FACTSHEET COLOR IN THE PHOTOVOLTAICS

How can you design photovoltaics (PV) in color?

There is a growing demand for alternative colors and designs for PV modules. For example, in densely built-up city and town centers, where historic buildings and the design requirements of modern architecture come together. Numerous innovations are bringing color to the world of PV modules.

1. Color perception

Solar radiation on Earth has a spectral distribution in the wavelength range (λ) of around 300 nm to 2500 nm and can be divided into three spectral regions: ultraviolet (UV), visible (VIS) and near infrared (NIR). The part of solar radiation that is visible to the human eye covers a spectral range from 380 nm to 780 nm.

A solar cell made of c-Si material can utilize wavelengths < 1150nm and therefore converts sunlight from the (UV) range over the entire visible range (VIS) to the near infrared range (NIR) into electrical energy. [1]

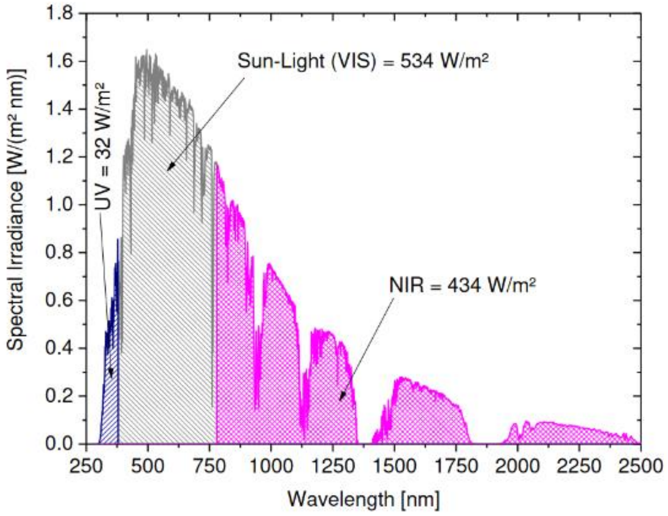

Figure 1: This figure shows a terrestrial solar spectrum, with the visible (VIS) sunlight appearing in gray. The visible part of the solar radiation contributes about half of the total intensity of the solar spectrum shown.

2. Connection between color and efficiency

When light interacts with materials, it can either be absorbed, reflected or transmitted through the material. Which parts of the reflected and transmitted light are scattered is determined by the surface structure and the internal optical structure of the materials. [1] The perception of a strongly absorbing and weakly reflecting object, such as a highly efficient PV module, is dark or black. A colored PV element is equivalent to partial reflection of the irradiation in the visible range. Consequently, with a colored PV element, the amount of solar energy that can be converted into electricity is reduced compared to a product without coloring.

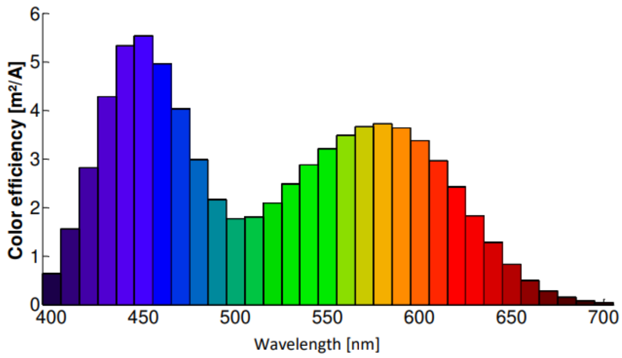

Figure 2: Ceff for monochromatic colors, derived from reflectance spectra with "pill-box" shape (width = 40 nm and height = 100%) The most efficient monochromatic color corresponds to a center wavelength of about 450 nm (blue). In particular, blue appears to be about twice as efficient as green and red.

Absorptive colors create the coloration by absorbing certain wavelengths. The reflected part of the spectrum defines the color. Opaque absorptive layers produce strong colors regardless of light incidence and viewing angle. Thin layers also enable colorful PV modules with absorptive colors, although this is associated with a loss of performance. Structural colors, on the other hand, create the colors by selectively reflecting certain wavelengths. As almost no light is absorbed, these materials enable significantly lower power losses.

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3. Methods for implementing color in PV

The challenges of optimally balancing aesthetic quality with energy efficiency, reliability and safety are driving innovation. Below are some techniques that can be used to develop colored or textured BIPV modules: [1,3]

1) Colored polymer embedding films: In addition to their own intermediate layers, the polymer embedding films can also be colored. This is a material-saving and flexible solution that does not require

the module production process does not have to be changed. In amorphous silicon technology, colored polyvinyl butyral (PVB) films can be used as the backside embedding layer to produce PV colored glass with various degrees of transparency.

2) Colored and/or semi-transparent PV active layers: Semi-transparent PV layers can be achieved, for example, in amorphous silicon PV modules (a-Si) by laser treatment of the active layer, partially removing it to increase light transmittance. One possible application can be seen in fully glazed buildings, where the available area for BIPV is very large and therefore high-performance solutions are often not required. Other third-generation solar cells (e.g. dye solar cells or organic solar cells) can be made to look different colors from the ground up by cleverly choosing the materials used.

3) Coatings or interlayers with colors or patterns: An interlayer with a specific color/pattern can be laminated with the help of an additional embedding layer in the module, which provides greater flexibility in the production of BIPV elements of different sizes compared to glass printing.

4) Modified front glass by printing or coating: Various surface treatments can be applied to the front glass pane, usually on the inside: ceramic pigments can be applied to glass by screen printing or digital inkjet printing and then fused to the glass substrate by firing in an oven to form an enamel coating. Due to its high flexibility, which also allows the application of various patterns, this is one of the most frequently used methods for coloring in BIPV.[4] Alternatively, the aforementioned thin layers for structural colors can also be applied to glass, for example by means of cathode sputtering.

5) Colored front glass by additives: For PV applications, it is common to use flat glass with a low iron oxide content, which results in a slightly green color for normal flat glass to maximize light transmission. Alternatively, however, additional ingredients can be added to the glass composition, for example, additional iron can be used to produce a green color, cobalt and iron for a blue color, cobalt and selenium for a bronze or grey color. However, this method of coloring is not very common due to the high cost of small batches and high performance losses.

6) Anti-reflective coatings on solar cells: As uncoated crystalline silicon (c-Si) has high reflection values (approx. 30 %), both monocrystalline and multicrystalline PV cells have anti-reflective coatings on their surfaces. The optimized thickness of the AR coating gives the cells their typical blue color. By changing the coating thickness, colors such as green, yellow, orange and pink can be achieved, whereby the reflection minimum is shifted to the near infrared range and the reflection in the visible spectrum is increased.

4.Links

[1] IEA Photovoltaic Power Systems Programme (PVPS) Task 15: Coloured BIPV: Market, Research and Development. Feb. 2019. Download: Coloured BIPV (iea-pvps.org)

[2] Gerhard Peharz, Andreas Ulm, "Quantifying the influence of colors on the performance of c-Si photovoltaic devices," Renewable Energy (2018) 129, 299-308;

[3] Erika Saretta, Pierluigi Bonomo, Francesco Frontini, "Active BIPV Glass Facades: Current Trends of Innovation"; GPD Glass Performance Days 2017 - Conference Proceedings, pp.2-7; https://www.glassonweb.com/article/active-bipv-glass-facades-current-trends-innovation

[4] Philipp Krampe, "Zur Festigkeit emaillierter Gläser/On the Solidity of Enamelled Glazing Units"; Doctoral Thesis, Technische Universität Dresden (2013); http://tud.qucosa.de/api/qucosa%3A28115/attachment/ATT-0/

[5]PV@fassade (2014-2017) "Facade-elements with PV-active layers"; Energieforschung Austria; Project ID: FFG 843803; https://www.energy-innovation-austria.at/article/pvfassade

IEA PVPS Task 15 focuses on international cooperation to create a supportive framework for the global deployment of BIPV in the renewable energy sector. Learn more: https://iea-pvps.org/research-tasks/enabling-framework-for-the-development-of-bipv/