Organic MEMS/NEMS based bulk heterojunction photovoltaic cells with 3D electrodes

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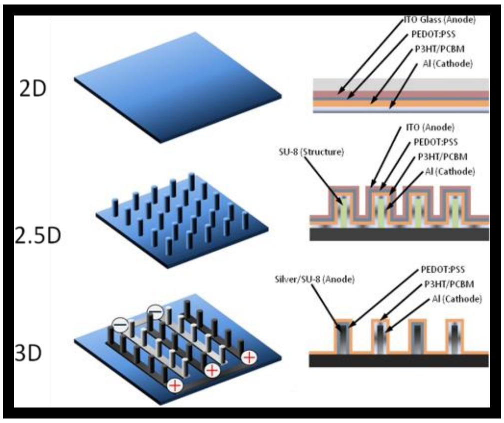
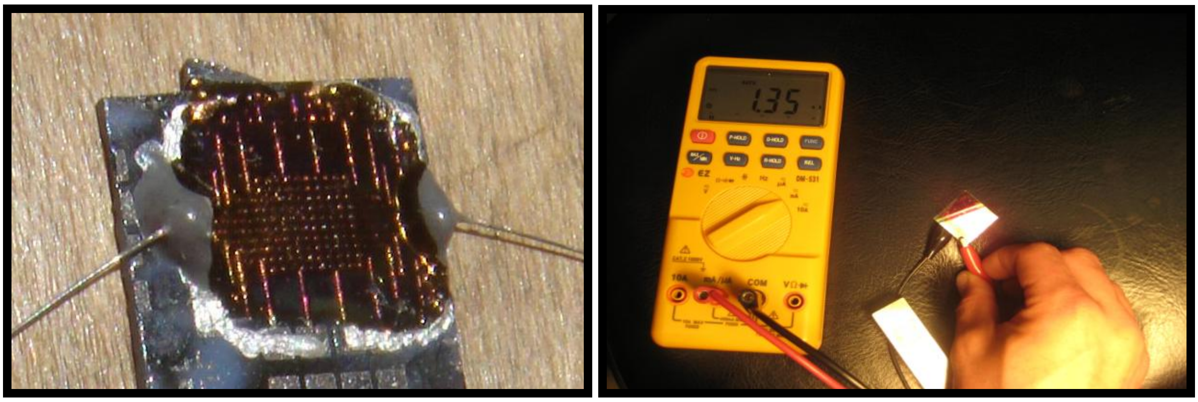
The field of organic electronics is entering its commercial phase. Organic solar cells are emerging as a major area of interest, prompted both by favorable government policy in alternative energy and by the increasing commercial opportunities as cell performance improves. Bulk heterojunction photovoltaic devices, based on polymer/fullerene-blend films, are advancing rapidly toward commercial viability since they can achieve a compromise between power conversion efficiency and compatibility with the type of manufacturing processes that enable low-cost production. Improvements in device efficiency are being achieved by focusing on new materials that have well-designed electronic energy levels capable of generating larger cell voltages, absorbing more light, improving charge separation, avoiding losses from the recombination of generated charges, and having optimal transport properties. Electrode materials are also an important subject of investigation, with the replacement of indium tin oxide (ITO) by lower cost printable inks being a particular focus. Nonetheless, an alternative strategy so as to achieve device efficiencies in excess of 4% is to improve the photocurrent by enhancing light absorption by increasing the exposed surface.

The Applied Optoelectronics Group for Agricultural Engineering, in collaboration with the MEMS Lab at San Diego State University (San Diego, CA), has developed a novel 3D architecture of organic PV cells that is, in most aspects, a significant departure from existing technologies. It consists of organic photoactive material and 3D carbon-based charge collectors with decreased diffusion length and increased light absorption area enabled by large electrode surface area. As shown in the figures, the core concept employs a 3-dimensional photovoltaic cell of several microns depth consisting of a large array of high-aspect ratio carbon electrodes of few microns diameter surrounded by a matrix of heterojunction photoactive material. The carbon electrodes introduced here replace conventional thin film metal electrodes such as aluminum and ITO which require expensive vacuum deposition (transparency is not a must, due to the electron flow direction, which is traditionally perpendicular to the surface). These 3D carbon electrodes are patterned through a lithography process followed by pyrolysis of SU-8 negative photoresist. The patterning consists of two layers: the bottom layer is for the wire traces that connect a series of anodes and cathodes separately whereas the second layer consists of the high-aspect ratio electrodes. Electrodes are not layered, but staggered. The photoactive material is spin-coated on the microarray of electrodes: heterojunction photoactive polymer such as a blend of P3HT (poly(3-hexylthiophene)) and PCBM (phenyl-C61-butyric acid methyl ester). All processes, except aluminum deposition, are performed under natural environment conditions.
A short circuit current density of 2.03 mA/cm^2 is demonstrated on a cloudy day under AM1.21G light.

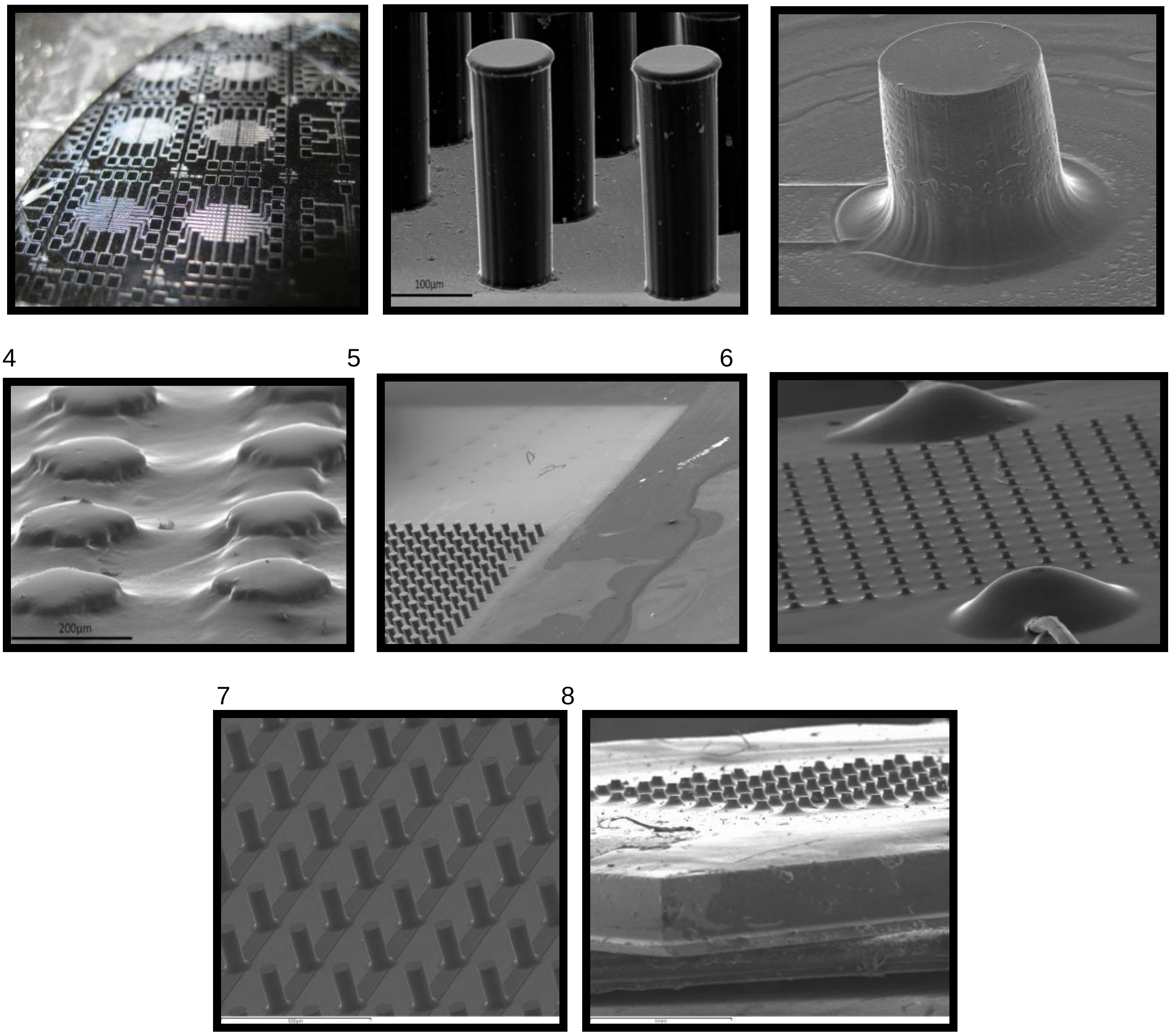
Figures



2D, 2.5D, and 3D concept representations



Fabricated devices



Manufacture steps (from left to right): (1) Electrical connection patterned wafer after the first lithography step; (2) SEM image of high aspect ratio SU-8 posts; (3) SEM image of a sample anode after PEDOT:PSS was applied; (4) SEM image of P3HT/PCBM coated SU-8 composite; (5) SEM image of aluminum electrode contact area; (6) Generation II chip with bonding pads; (7) SEM Images showing the micro array of electrodes in a single staggered chip; (8) SEM images of 10 x 10 Generation I chip at an 80° tilt angle (cross-section).