Quantum dots luminescent solar concentrator for fiber embedded solar cells

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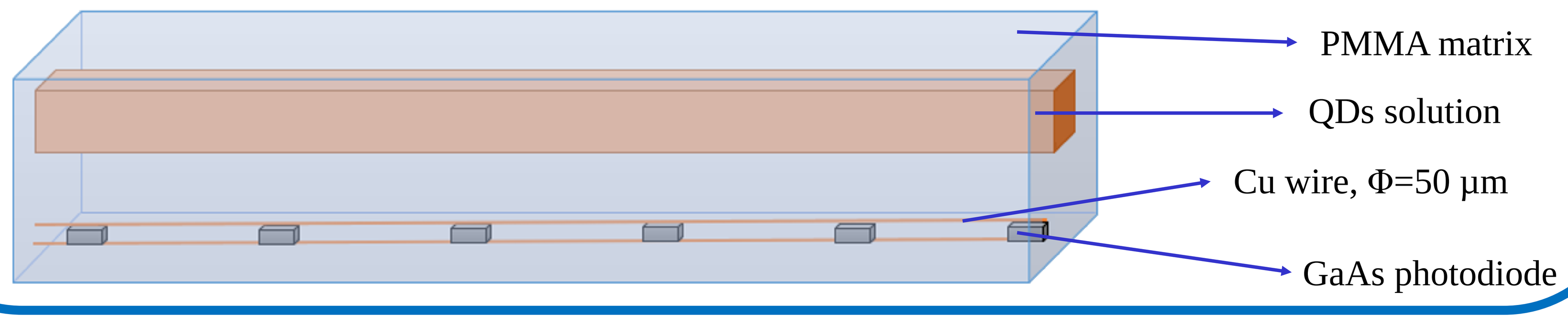
Introduction and objectives

In view of the impressive advances in the exploitation of solar energy during recent years, the integration of photovoltaic capability into smart fibers and, therefore, fabrics has a tremendous potential in a broad range of applications. However the fabrication of such devices remains challenging. In this project we demonstrate the feasibility of the manufacturing of a photovoltaic fiber based on a luminescent solar concentrator combined with an array of GaAs photodiodes embedded in a polymeric matrix. We investigate the concentration of light provided by $CuInS_2$ quantum dots (CIS *QDs*) synthesized in colloidal solution, as well as the fabrication parameters to embed a series of regularly spaced photodiodes, which are electrically connected through the convergence of copper wires, into PMMA fibers. The electrical properties of the fiber are determined by measuring the I(V) curves under different conditions. The objectives of the project are to:

- Propose a fiber design.
- Develop a fabrication process and produce a working fiber.
- Characterize the obtained device.

Concept of the device

The fiber is formed by two components: a photosensitive element, consisting in a discretized array of photodiodes connected in parallel, to convert light into electrical current, and a light concentration element, to collect and guide the light along the fiber. The momentum of the photons is altered by the QDs solution, which absorbs the incoming light and re-emits photons with longer wavelengths in all directions. The propagation of light is accomplished by total internal reflection.

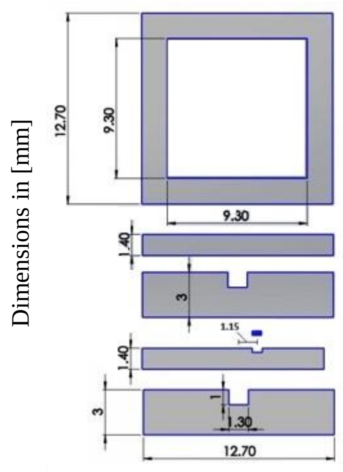


Materials and methods

The design of the preform (a) includes the presence of a hollow squared channel for the injection of the liquid QDs solution. The photodiode (b) has a front electrode which is misaligned with respect to the center of the chip.

The preform is then thermally drawn to obtain a fiber (c). The Cu wires are continuously fed into the preform to make the electrical contacts. During the drawing process the polymer matrix shrinks, while both the wires and the photodiodes keep their dimensions unchanged. The geometry of the photodiode is therefore a limiting factor for the design of the fiber itself.

a)



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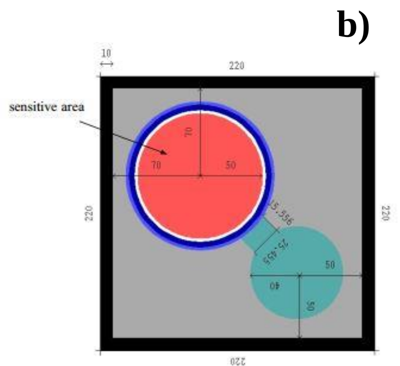
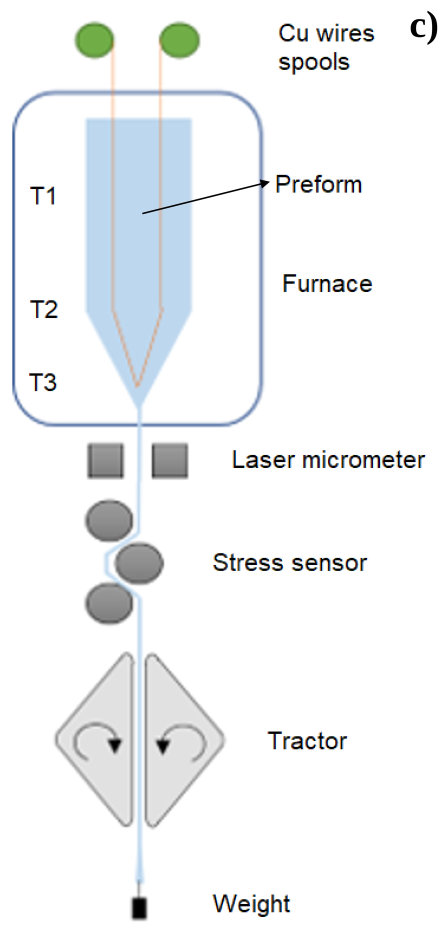


c)

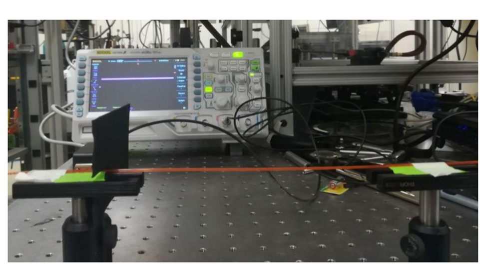


Optical characterization of the QDs solutions

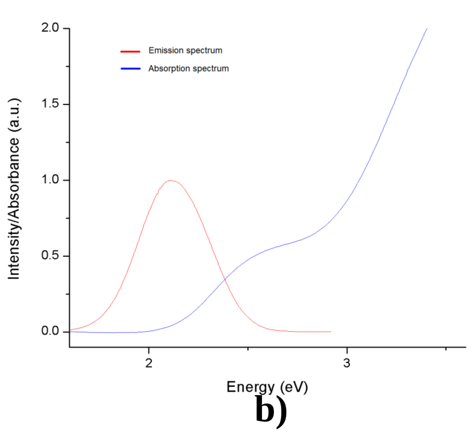
Seven different concentrations of QDs in hexane are prepared to determine the optimal QDs concentration that enables the maximal yield of concentrated and transmitted light.

	S1	S2	S3	S4	S5	S6	S7
C [mM]	0.195	0.02	0.05	0.1	0.15	0.3	0.4
n [-]	1.4001	1.3796	1.3836	1.3890	1.3947	1.4150	1.4535

The light concentration yield of the solutions is assessed by shining light (laser, λ=532nm) on a hollow fiber containing the solutions. The output light is measured by a photodetector connected to an oscilloscope (a). The light is absorbed by the QDs mainly in the green side of the spectrum, while the re-emitted photons are shifted to the red (b). The output voltage is recorded as the laser is moved away from the sensor, giving the voltage as a function of distance between the light source and the detector. Higher QDs concentrations result in higher light concentration yield, but also in increased photon re-absorption (c).



a)



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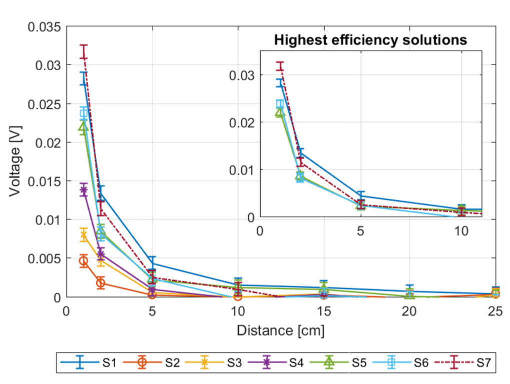
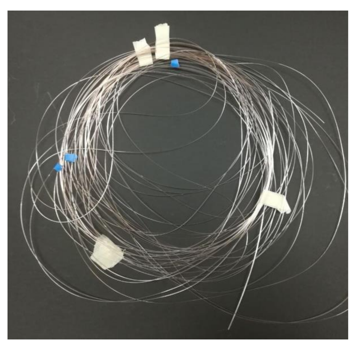


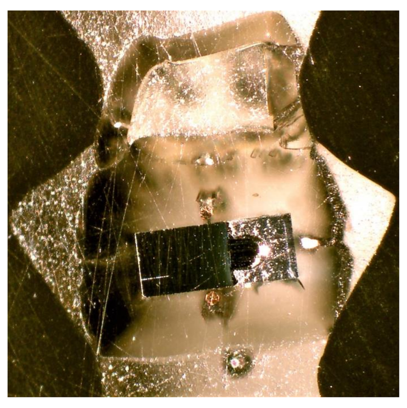
c)

Electrical characterization

Two fibers of 44m and 64m of length and with yields of working diodes of 71% and 41% respectively, are obtained (a). The cross section of one fiber (b) shows the geometry of the device after the draw, with a photodiode, the two Cu wires and the hollow channel. The QDs solution S1 is injected into the hollow channel to study the light concentration potential of the QDs in a real device. It is possible to notice that a fluorescent response is observed upon illumination of one end of the fiber (c).



a)



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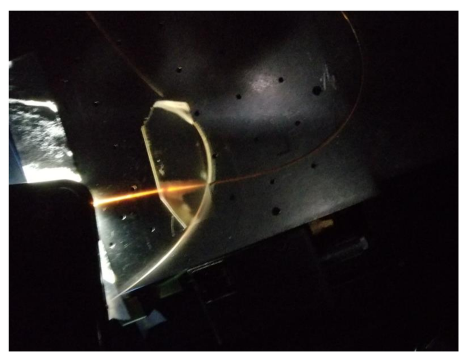
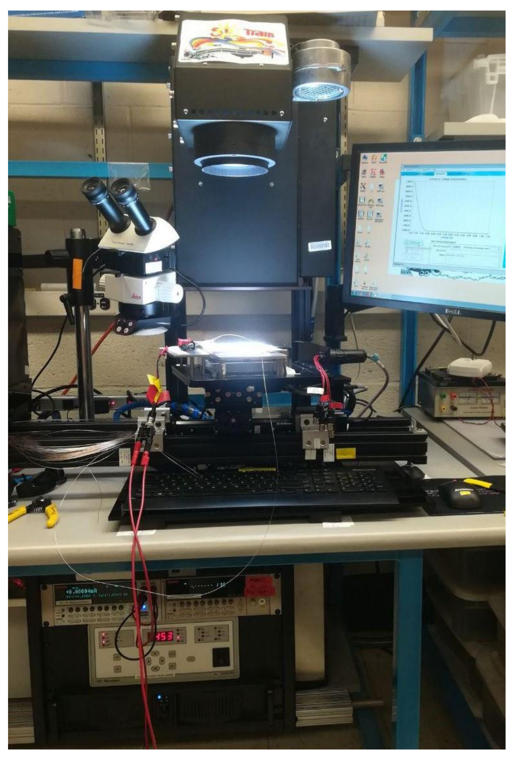


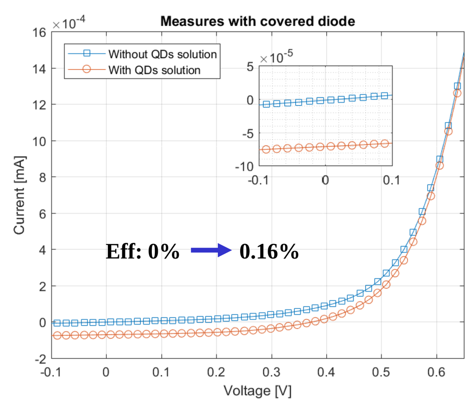
c)

To simulate the behavior of the solar cells in everyday applications, the I(V) curves can be measured using a solar simulator (d). The setup consists in a moving stage with pre-installed connections, illuminated by a lamp which provides 1-Sun conditions, i.e. an irradiance of $1 kW/m^2$ with a AM1.5G spectrum. The voltage is swept between a set interval and the resulting electrical current is measured. The short circuit current density J_{sc}, the open circuit voltage V_{oc} and the cell efficiency can be calculated using the measured data and the active surface of the photodiode.

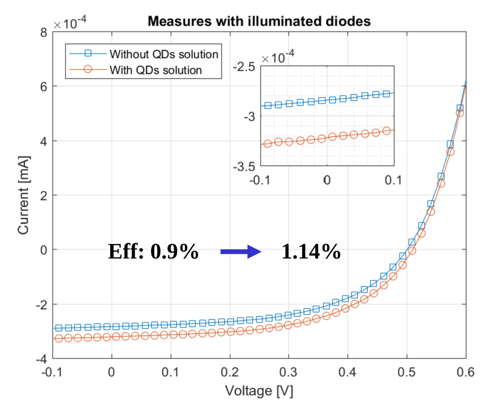


d)

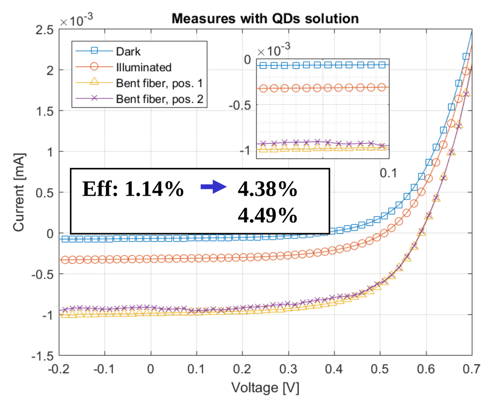
The I(V) curve of the photodiode is measured when the diode is covered (e) and when the diode is fully exposed to the light source (f). In both cases, it's possible to notice that the values of I_{sc}, V_{oc} and efficiency increase when the QDs solution is injected inside the hollow channel of the fiber, thus proving that QDs can effectively concentrate light towards the photodiodes array.



e)



f)



g)

By bending the fiber at the position of the photodiode, the number of photons that impinge on the diode increases dramatically. This results in much higher values of I_{sc}, V_{oc} and efficiency (g) with respect to the case of a straight fiber.

Conclusions

- It was possible to thermally draw two fibers with multiple functional GaAs photodiodes in a PMMA matrix and to test their efficiency.
- QDs-hexane solutions proved to be effective as luminescent solar concentrators, transmitting light up to 15 cm. Thus, the distance between photodiodes in a future device can be as high as 30 cm.
- The I(V) curves showed an increased efficiency of the photodiodes when the QDs solution was injected in the hollow channel of the fibers.
- Bending the fibers at the position of the chip proved to be very effective in increasing the efficiency of the photodiodes.

Outlooks

- Develop a light deflection mechanism to increase the efficiency of the photodiodes by redirecting more photons from the luminescent solar concentrator layer to the diodes.
- Modify the synthesis method of the CIS QDs to shift their emission spectrum more towards the red, in order to decrease the re-absorption of the re-emitted photons.
- Develop a drawable QDs-polymer composite with a reduced fluorescent quenching.

Acknowledgements

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