Possibilities of Using Photovoltaics in Automobiles

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Abstract — **There are many photovoltaic technologies nowadays. Some of them can be advantageously used for mobile applications. Although the most widespread photovoltaic silicon based cells have relatively high efficiency, it is more suitable to use different technologies in some cases. In this article the most important parameters of individual technologies are summarized as well as their suitability for using in mobile applications and automobiles.**

Keywords — *photovoltaics, mobile applications, automobile, silicon solar cells, thin-film solar cells*.

I. INTRODUCTION

Nowadays, there is explosive boom of renewable energy sources because of the fossil fuel resources giving out. The most discussed is photovoltaics, which has owing to feed-in tariffs come to the fore. Owing to the demand growth the cost of photovoltaic technologies rapidly depreciated and that leads to expanse of photovoltaics to the other branches of industry. Some of used technologies don't achieve too high efficiency, so they don't find practical applications in high-energy applications, but thanks to their other properties it is possible to use them like mobile power sources for less demanding applications.

In mobile applications PV cells are commonly used in combination with accumulators, which eliminate the greatest disadvantage of photovoltaics – its dependency on sun light (a light source respectively). The connection with accumulators is not used only for mobile applications, but in places where a grid is not available (off-grid systems). Interesting milestone between high and low energy applications is automobile industry. It is not possible to cover whole automobile operation effectively with current PV systems technologies, except experimental vehicles, but they can be used for replenishing accumulators in electro-mobiles as well as in hybrid cars and consequently increase their trailing throttle up to tens of kilometers.

II. PHOTOVOLTAIC CELLS

Nowadays many PV cells technologies exist (see Fig. 1), some of them are more suitable for mobile applications using then the other one. Most of them use semiconductor structures for photovoltaic phenomenon formation (it means the transformation of solar radiation to electricity). The key property for using them in a mobile application is addition to power the mechanical resistance and price as well. Individual technologies are often combined and create together cells with higher efficiency.

A. Crystalline PV cells

Silicon crystalline cells

They come under the oldest used PV cells at all. It is possible to group them into three groups in dependence on manufacturing technology:

- monocrystalline,
- multicrystalline (same as polycrystalline),
- ribbon.

Monocrystalline cells are produced from silicon by using Czochralski method of dragging ingot from molten mass. Ingot is cut to wafers and deposition and diffusion processes are performed on them. Final cell has voltage about 0,5 V to 0,6 V and current, in dependence on area, in the order of Amperes. Ingots have smaller size then silicon ingots used in electronics. The reason is both necessity of manipulation with cells and price. Cells are serial connected and then encapsulated. The highest achieved efficiency of laboratory sample is 25 % [12]. Serial produced PV cells have efficiency about 19 % and final module about 16 % [7].

Multicrystalline PV cells are produced by block dragging from molten silicon mass. The block is then (if necessary) cut to smaller ingots and then there are made similar operations like in monocrystalline PV cells production. The efficiency of final modules is about 14 % [7].

The special cases of multicrystalline PV cells are ribbon cells. The ribbon is produced directly by dragging from molten silicon mass which leads to elimination of ingot wafers cutting loss. But these ribbon modules have relatively low efficiency, and therefore their production is not so extended.

Other crystalline cells

In addition to silicon PV cells, there are the cells produced from different materials, which find applications for example in space applications. Such material may be e.g. InP with efficiency 22,1 % [12] or GaAs with efficiency above 28 % [12] (high efficiency is big advantage), which is more sensitive for UV radiation and therefore is more suitable for these applications.

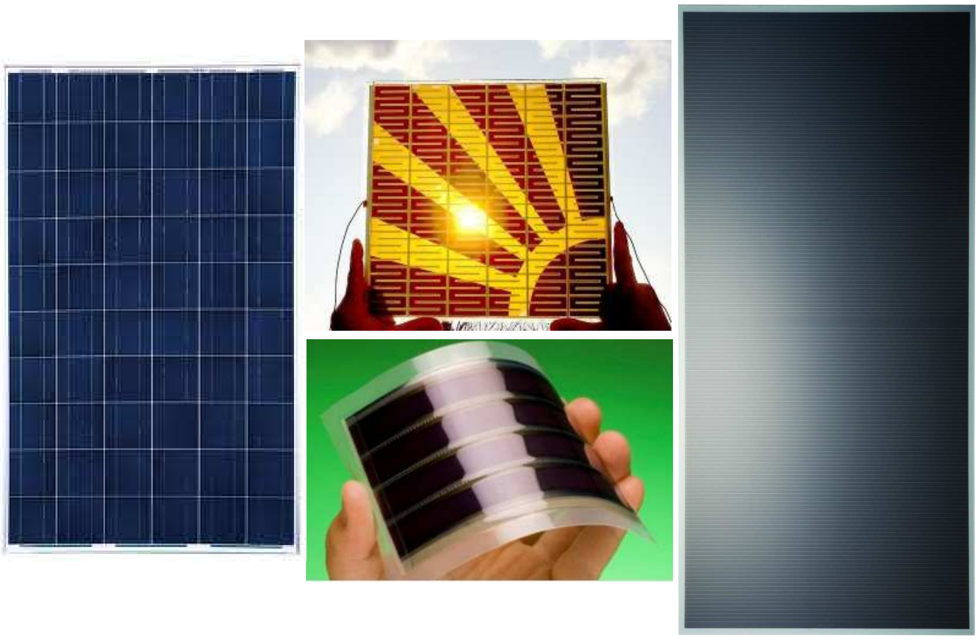

Fig. 1: Types of PV modules (left): multicrystalline module [7], organic module [11], DSSC module [6] and CdTe module [8]

Because of their high cost, these materials are usually designed in form of crystalline layers on advisable substrate - ideal the same material. This substrate can be Ge or Si as well (it is cheaper), but the different crystal structure creates imperfections and leads to lowering the efficiency of the final module. These materials are produced by thin-film technology as well [15].

B. Thin-film PV cells

During PV cells development increased pressure on the cost reduction exists. The cost of crystalline solar modules has fallen by half of its value ten years ago, but there are still processes that use other materials that are so cheap that their cost of acquisition compensates their low efficiency [2].

The big advantage of thin-film solar cells is their ability to be deposited on arbitrary surface. It allows production of elastic cells, which eliminates the need of framework and problems with weight [9], [14].

During the production, the layers are deposited on supporting surface and the cells are created by grooves (commonly made by laser). Contacts are realized like transparent conductive oxide (the convenient metallic contacts have too large serial resistance and lead to power losses). These oxides are suitably doped semiconductor oxides with wide energy band gap, so they are transparent for almost whole useful sun radiation (the most frequently used materials are ITO – indium tin oxide and ZnO [15]). Modules are, thanks to shape of cells – they usually are long narrow strips, less sensitive to shading then the conventional crystalline modules.

Advantage is also relatively lower decreasing of efficiency (respectively power) by diffusion radiation against silicon based technologies and the better temporal stability as well. In geographical location with lower proportion of direct solar radiation it is by the same installed capacity (and same initial costs) possible to produce more electricity per annum.

CIS, CIGS, CGS modules

It is a technology using thin-film layers from materials like $CuInSe_2$ (CIS), Cu(In, Ga)Se_2 (CIGS) and $CuGaSe_2$ (CGS).

The most discussed technology is modules CIGS, which achieved record efficiency 15,7 % by serial manufacture used in 2011 (company Miasolé [13]). The price of these modules should reduce thenceforth, even below the magical limit 1 USD per Wp.

Thanks to manufacturing technology, thin-film layer modules are available in several versions. There are flat modules and both-side (formed from tubes [10]) modules, where the reflector is very important. However the price of cylindrical technology is rather high and the producer of these modules doesn’t exist anymore.

CdTe modules

CdTe modules are the most widespread as well as cheapest thin-film layer modules. Their efficiency is for serial production about 15 % [3].

Thin film silicon modules

Thin film silicon solar modules are rather extended, however the efficiency of common ones is 8 % maximally, so by the same initial costs dominates the disadvantage of large area required for their installation [14].

Other thin-film PV cells

Increasingly widespread technology is becoming solar cells which use more than one material or layer [1]. Various combinations allow efficiency increase (above 30 %). These solar cells are usually rather expensive and they don’t have large area (but the small ones can be used like concentrator cells). The exceptions are HIT modules, which have thin amorphous silicon layer on crystalline silicon wafer. The amorphous layer is more sensitive to diffuse radiation, so the final cell is able to use more incident light. Commonly used HIT modules have efficiency about 18 % [4].

Next special group of solar cells create dye sensitized solar cells (DSSC). These cells use dye sensitized layers for better use of light radiation and nano-particles (or tubes respectively). They have better sensitivity for diffusion radiation then the other ones and their efficiency is quite stable. Additionally, they have quite attractive appearance, because they can be not only colored, but even transparent so they can be placed on windows or walls. The biggest advantage is their temperature coefficient, because it is positive [5], [6].

C. Organic PV cells

There are special organic materials which are able to produce electricity as well. There is massive research in field of suitable organic materials (the reason is very low price especially). Current organic solar cells use most often polymer structures with fullerene. The efficiency of laboratory samples reaches 10 %, but by production larger panels it rapidly decreases [11].

D. Concentrator PV cells

The special types of PV solar cells are concentrator cells that use concentrated solar radiation. The cell of small area is placed in the middle of mirror (most often parabolic one) which reflects incident light into the small cell. The efficiency of concentrator cells is commonly above 25 % (even about 40%), but the initial cost of whole system is rather expensive [12], [15].

III. USING PV CELLS FOR MOBILE APPLICATIONS AND AUTOMOBILES

If we focused on using PV cells like help, or even main power supply for electro-mobile, then it is necessary to take into account in addition to previous table furthermore aspects.

PV modules for mobile applications must be mechanical resistant against vibrations and in accordance with safety standards for using in automobile industry. It is further demanded for easy workability of PV modules - their adjusting to car aerodynamic requirements. Table 1, which is arranged in order to efficiency, begins to change now. Technologies ensuring easy workability by sufficient efficiency gain ground. Also PV module resistance against partially shadowing is far more important parameter (the vehicle body cannot be aerodynamic and ensuring the ideal angular displacement and direction to the sun at the same time). Other way round, parameter “costs” in Table 1 is not so important for using in mobile applications. It is because for electro-mobile supply it cannot be used standard solar modules produced in series for power industry.

Table 1: The comparison of commonly used PV modules properties

Technology	Max. efficiency of common types	Possibility of mechanical working	Relative efficiency by diffusion radiation	Costs	Temporal stability
a-Si	4,4 % - 8,2 %	high	medium	low	Medium
CIGS	8,9 % - 15,7 %	high	high	medium	Medium
DSSC	7 %	high	high	low	high (positive TC)
CdTe	15,3 %	medium	medium	very low	Medium
Multi c-Si	18,5 %	low	low	medium	Low
Mono c-Si	22,9 %	low	low	medium	Low

Not cells, but solar modules production is part and parcel of costs for automobile solar supply realization.

If we will calculate the possible power that can be obtained from common vehicle body area – about 7 m^2, then by optimal sunshine we get from 400 W to 1200 W maximally (dependence on efficiency). In fact, this power will probably be in dependent on used technology and car position lower.

IV. CONCLUSION

The parameters of single PV technologies were discussed. The most widely used monocrystalline silicon solar cells in solar cars have many disadvantages against other technologies for the future.

If we re-arrange Table 1, now with reference to the future views, then we get like most perspective PV modules technology for using in cars DSSC modules or CdTe modules eventually. DSSC modules have against CdTe modules two big advantages: the transparency of modules, which enables to place modules not only on vehicle body, but on the windows as well and the temperature coefficient. According to [5] efficiency is by high cell temperature even better than in silicon based modules. The problem can be only lifetime that is not well known yet.

Another important factor for solar car boom will be dependent not only on photovoltaics, but on the accumulator technology as well.

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