. At this stage we aim to start development of industrial printers for additive manufacturing of window large area solar concentrator*

Targets , Budget and Plan

Expected impacts:

Key objectives or questions that need to be clarified during the project include:

- The efficiency of solar concentrator, the percentage of scattering and absorption of light.
- The dependence of efficiency and cost of the concentrator and the solar cell on the production technology and materials used.
- The ability to reduce the size of the concentrator.
- The effectiveness of tracking the sun with liquid lenses.
- The maximum temperature obtained without cooling of the hub (concentrator and cell assembly).
- The stability of the solar cell parameters (perovskite, silicon, gallium arsenide) inside the hub.
- The efficiency of the concentrator in cloudy weather.

The significance of the project includes:

The combination of printing manufacturing techniques of the optical waveguide concentrator made of plastic and gel with different refractive indices, and tracking of the sun by means of liquid lenses are novel aspects of this work and have not been previously reported in literature.

Deliverables:

1. Getting data about the possibility of stabilizing the perovskite for more than two years and data of the perovskite degradation of solar cells for the said period.
2. Obtaining stable organometallic perovskites with a maturity of more than a few months, and further expansion of working hours to a few years.
3. Obtaining thermostable solar cells and the ability to create hybrids of vacuum solar thermal collectors and photovoltaic cells.

Target via-a-vis Technological Benchmark:

Key questions that need to be clarified during the project.

1. The efficiency of solar concentrator, the percentage of the scattering and absorption of light.
2. The dependence of the efficiency and cost of the concentrator and the solar cell from the production technology and materials used.
3. The ability to reduce the maximum size of the concentrator. The effectiveness of tracking the sun liquid lenses.
4. The maximum temperature obtained without cooling and the hub.
5. The stability of the solar cell parameters (perovskite, silicon, gallium arsenide) inside the hub.
6. The efficiency of the concentrator in cloudy weather.

Potential application areas:

Applications and commercialization. The main advantage of this application – is to look for the possibility to further reducing the solar energy costs. In addition the hub can be used to heat water and desalination.

Stage 1:

3 Month Target1:

a) Making of new prototype of printer for the additive manufacturing of solar cells and solar concentrators.
b) Printing of prototypes of translucent solar concentrators. We plan this as a main product because it is very close to the main profile of the company.
c) Registration of Intellectual Property in the territory of the European Union on the basis of Russian patent applications and to make new patent applications.

3 Month Targets2:

a) To create and assemble the device for printing (additive manufacturing) light concentrators in Riva Engineering.
b) To determine the extent of absorption in the reflective material along with

total power efficiency.

c) Calculation of the optical beam path tracking.

Total Expenses for first 6 month target: 100 000/- EURO

Stage 2:

6 Month Target:

a) Test printing of solar cells in Riva Engineering Lab for scaling and increased area from 20x20 cm^2 to 100x100 cm^2.

b) Selection of materials for the increased efficiency and to measure efficiency losses for different constructions: Construction with one or two active glasses.

c) To determine the primary cost of manufacturing. At this stage we aim to start development of industrial printers for additive manufacturing of window large area solar concentrator

Expenses: 300 000/- EURO

Stage 3:

6 Month Target:

a) Assembly of industrial printer for additive production of large area window concentrators.

b) Testing of manufactured windows with large area solar concentrators.

c) Certification of electrical, light parameters of the manufactured solar windows concentrator. Testing with potential customers.

Expenses: 500 000 -800 000/- EURO

Thus the total development time is 18 months and the total cost to have a product of industrial value is approximately 900 000 to 1 200 000 EURO. This is private funding, planned in this project. We ask the IRA SME funding with 90000 EURO on German Side and 50000 EURO on Russian Side.

<u>IMPROVEMENTS:</u>

Time 3-6 Month

PRINTER HEAD:

Decreasing the size of Printer Head
Printer head heat sink
Size control of print area (minimum 15 μm)
Self-cleaning
Cover for the printer

SOFTWARE & AUTOMATION:

Regulating of printer head moving (motors)
Regulate power of ultrasonic transducer, electric field, syringe pump, heating laser
Macro view camera and digital recognition software
Interface from the printer to the computer via current USB cable/Wi-Fi
Software for printer with GUI

INK:

Inks preparation, research of deposition layers for solar cells, membranes and properties
Prepare inks with fixed viscosity, drying time
Technique of deposition
Method of express control surface
Program profile for deposition material (carbon nanotubes, graphene, polymers, etc)

Improvement Cost Estimates:

1. Development/enhancement printer head (Shahid, Dmitry, Oleg, Elizaveta)
Subcontracting / freelancers: 150 k€
 i) AutoCAD /Autodesk inventor specialist for 3d design
 ii) prototyping on CNC machine tool
 iii) mathematical modeling /Calculation Matlab, Comsol

2. Software. Graphical user interface PC (Dmitry, Shahid, Oleg)
Subcontracting/ freelancers: 25 k€
i) GUI programmer (windows) Maybe from LabVIEW
ii) USB driver programmer (Windows)
iii) CNC, oriental, programming
iv) digital picture recognition

1. ***Hardware. Automation (Oleg, Dmitry)***
Subcontractors/freelancers:
 i) One board computer/ microcontroller programming
 ii) FPGU programming (ASIC)
 iii) Semiconductor μC

4. Inks preparation, research of deposition layers for solar cells, membranes and properties

(Dmitry, Elizaveta, Oleg, Shahid)

Subcontractors:

i) Analysis of printed cells, materials. Microscope, structural analysis, chemical analysis

ii) Organic chemistry synthesis

ISSUES TO WORRY ABOUT

1. We may need specialists for developing software (2-5 people). May lead to exceed the part of budget for subcontractors.
2. Non-directed connections between team and investors
3. Some part of work (software, printer head development) would be carried out in Russia
4. Travel cost: Russia, Europe, USA for tools development and meet potential investors, consumers, made subsidiary companies
5. Delays from subcontractors and parts delivery, delays of finance, holidays etc
6. We would like to have a flexible financial system with corporate and personal bank cards.
7. Good conditions in workplace (temperature, water, cleaning).
8. Intellectual property (very slow process for patent expertise.

Advantage:

We will have advantage over others (Fujifilm Dimatix, Optomec, Sono TeK, Ultra spray, 3D bioplotter) through digital recognition of feedback, better accuracy, better adhesion, more materials, more speed, curved surfaces

PLANNED REACHED PARAMETERS FOR PRINTER

We plan to improve the following parameters:

- Minimum line width 15-25 µm
- minimal thickness Min 100 nm.
- Thickness uniformity +/- 50 nm

This task can be done in 3-6 month

BASIC ADVANTAGES:

i) High adhesion between layers and substrate, enhanced by electrically charging drops and plasma ionization

ii) High speed print on big area

iii) It can print on the 3d curved surface. Ultrasonic alignment of layer

Specifications After Improvement

Minimum line width	15 µm
Single Pass Layer Thickness	Min 100 nm max 500 mkm

Print Speed	40 mm/s normal, 200mm/s max
Mechanical shutter	Response time 2 ms
Ink Viscosity Range	1-50 cP
Atomizer temperature control	Controls ink temperature, 25-60°C, Oil cooling Optional freeze of ink under -20 C with Peltier freezer
Inks stirrer	Ultrasonic stirrer /reactor, viscosity dependent.
Platen (Standard)	300 mm x 300 mm; temp control up to 150°C Freezer
Platen (Optional)	Robot arm for print on 3d curved surfaces
Laser (Optional)	2 W blue/UV 300-450nm laser 10 W 1500 nm IR laser
Droplet size	0,5-2 mkm
Stand-off height (size between head and surface)	2-5 mm
Motion accuracy	+/- 10 µm for each axis
Motion repeatability	+/- 2 µm for each axis
Standalone system dimensions	TO BE ADVISED
Standalone system weight Electrical	TO BE ADVISED
Utilities	220 V