Optical coupling upset in multijunction solar cells with built-in Bragg reflectors

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Abstract. In the present work, an opportunity to block the negative influence of luminescent coupling between subcells in multijunction solar cells with help of built-in Bragg reflectors is investigated. Temperature modes, at which the blocking of optical interaction in the GaAs-Ge pair of subcells is possible, have been determined.

1. Introduction
Distributed Bragg reflectors (BRs) have found wide application in devices of modern optoelectronics [1, 2], providing control over the transmission, recycling and optical absorption of radiation in semiconductor structures. BRs are successively applied in solar cells to raise their performance and radiation resistance owing to increase the efficiency of generation and separation of charge carriers in the photoactive layers with repeated reflection (recycling) of radiation [3, 4].

In multijunction solar cells (MJ SCs) based on semiconductors of high crystallographic perfection with the dominance of radiative processes over non-radiative ones, the radiation recycling processes are usually considered in a wider context, not limited to areas of separate subcells. In such MJ SCs, recombination (luminescent) radiation is cycled not only within layers of a “native” subcell but also penetrates in adjacent photoactive regions forming processes of optical coupling between subcells [5]. Clearly, in the modes of current matching between subcells, excessive charge carriers having no way to escape into the external circuit recombine radiatively and form light flux with radiation wavelength within the range of the narrowband p-n junction sensitivity. With some probability such luminescent photons will be absorbed in the adjacent narrowband subcell with the generation of an additional photocurrent. The investigations show that, in some cases, the optical coupling effect can play a positive role of self-balancing, transferring a MJ SC into the current matching mode for subcells [6]. However, in determining rated photovoltaic characteristics of MJ SC, the negative contribution of such luminescent interaction among subcells complicates substantially the experimental methodology and techniques, and makes interpretation of results difficult [7-9].

The pronounced influence of the optics coupling is manifested in studying the spectral dependencies of photoresponse of narrowband subcells. So, in the narrowband p-n junction spectral sensitivity range, an uncontrollable drop of sensitivity is observed, and beyond it, on the contrary, an anomalous photoresponse is registered [10].

Different methods for eliminating the mentioned “negative” effect of the optical coupling on the measurement results have been proposed [5-9]. Most of them are based on simplified models, which are varied depending on a type or peculiarities of solar cells. For this reason, they cannot be considered universal ones. Another radical way to decrease the effectiveness of optical coupling or, practically, its complete elimination is high-energy (about several MeV) electron irradiation of samples [11]. Such an approach results in changing a dominant recombination mechanism for non-
radiative one, what leads to optical coupling suppression. It is obvious that all considered examples have their own limitations and disadvantages.

In the present work, mechanisms of selective optical blocking for luminescent radiation propagating between MJ SC subcells owing to using built-in BRs were investigated.

2. Experimental results
Let us consider the mechanisms of sunlight propagation and absorption in the monolithic multilayer structure on the example of the GaAs-BR-Ge stack. External radiation, spectrally covering the GaAs sensitivity range, initiates processes of charge carrier (electron-hole pair) generation in the wideband subcell, which, then, recombine radiatively with producing secondary photons in the range of 860-870nm. In the structure, such a secondary radiation will be either reflected by a Bragg mirror with initiating the recycling mechanism in the “native” GaAs subcell or penetrates the Ge subcell determining optical coupling between GaAs and Ge subcells.

If a BR completely reflects the luminescent flux in the direction to the Ge subcell, optical interaction will be perfectly blocked, and the values being registered for the Ge subcell photoreponse spectral dependence will have the true value without a necessity for any correction in correspondence with [10].

In case if the mirror reflection spectrum overlaps the wavelength range of recombination radiation only partially, the photon flux $\Phi_1$ or $\Phi_2$ (fig.1) will penetrate beyond a BR with generating an additional photocurrent at absorption in Ge subcell. In circumstances like this, optical coupling between subcells can be upset (blocked), if a shift of the BR reflection spectrum and luminescent radiation with respect to each other is initiated by heating/cooling the structure.

![Figure 1](image1.png)

**Figure 1.** Spectra of electroluminescent radiation of the GaAs subcell (green and orange lines) and of reflection of built-in Bragg mirrors (green and blue lines) of two samples: (a) – BR#1; (b) – BR#2. All spectral dependences was obtained at 298K. Fluxes $\Phi_1$ and $\Phi_2$ (filled area) correspond to radiation passing into the bottom Ge subcell and forming optical coupling between two junctions.

In the work, temperature conditions essential for blocking optical coupling, if such an effect is observed at standard conditions (298K), in two different MJ SCs with the BR (structures BR#1, BR#2), have been determined. It is obvious that, to initiate mechanisms of blocking the optical coupling, the BR#1 structure should be cooled and BR#2 one be heated promoting a shift of the luminescence emission peak towards the short- or long-wavelength spectral range, respectively.

It has been established during investigation that shift of the electroluminescence peak of GaAs subcell (fig.2a) with temperature is approximately 0.4nm/K (fig.2c, blue). As the peak shifts toward longer wavelengths with temperature gain, the half-width of the electroluminescence spectrum increases with a coefficient of the order of 0.1nm/K (fig.2d, blue line). Thus, it is more likely that a
Complete upset of optical coupling could be observed in ordinary SC with BR at cooling (low temperature mode of operation) rather than heating.

As for the BR reflection spectra (fig.2b), with a temperature variation, its half-width remains practically unchanged (fig.2d, green), as well as the shift of the resonance reflectance is practically negligible and are only 0.08 nm/K (fig.2c, green). Figure 2b shows theoretical and experimental temperature dependences of the BR reflection spectra. The discrepancies between of experimental data and model results (fig. 2b on the left) are due to a part of the reflected radiation was absorbed in the upper (relative to the BR) photoactive layers of the structure. With increasing temperature, the reflection range of the Bragg mirror becomes more and more "covered" by GaAs absorption curve, which is most pronounced on the left side of fig.2b. Consequently, at some temperature (393 K) the ability to observe/distinguish the reflection spectrum of the BR is completely lost. In such a case the change in the spectral half-width and the shift of the absorption edge of BR resonance reflectance with temperature can be obtained only through theoretical consideration.

![Figure 2](image_url)

**Figure 2.** Temperature dependencies of: (a) – of GaAs electroluminescence spectra; (b) – of BR reflection spectra; (c) – the GaAs electroluminescence peak position (blue) and half-widths of GaAs electroluminescence spectrum (red); (d) – position of the edge of BR resonance reflection (violet) and half-widths of BR reflection spectrum (green).

Hence, the temperature-controlled transition of the SC into the blocking mode of optical coupling is possible if:
- the luminescence peak is apart from the right edge of BR resonance reflectance less than 70-80 nm (fig.1a), that is enough to provide EL light to be reflected backwards to GaAs subcell at cooling.
the luminescence peak is located at the distance less than 30-40nm from the left edge of BR resonance reflectance to get overlapping the spectra in heating.

3. Results
In this article, possibilities to block optical interaction between p-n junction in multijunction solar cells with use of built-in Bragg reflectors were investigated. Temperature modes, at which can be achieved violation of optical interaction in the GaAs-Ge pair of subcells, have been determined. It was found that if discrepancy between spectra of GaAs electroluminescence and BR reflection is less then 80nm (the luminescence peak is apart the right edge of the BR resonance reflection) or 40nm (left edge) cooling/heating of the sample is able to overcome optical coupling.

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