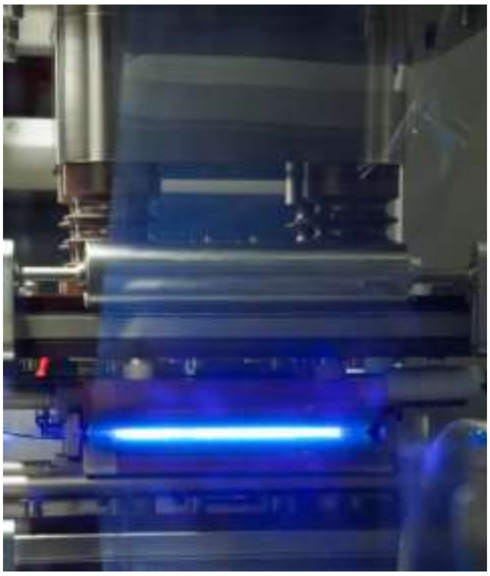
Atmospheric plasma

Atmospheric Pressure Plasma Enhanced Chemical Vapour Deposition (AP-PECVD) is a novel technology for producing uniform high quality inorganic coatings on polymer substrates. These thin films are deposited in a roll-to-roll process using plasma under atmospheric circumstances.



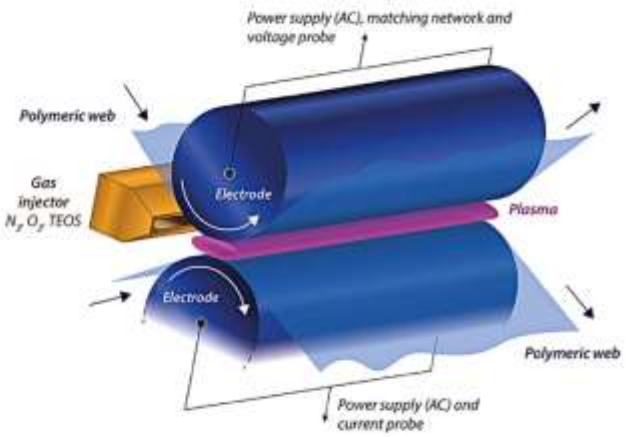
The common operation mode of the DBD is characterized by a randomly generated highly non-uniform filamentary discharge, generally called a corona discharge. Our Green Plasma technology is characterized by the absence of randomly generated non-uniform discharges. Hence, a clear difference in the appearance of the two discharge modes exists.

Dielectric barrier discharge (DBD)

The principle behind our set-up is a dielectric barrier discharge. A pulsed high voltage is applied across two electrodes. As a result, in the small space between the electrodes, plasma (ionised gas) is generated. A foil (substrate) is transported over the electrodes which is then in direct contact with the plasma. The plasma itself modifies the substrate uniformly, most noticeable by uniform wettability enhancement and adhesion improvement. Actual thin films are deposited by inserting a gas mixture with a precursor vapour in the gaseous gap between the electrodes. In a chemical process a layer of e.g. silicon dioxide is formed on the foil. Because of the uniformity an unsurpassed layer quality is achieved.

Facilities

In the present pilot scale set-up the foil is transported through the plasma from an unwinding to a winding coil. This roll-to-roll process has been stabilized for experimental purposes on a 15 cm web width (set-up FS-1). Scaling up the process to wide width is straightforward. A pre-industrial scale system (large pilot plant, ion-3) with a web width of 65 cm is already operational at Fujifilm Plasma Innovation Centre. This system can be extended to a full manufacturing scale with a 120 cm web width.



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Partners

To explore our new technology platform in all its facets Fujifilm works together with its strategic partners.

- Dutch Institute for Fundamental Energy Research DIFFER (NL), performs leading fundamental research in the fields of fusion energy and solar fuels.
- Fraunhofer Institute for Surface Engineering and Thin Films IST (GER), leading scientific organisation in the field of plasma research.
- SEMCO Engineering (FR), engineering company for the design of process lines used in e.g. photovoltaic and semi-conductor industries.

Value from innovation

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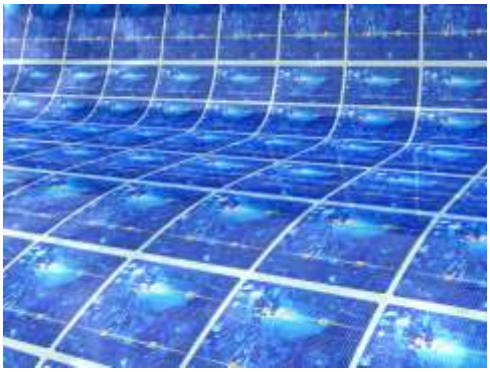
Environmental care

Life-Green-Plasma is a running project subsidized by the European Union. Our main objective is to demonstrate and disseminate to the European Industrial Community a new environmental friendly technology for manufacturing of flexible electronic components.



The coating made with our atmospheric plasma technology can potentially protect the surface of a solar cell against the intrusion of water and oxygen. Thereby it prevents quick deterioration of the quality of the solar cell. To do this at low cost, a cheap and reliable protective layer is needed that can be laminated **roll-to-roll** in a continuous process. The water permeability of a 100 nm thick film made in our set-up is in the order of 1000 times smaller with respect to the pristine polymer foil.

EU LIFE+ programme

Part of the research programme on atmospheric plasma deposition is being funded by the EU programme LIFE+. This is a programme for the stimulation of sustainable solutions. Our Life-Green-Plasma project matches closely with the programme ambition to 'decouple economic growth from the use of resources' and 'shift to a low carbon economy' which means 'increasing use of renewable energy resources'. To realize these EU ambitions the large scale low cost roll-to-roll manufacturing of thin film photovoltaics is prerequisite. Our technology platform can be the key enabling technology for this transition.

Objectives

Our main objective is to demonstrate and disseminate to the European Industrial Community a new environmental friendly technology for manufacturing of flexible electronic components. Therefore we make a comparison in efficiency of vacuum plasma with our new atmospheric technology.

With our new technology we aim on an accelerated introduction of sustainable flexible photovoltaic energy systems in Europe. Our other objectives are:

- Raising the energy efficiency of the manufacturing of flexible electronics.
- Stimulate the application of earth abundant elements.
- Reducing carbon footprint e.g. by engineering technology with lowest possible power consumption.

Efficiency

Nowadays the manufacturing industry uses vacuum plasma deposition systems that are characterized by low precursor efficiency and a high use of energy. This is inefficient with natural resources "by nature". Our novel atmospheric APG-CVD process has a high precursor-to-product ratio of 90% and is based on non-toxic precursor chemistry. Substitution of the traditional technology with our novel atmospheric green plasma process will decrease the annual raw material waste.

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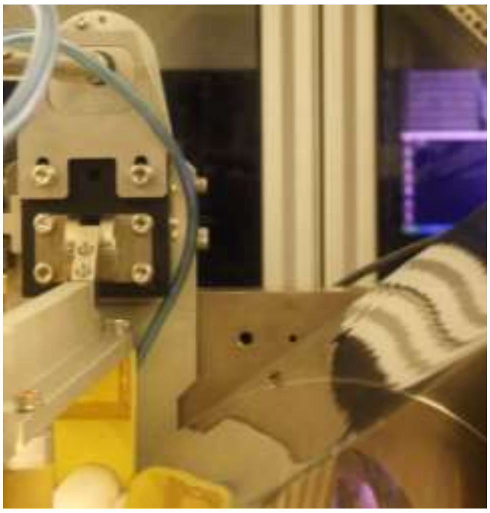
Value from Innovation

Licensing out

Our research has led to a technology platform closely compatible to industrial production demands. To enable such industrial roll-to-roll processing the plasma reactor is incorporated in a cylindrical drum electrode configuration. The influence of deposition rate and substrate temperature was investigated comprehensively in relation to moisture barrier performance. At now our technology of atmospheric plasma is ready for scaling up.



With functional foils a number of applications in e.g. flexible electronics and membrane technology is possible. In short:

Surface treatment: planarization, removal of impurities, sterilization.

Deposition: ultra-thin layers that can be used as barrier-layer.

Patterning: screening at high throughput, making of displays and integrated circuits.

Patents and performance

Sustaining filament-free non-thermal plasma over a large area is considered a unique first-in-the world achievement within the low temperature plasma physics community. With our new technology platform several multi-layer stacks have already been deposited on PET foils. Our atmospheric plasma technology has unique features. For example helium, the common carrier gas, has been replaced by simple air! This is considered a breakthrough, realized by a number of innovations that are protected by over 30 patents (US/EU based). To mention a few: design of the power matching method, electrode geometry, method of gas injection.

Analysis and support

A complete set of state-of-the-art analytical tools is available for characterization of the plasma process and the flexible electronic product specifications. Among others we have access to scanning electron microscopy (SEM), energy dispersive x-ray spectroscopy (EDX), X-ray photon spectroscopy (XPS), atomic force microscopy (AFM), infrared spectroscopy (FTIR) and spectroscopic ellipsometry (SE). Fraunhofer and Fujifilm can support you with relevant product characterizations, with reference to benchmark products that are produced with traditional technologies.

Implementation

Much research was needed in order to generate plasma that is uniform across the width of the substrate. This is essential in order to apply the coating evenly. The challenge for the plasma group is the scaling up of the process and the implementation into an existing production line. For this purpose, Fujifilm is looking for industrial partners. See also: www.green-plasma.eu

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Moisture barrier

Future markets for e.g. flexible electronics and photovoltaics require high quality functional foils which can be manufactured at a large scale and at low cost. Because of these stringent cost requirements usually low density polymer foils are preferred (low weight, robust, transparent, and flexible). To improve the properties of a foil a moisture barrier can be applied.

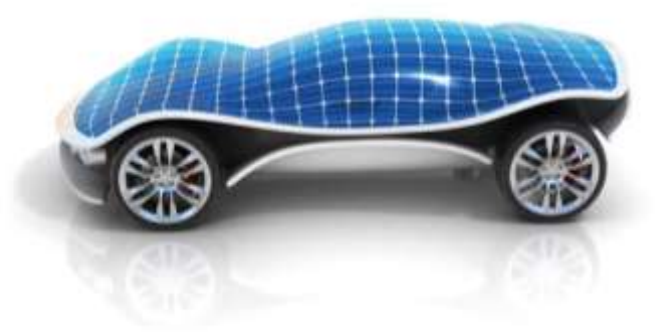
Much research was needed in order to generate plasma that is uniform across the width of the substrate. This is essential in order to apply the coating evenly. The challenge for the plasma group is the scaling up of the process and the implementation into an existing production line. For this purpose, Fujifilm is looking for **industrial partners**.

Applications

The surface of a flexible photovoltaic cell is an example of a material that needs to be protected from water intrusion. With a moisture barrier, a high-quality organic polymer is obtained with the properties of an inorganic material. With our technology large scale roll-to-roll production of dye-sensitised solar cell (DSSC), perovskite, Copper Indium Gallium Selinide (CIGS) and organic photovoltaics (OPV) is possible. Even building-integrated photovoltaics come in reach. The plasma group keeps working on thinner layers retaining the good barrier features.

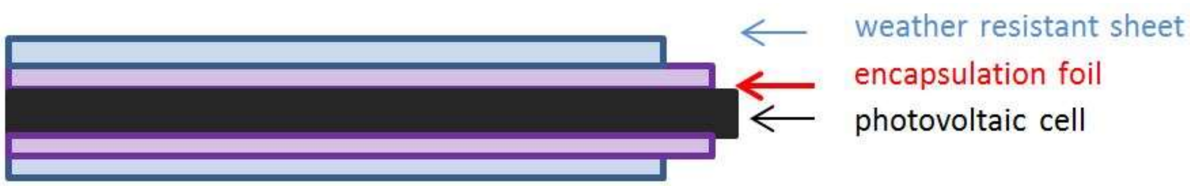
Technology

An ultra-barrier of e.g. 100 nanometres thick can be applied to a foil of polyethylene naphthalate (PEN and PET). In our set-up a high pulsed voltage is applied across two electrodes. As a result, in the small space between the electrodes, plasma (ionised gas) is generated. After the injection of a silicon-containing gas mixture into the gap between the electrodes, a chemical reaction occurs. Thereby a layer of silicon dioxide is deposited onto the foil which moves over the electrodes. No vacuum is required to keep the plasma stable. This makes the Fujifilm plasma deposition technology cheap and easy to integrate into existing production processes.



Properties

With a barrier layer of circa 100 nanometres thick applied to a foil of polyethylene naphthalate (PEN) the water vapour transmission rate (WVTR) can be in the order 1000 times smaller than the pristine foil. SiO_2-like films deposited by Fujifilm's APG technology also have attractive mechanical properties. These films can meet the strain requirements for the future bendable/flexible applications demanding excellent moisture barrier properties.



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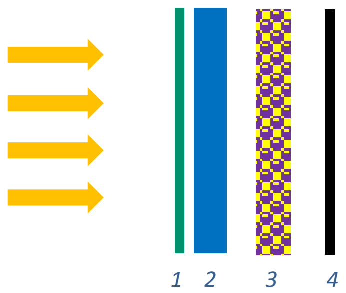
Flexible solar cells

Dye sensitized solar cells (DSSC) show great promise. They are ease to manufacture by printing on a flexible polymeric substrate. Former disadvantages as robustness and manufacturing costs can be taken away by using our green plasma technology. Interesting markets are consumer electronics, street signs, energy generating window panes and architecture.



1 Polymeric moisture barrier
2 Transparent anode
3 TiO_2-nanoparticles in electrolyte
4 Cathode

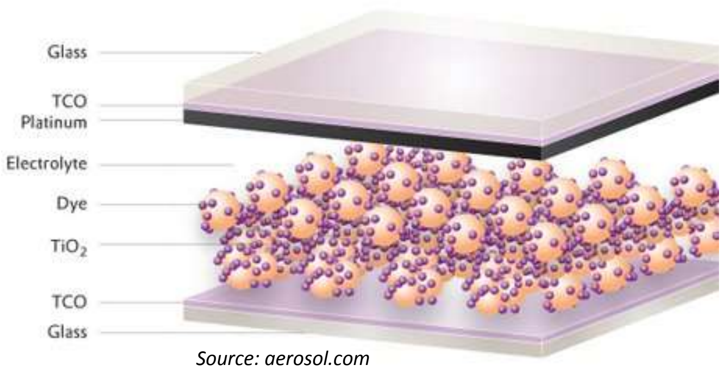
The anode (2) is made of a **transparent conductive oxide** (TCO), usually tin oxide or zinc oxide. With our green plasma technology processing at low temperature enables deposition of an oxide layer on a polymer substrate. It is even possible to integrate the H_2O/O_2 ultra-barrier (1) and the electrical conducting layer thus slimming down the thickness of the device. With this integration a cost reduction of 30% and a performance of over 20% (efficiency, flexibility and robustness) can be reached.

How it works

The core of a dye sensitized solar cell is formed by a layer of titanium dioxide (TiO_2). This layer exists of transparent nanoparticles. When sunlight hits the dye on these particles free electrons are generated. These electrons start to move through the cell in the direction of the anode and thus form an electrical current. In this way energy from the sun is converted into electrical energy (moving electrons). To 'refill' the dye with electrons the TiO_2 layer is filled with an electrolyte.

Barrier

The aforementioned layers are transparent and flexible. This provides comprehensive application possibilities provided that the outer protective layers (1) are transparent and flexible as well. With the Fujifilm atmospheric plasma technology such layers can be made in a roll-to-roll process. With our technology platform organic solar cells can be mass-manufactured in a cost-effective way. We make robust encapsulation solutions having a water vapour transmission rate of less than 10^{-4}g/m^2/day.



Source: aerosol.com

Aesthetics and use

A flexible solar cell can be used building-integrated which enables the easy combination of freedom in design and collecting energy from the sun. With ultrathin layers even photovoltaic cells in a windowpane are possible. Moreover future markets for flexible consumer electronics require high quality functional foils which can be manufactured at a large scale and at low cost.

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