Solar concentration and spectral splitting for multi cells high efficiency photovoltaics

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Motivation

Many consider solar photovoltaic as the most promising approach to a widespread sustainable energy production. Still commercially available photovoltaic systems lack the ability to directly compete with the cost of fossil based generation and are not even competitive with other renewable sources like wind.

High efficiency photovoltaic, in the form of power plants based on solar concentration, could offer a viable approach fur sun soaked countries like the Emirates to differentiate their energy supply and to reduce the carbon footprint of their current oil based approach.

This fits in the mission of Masdar Institute and City to foster an approach to sustainable development and power production.

Optical concentration of solar light is one of the key ingredients to allow the economically sound use of more sophisticated and expensive high efficiency solar cells because it substantially reduces the necessary surface of active material.

Single bandgap solar cells have only a limited light frequency region where they can efficiently convert solar radiation and, therefore, their overall efficiency in converting the whole solar spectrum is limited below (currently) 20%.

If we could "separate" the different wavelengths of the solar light and send each of them on different, specialized, solar cells we could achieve 40% or more of conversion efficiency.

Key points:

- **Concentrate solar light (100 or more times)**
  - **Reduces by 100 or more the total cells area**
  - **Allows expensive high efficiency cells to be used**
  - **Reduces carbon footprint of solar system**
- **Separate solar radiation wavelength**
  - **Multiple specialized solar cells can be employed**
  - **Reduces sensitivity to different environmental conditions (humidity, dust in atmosphere etc)**
  - **New high efficiency "narrow band" solar cells can be developed and employed**
- **Moving towards the "thermo dynamical" conversion limit? (>80%)**

Dividing the wavelength can be done by the use of a "dichroic mirror" being a mirror for certain "colors" (wavelength) of the light and a transparent glass for the others. A low pass dichroic will transmit, for example, yellow, green and IR and reflect the green, blue and UV radiation.

This has been successfully employed but it introduces losses due to the use of many different optical components.

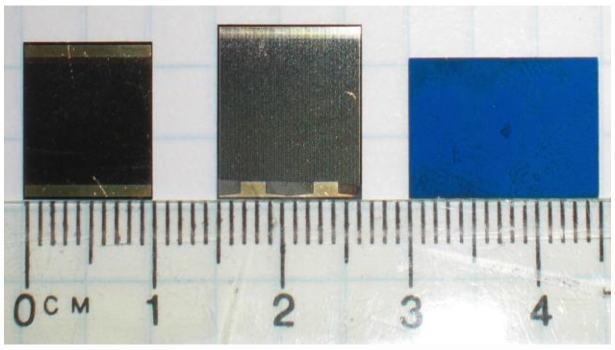
The second point are the cells.

Each material has a specific "bandgap" making it more suitable for some wavelength more than for others.

There are plenty of different cells out there and many more can be developed with high efficiency in a narrow wavelength region.

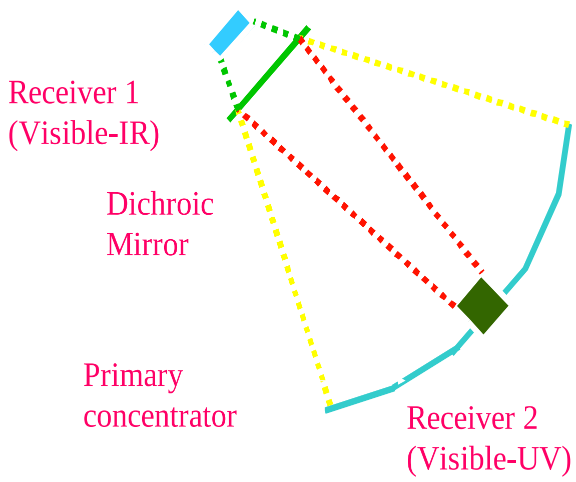
Are the cells out there?

- **High efficiency solar cells are essentially for concentrator systems**
- **Small dimension**
- **Highly sophisticated**
- **Expensive (per unit area)**

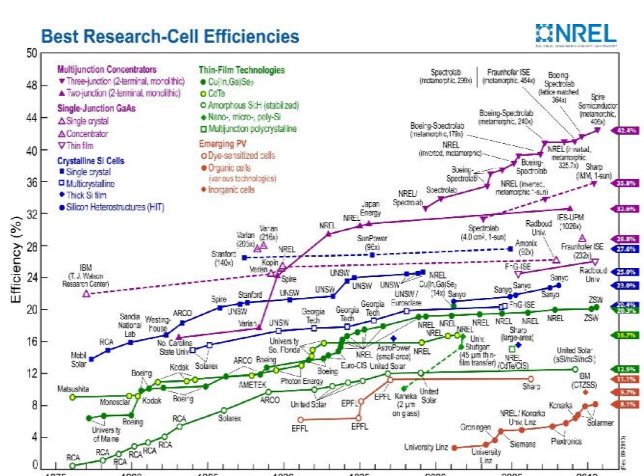


Concentrator solar cells, from left Germanium (IR), GaAs (Visible-UV), Silicon (Visible-IR)

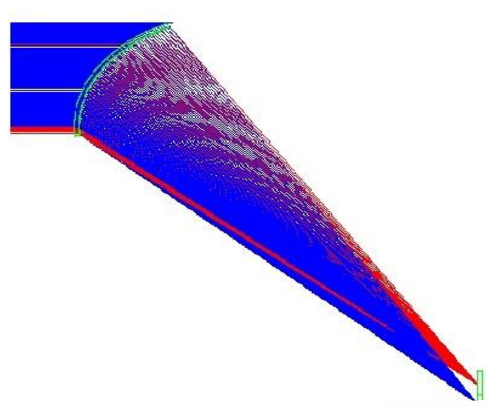
A mirror based photovoltaic concentrator (Courtesy of Univ. of Ferrara, Italy)



Conceptual idea of a spectral splitting system based on dichroic mirror



A comparison chart for solar cells efficiencies and technologies in the last 40 years



Raytracing and realized sample of the spectral splitting solar concentrator being tested in Masdar

The question and the idea

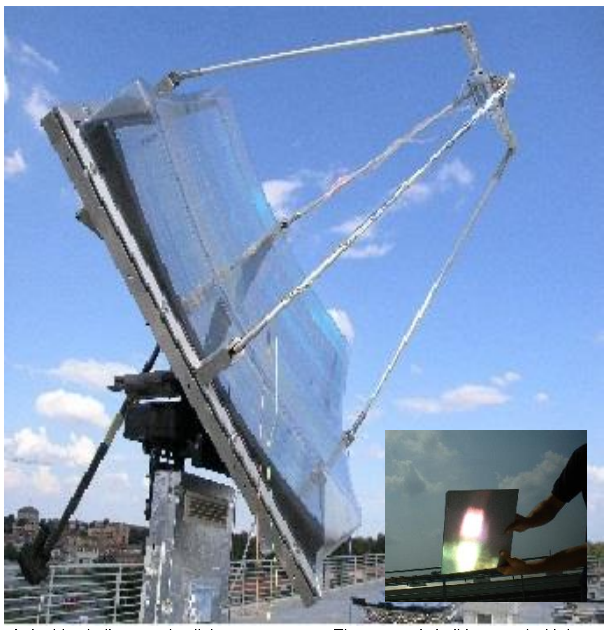
Can we perform both the light concentration and spectral splitting with the same optical component?

Many approaches could lead to this breakthrough

-Coating a shaped optical collector with dichroic multilayers would create a selective concentrator

-Interference patterns (like those in diffraction gratings, could be designed to concentrate and split

-The dispersion of materials could be used to obtain the desired effect.



A double shell spectral splitting concentrator. The external shell is coated with low pass dichroic mirror while the bottom part is coated with a broadband reflector. The concentrated splitted beam is visible in the right corner (Courtesy of M. Stefancich: University of Ferrara)

But maybe something better can be done….

The development of advanced non imaging optics allows to simultaneously split the light wavelengths and concentrate the solar radiation.

Numerical algorithms are developed and free form optical design is carried out for the desired optical components.

A CAD solid model is extracted from the mathematical design.

Raytrace simulations are employed to verify the component performances and characteristics

CAM is performed on the design to finally obtain the desired optics.

This approach can, in short turnaround, generate completely novel solutions and allow them to be realized and tested in real systems.

… and maybe the solution we are looking for….