DESIGN CONSTRUCTION AND TESTING OF PHOTOVOLTAIC (PV) USING TEXTILES MATERIALS (FABRICS)

Abba Musa Yau
Department of Fashion and Clothing Technology
School of Science and Technology
Hussaini Adamu Federal Polytechnic Kazaure, Jigawa State
Email :abbamusayau@yahoo.com
Phone Number: 08068160068

Abstract

Solar photovoltaic (PV) arrays are providing an increasing fraction of global electrical demand, with an accelerating rate of new installations. Most of these employ conventional glass-fronted panels, but this type of PV array does not satisfy applications that require a light-weight, flexible PV generator. An option discussed in this article is to consider textiles for such solar cell substrates. As explained in this review, combining the choice of PV cell type with the choice of textile offers alternative structures for flexible PV cells. In particular, the relative advantages and disadvantages are contrasted, either forming PV-coated fibres into a fabric, or coating an already formed fabric with the PV materials. It is shown that combining thin-film amorphous silicon PV technology and woven polyester fabric offers one solution to realizing flexible fabric PV cells, using well-understood coating methods from the textile and semiconductor industries.

Key words *– solar, photovoltaic, textiles, fabric,*

1.0 INTRODUCTION

Photovoltaics (PV) have started replacing fossil fuels as major energy generation roadmaps, targeting higher efficiencies and/or lower costs are aggressively pursued to bring PV to cost parity with grid electricity. With first generation semiconducting p-n junctions and the second generation thin film cells, the third generation PV technologies may overcome the fundamental limitations of photon to electron conversion in single-junction devices and, thus, improve both their efficiency and cost. Even more, recently developed "inorganics-to-organics" 4G polymer solar cells, brought new challenges for development, investigation and application of such sophisticated energy resources in various fields. Recently, mostly due to exhaustion of other conventional energy resources, especially fossil-based fuels, various alternative renewable energy sources including that obtained by solar cells have attracted much attention. Fossil fuels lead to high emissions of CO_2 and other pollutants and consequently have aggravating influence on human health due to adverse environmental conditions. On the other hand, the PV energy generated using various types of solar cells, is one of the cleanest, most applicable and promising alternative energy using limitless sun light as raw energy source (Singh, 2011; Kumar & Rosen, 2011). From the physical viewpoint, the PV conversion represents the direct conversion of sunlight into electricity without any heat engine to interfere. Photovoltaic devices are rugged and simple in design requiring very little maintenance and their biggest advantage being their construction as stand-alone systems to give outputs from microwatts to megawatts. Hence they have wide implementation range used for power source, water pumping, solar home systems, communications, satellites and space vehicles, and for even megawatt scale power plants (Parida et al., 2011).

PV history could be traced back to 1839, when Alexandre-Edmund Becquerel observed that “electrical currents arose from certain light induced chemical reactions”. However, in the late 1940s the development of the first solid state devices paved the way for production of the first silicon-based solar cell with modest efficiency of only 6%. Presently, various types of solar cells are commercially available, however, strive for research and development continuously expand, improve and invent even better types of solar cells. The growth of such technology strongly depends on materials and structure development; however the goal will always be: maximum power at minimum cost. The historical development of solar cells usually is divided into several major deployment stages, called generations, the silicon-based solar cells being the so- called first generation (1G) of solar cells. Second generation (2G) of PV or solar cells is usually closely associates with the emerging of the thin-film solar cells, whiles the third generation (3G), currently widely analyzed and full of potential generation, is so-called “tandem” or “organic” PV cells.(Parida et al., 2011). Thus, although the inorganic solar cells (generally silicon-based solar cells) still dominate in today’s world photovoltaic market, organic solar cells as the new emerging PV cells has explored new possibilities for different smart applications with their advanced properties including flexibility, light-weight, and graded transparency. In addition, the low cost production and easy processing of organic solar cells comparing to conventional silicon-based solar cells make them interesting and worth employing for personal use and large scale applications (Bedeloglu, 2011; Galagan & Andriessen, 2012; Anctil & Fthenakis, 2012; Sohrabi, 2013).

Today, the smart textiles as the part of technical textiles using smart materials including photoactive materials, conductive polymers, shape memory materials, etc. are developed to mimic the nature in order to form novel materials with a variety of functionalities. These new solar cell-based textiles have found its application in various novel field and promising development obtaining new features. The photovoltaic textile materials can be used to manufacture power wearable, mobile and stationary electronic devices to communicate, lighten, cool and heat, etc. by converting sun light into electrical energy. The photovoltaic materials can be integrated onto the textile structures especially on clothes, however, the best promising results from an efficient photovoltaic fiber has to be come which can constitute a variety of smart textile structures and related products (Singh, 2011).

This paper presents some notable advances in these technologies, namely organic, nanostructures, polymer and dye-sensitized solar cells and their potential applications in the tourism and hotel industry.

1.1 Photovoltaic effect, photovoltaic cells, and their classification

The basic physical process within solar cells is the process called photovoltaic effect. The photovoltaic effect is a process that generates voltage or electric current in specially

designed physical materials when they are exposed to sunlight, i.e. process of conversion of sunlight into electrical energy. A key feature of photovoltaic systems is their ability to provide direct and instantaneous conversion of solar energy into electricity without complicated mechanical parts or integration. (Parida et al., 2011).
These specially designed materials with photovoltaic properties are commonly called photovoltaic (PV) or solar cells. They are composed of two different types of semiconductors, a p-type and an n-type semiconductors that are joined together to create a so-called p-n junction. By joining these two types of semiconductors, an electric potential field is formed in the region of the junction as electrons move to the positive p-side and holes move to the negative n-side. This electric potential field causes negatively charged particles to move in one direction and positively charged particles in the other direction, thus enables flow of electric current (Figure 1). (Singh, 2011).

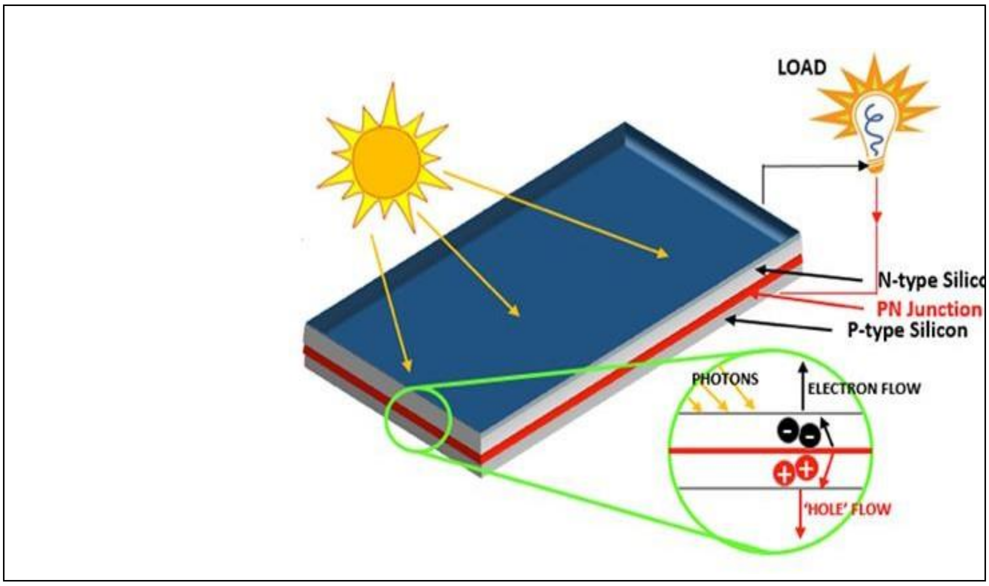

Fig. 1. Photovoltaic effect and operation

(*Source*: http://www.eworkzpower.pk/how-solar-works.php)

Photovoltaic systems can be further distinguished based on the solar cell technology (Figure 2). Silicon (Si) based technologies can be categorized as a crystalline silicon and amorphous silicon or thin film, and are considered the most mature. Crystalline silicon cells can have different crystalline structures: mono-crystalline (mono-crystalline) silicon, multi-crystalline silicon and ribbon cast multi-crystalline silicon (Kumar & Rosen, 2011).

The 1G of PV technologies was made of crystalline structure which used silicon (Si) to produce the solar cells that are combined to make PV modules. However, this technology even today is not obsolete rather it is constantly being developed to improve its capability and efficiency. Mono-crystalline, multi-crystalline, and emitter wrap through (EWT) are cells under the umbrella of silicon crystalline structures and are still widely used as solar cells in various applications. (Singh, 2011).

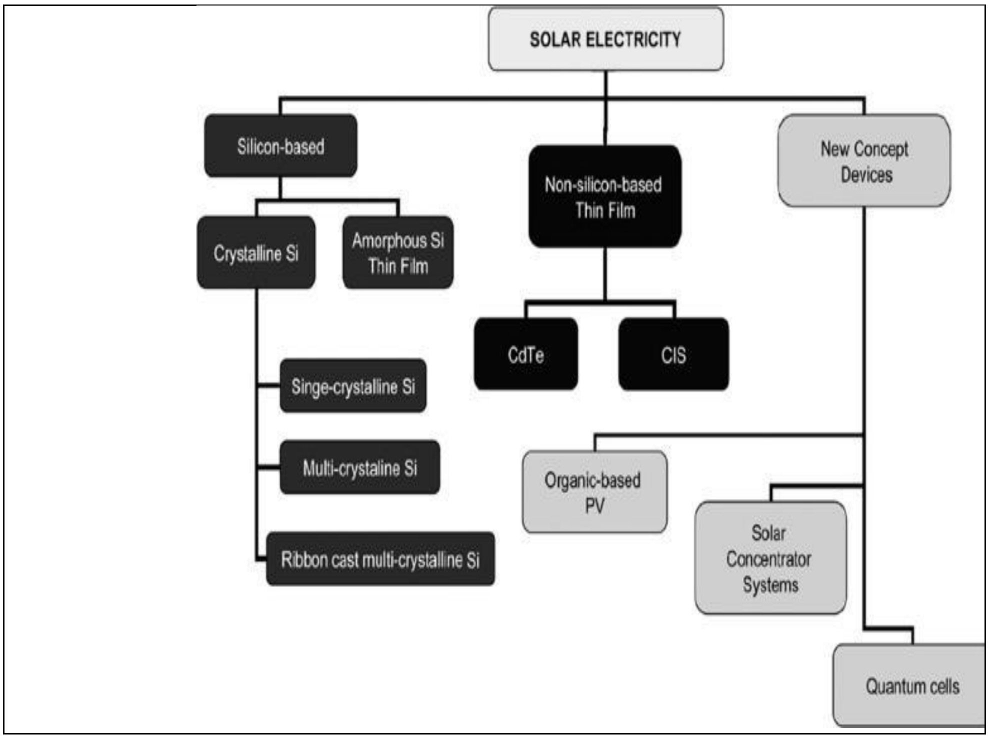

Fig. 2. Classification of pv cells *(Source*: Akarslan. (2012).

1.2 Mono (single)-crystalline photovoltaic cells/panels

This type of cell is the most commonly used, constitutes about 80% of the market recently and will continue to be used until a more efficient and cost effective PV technology is developed (Chaar et al., 2011). Because these cells essentially use crystalline Si *p–n* junctions, currently attempts to enhance the efficiency are limited by the amount of energy produced by the photons since it decreases at higher wavelengths. The maximum efficiency of mono-crystalline silicon solar cell has reached around 23%, but the highest recorded was 24.7%. However, module efficiencies always tend to be lower than the actual cell and Sun power recently announced 20.4% full panel efficiency. These types of mono-junction, silicon-wafer devices are now commonly referred to as the first generation (1G) technology, the majority of which is based on a screen printing-based device. (Singh, 2011).

Multi (poly)-crystalline photovoltaic cells/panels

The efforts of the photovoltaic industry to reduce costs and increase production level have led to the development of new crystallization techniques (Chaar et al., 2011). Initially, multi-crystalline was the dominant and more attractive in the solar industry because manufacturing cost is lower even though these cells are slightly less efficient (15%) than mono-crystalline. The advantage of converting the production of crystalline solar cells from mono-silicon to multi-silicon is to decrease the flaws in metal contamination and crystal structure. Multi-crystalline cell manufacturing is initiated by melting silicon and solidifying it to orient crystals in a fixed direction producing rectangular ingot of multi-crystalline silicon to be sliced into blocks and finally into thin wafers (Figure 3). (Akarslan, F. (2012).

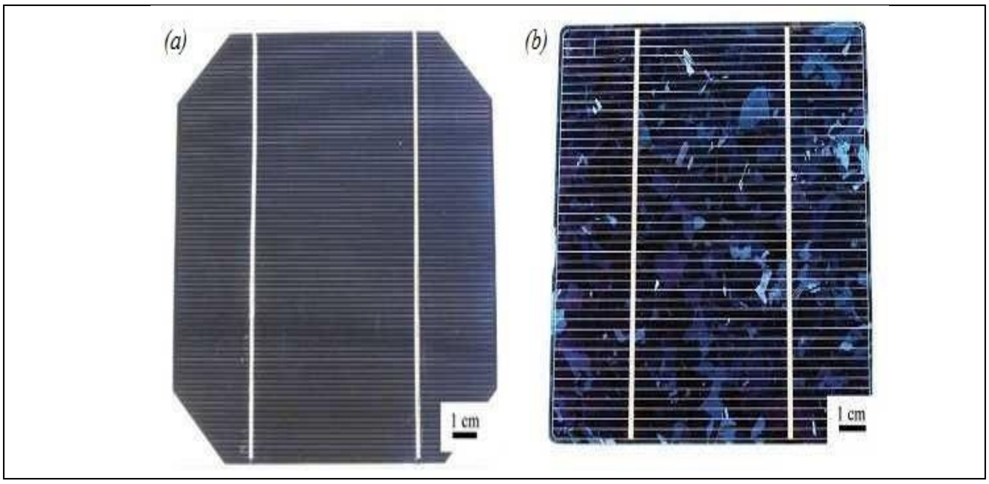

Figure 3. Photographs of (a) crystalline, and (b) multi- crystalline si solar cells *Source*: Akarslan. (2012).

2.0 THIN FILM TECHNOLOGY

The second generation (2G) of solar cells is usually named as thin-film solar cells. A thin-film solar cell is made by depositing one or more thin layers or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si). Thin films greatly reduce the amount of semiconductor material required for each cell when compared to silicon wafers and hence lowers the cost of production of photovoltaic cells (Parida et al., 2011). Unlike crystalline forms of solar cells, thin film panels are created by depositing thin layers of certain materials on glass or stainless steel (SS) substrates, using sputtering tools. The advantage of this methodology lies in the fact that the thickness of the deposited layers which are barely a few micron (smaller than 10 µm) thick allows the creation of flexible PV modules. Technically, the fact that the layers are much thinner, results in less photovoltaic material to absorb incoming solar radiation, hence the efficiencies of thin film solar modules are lower than crystalline (Sohrabi, 2013).

2.1 THIRD GENERATION OF SOLAR CELLS

With further research, various improvements and inclusion of new materials in the existing 2G of thin film solar cells, recently a new so-called emerging or third generation photovoltaic cells (3G) has become commercially available. Among them the most promising are the organic, dye-sensitized (“Grätzel cell”), and polymer solar cells, as well as quantum dot, copper zinc tin sulfide (CZTS), nanocrystal, micromorph, and Perovskite solar cells (Chaar et al., 2011).

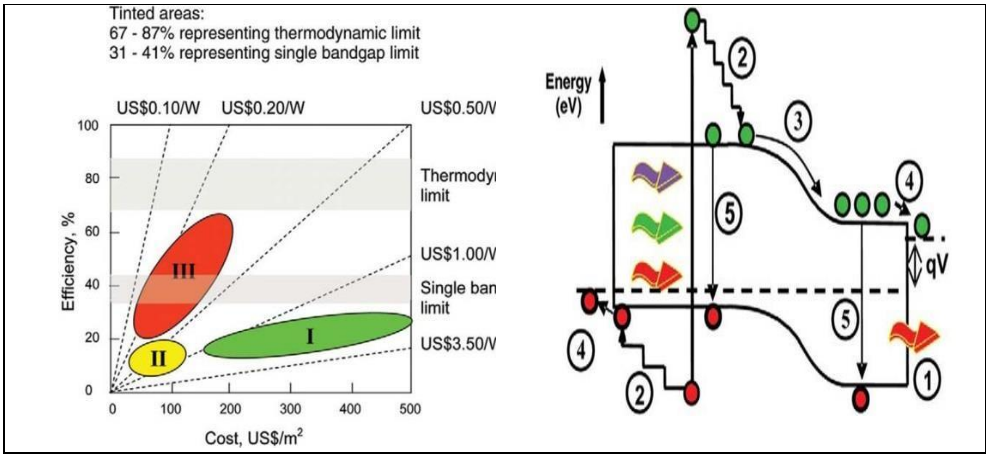

Fig. 4. (a) Efficiency and cost projections for first (I), second (II) and third generation (III) PV technologies, (b) Loss processes in a standard solar cell: (1) non absorption of below band gap photons; (2) lattice thermalization loss; (3) and (4) junction and contact voltage losses; (5) recombination loss (radioactive recombination is unavoidable).

Source: Sohrabi et al., (2011).

The main aim of third generation solar cell is obtaining high efficiency. To achieve such efficiency improvements, devices aim to circumvent the Shockley-Queisser limit for single band gap devices that limits efficiencies to either 31% or 41%, depending on concentration ratio (Sohrabi et al., 2011). Researchers showed that it is possible to greatly improve on a single-junction cell by stacking thin layers of material with varying energy barriers on top of each other and creating so-called "tandem cell" or "multi-junction” cell (Figure 4a). Traditional silicon preparation methods do not lend themselves to this approach. Most tandem-cell structures are based on higher performance semiconductors, notably gallium arsenide (GaAs). Three-layer GaAs cells achieved 41.6% efficiency for experimental examples, while on September 2013, a four layer cell reached 44.7% efficiency. A theoretical "infinity-layer" cell would have a theoretical efficiency of 68.2% for diffuse light. The second benefit of this type of solar cells is decreasing the losses, especially the lattice thermalization loss that could be achieved by capturing carriers before thermalization (**Fig.4b)**.

Finally, the 4G of solar cells which are still not commercially widely available are organic cells with polymer binding having donor and acceptor pair. The concept of these 4G solar cells has been developed with the aim of realizing both improved charge transport and an improvement in the optical coupling, in polymer solar cells through the incorporation of inorganic nanostructures into the device architecture. In addition to the optical and electronic benefits of incorporation of inorganic systems within active materials, certain inorganic materials are also known to improve the device lifetime as well. Therefore, as can be seen, the developments and improvements of the solar cell production is continues and concentrated on several important tasks such as improving their efficiency, decreasing the production cost, prolongation of their life expectance and increase the flexibility and variety of their potential applications. Schematically, the historical path starting from 1G of solar cells up to the present 4G of solar cells is given in Figure 4, (Imalka Jayawardena et al., 2013).

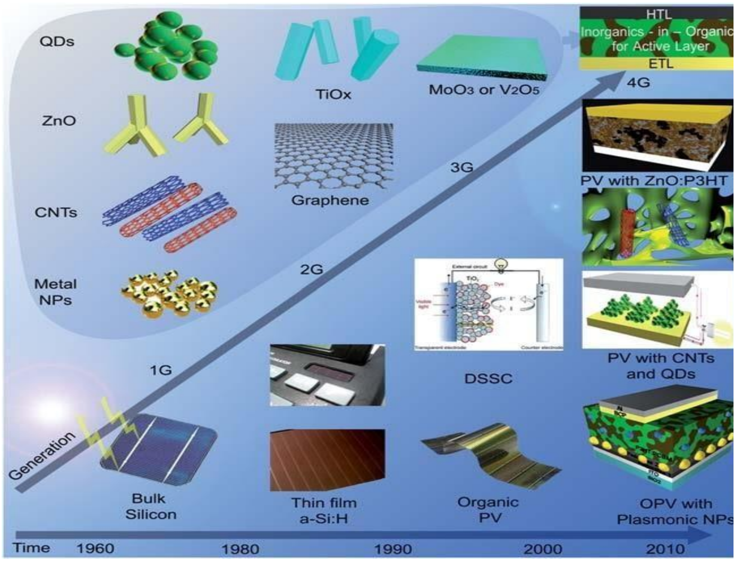

Fig. 5. Timeline of the four generations of photovoltaic devices from first generation (1g) to fourth generation (4g)

Source: Imalka Jayawardena et al., (2013).

Beside classification based on the solar cell technology, solar cells could be classified on the basis of their installations into four main types: grid-tied centralized (large power plants); grid-tied distributed (roof/ground mounted small installations); off- grid commercial (power plants and industrial installations in remote areas); and off- grid (mainly stand alone roof/ground based systems for houses and isolated applications). The balance-of-system requirements of each installation differ significantly, e.g. off-grid stand alone applications often require a battery bank or alternative electrical storage capacity (Kumar & Rosen, 2011).

2.2 FLEXIBLE PHOTOVOLTAIC TEXTILES

The solar cell-based textiles are very good example of so-called organic solar cells that have recently found its application in various novel field and promising development obtaining new features. The photovoltaic textile materials can be used to manufacture power wearable, mobile and stationary electronic devices to communicate, lighten, cool and heat, etc. by converting sun light into electrical energy. The photovoltaic materials can be integrated onto the textile structures especially on clothes, however, the best promising results from an efficient photovoltaic fiber has to be draw closer which can constitute a variety of smart textile structures and related products (Singh, 2011). Organic solar cells made of organic electronic materials based on liquid crystals, polymers, dyes, pigment etc. attracted maximum attention of scientific and industrial community due to low weight, graded transparency, low cost, low bending rigidity and environmental friendly processing potential. Various photovoltaic materials and devices similar to solar cells integrated with textile fabrics can harvest power by translating photon energy into electrical energy.

2.3 Manufacturing of organic photovoltaic cells

As a common transparent electrode in polymer-based solar cells, indium tin oxide (ITO) was used due to its remarkable efficiency and ability of light transmission. However, it is quite expensive and generally too fragile to be used with flexible textile substrates. Therefore, some other highly conductive materials such as poly (3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate), carbon nano-tube or metal layers are used to substitute ITO electrode (Singh, 2011).

3.0 SOME APPLICATIONS OF THE NEW GENERATIONS PV CELLS

The triggering point into wider commercial utilization and production of PV cells (solar cells) was their ability to convert the sunlight into electricity. Thus, they soon became alternative, renewable and almost inexhaustible energy sources to the existing fossil-based energy sources. However, as the time passed, the research in this field increased and certain advances were made in this field, the focus of interest gradually shifted to further exploration of cost advantages and application flexibilities.

Today the solar cells of all generations are widely used for various applications. The electricity produced by solar cells can be utilized in many applications such as cooling, heating, lighting, charging of batteries and providing power for different electrical devices (Curran et al., 2009). Solar cells using first generation technology have high areal production costs and moderate efficiency. Although with modest efficiency, the second generation solar cells, so-called thin-film solar cells have advantages such as increased size of the unit of manufacturing and reduction in material costs. Consequently, third generation technology concept has been developed to eliminate disadvantages of earlier photovoltaic technologies mostly into two directions: to achieve very high efficiencies and second one, to achieve cost per watt balance via moderate efficiency at low cost. Finally, this third generation solar cells, mostly renowned as organic solar cells, provides large flexibility of the cells enabling wide range of applications that were almost impossible with previous generations of solar cells. In this chapter, we would briefly address some applications that might be of interest especially in modern tourism and hotel industry.

3.1 CONCLUSION

Electricity produced from photovoltaic (PV) systems has several benefits over other mostly fossil fuels power sources such as need no fuel, give off no atmospheric or water pollutants and require no cooling, thus they do not contribute to global warming or acid rain problems. The use of PV systems is not constrained by material or land shortages and the sun is a virtually endless energy source. Current PV cells are reliable and already cost effective in certain applications such as remote power, with stand-alone PV plants built in regions not reached by the utility networks. Various alternatives have been designed for building-integrated PV systems, including roof-top, facade and sun-shield systems. Most recently developed flexible organic textile solar cells even further broaden application area of such modern energy devices for application previously unrealistic using older solar cell generations. In this paper, a brief, design construction and testing of photovoltaic (pv) using textiles materials(fabrics)performance and reliability of PV system, environmental aspects and PV applications is presented. The different applications of solar PV system such as building-integrated photovoltaic (BIPV) systems, solar shading, solar glazing and transparent solar windows, and few applications of flexible textile solar cells, with special aspect to the tourism and hotel industry, are also presented.

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