Bragg reflectors as a light trap in multijunction solar cells

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Abstract. The work is aimed at the study of multijunction solar cells with built-in Bragg reflectors. The possibility to use the photon structure for "locking" the secondary recombination radiation, which causes luminescent coupling between individual photoactive p–n junctions in a solar cell, is investigated. Temperature studies were carried out on the reflection spectra of a Bragg reflector, the electroluminescence spectrum of a middle wide bandgap subcell, and the spectra of the external quantum efficiency of a multijunction solar cell.

1. Introduction
The work is devoted to the study of luminescent coupling, which occurs in multijunction solar cells between photoactive p–n junctions, when photons (formed due to radiative recombination in a wide bandgap subcell) are absorbed in an adjacent narrow bandgap subcell and generate an additional photocurrent in the last one [1-2]. Different scenarios of interaction between junctions may develop depending on the type of the structure is used and the combination of the inner layers.

The most interesting structures, from the point of view of radiation recycling management, are multijunction solar cells with built-in photonic crystals, such as a Bragg reflector (BR). Such structures are widely used in modern photovoltaics and make it possible to increase the radiation resistance of solar cells [3]. Under certain conditions, the BR can act as a "blocking" layer for the secondary recombination radiation flux, thereby reducing the efficiency of luminescent coupling in a pair of subcells. In cases when the BR reflection spectrum is optically matched with the luminescence spectrum of a wide bandgap junction the luminescent photons are reflected back to the original subcell layers.

The production of semiconductor structures with a built-in BR is not a simple technological task, since it is not always possible to obtain devices with target BR optical parameters. Therefore, the main experimental tool that provides the required BR reflection spectrum in this work is the temperature of the sample under study. It is known that the spectral range of the mirror shifts along spectral range toward short (or long) waves with a decrease (or increase) in temperature with a coefficient of approximately Å per °C [4].

The shifts of a subcell band gap and its electroluminescence peak during the temperature changes proceed substantially faster and can be determined by [5]. Thus, sample temperature alignment makes it possible to achieve complete agreement between the mirror spectra and the recombination radiation, and to block luminescent coupling between subcells.

2. The study of BR reflectance
The multijunction GaInP-Ga (In) As-Ge solar cells with built-in BR between the Ga(In)As-Ge subcells were used to study the “locking” of the luminescent coupling (figure 1(a)).
Since the BR parameters in multilayer structures are rather difficult to estimate due to absorbing subcells located above them, the etching procedure was carried out to determine the true reflection spectrum of the BR (figure 2). The temperature coefficient for AlGaAs mirror layers was found to be around 0.05 - 0.1 nm/°C (figure 3(a)). As can be seen from figure 3(b) the BR spectrum does not shift much during temperature changes and slightly expands at its base when heated (figure 3(b)).

**Figure 2.** Temperature dependencies of the BR reflectance spectrum. Levels 1, 2, 3 correspond to the spread of the spectrum (figure 3(a)) with increasing temperature.

### 3. The study of electroluminescence and external quantum efficiency

Light coupling in the Ga(In)As-Ge pair occurs due to the flux of luminescent photons, the spectrum of which is determined by the band structure of the material with a wider band gap. This spectrum can be obtained through the electroluminescence measurements. Studies have shown (figure 4(a)) that the Ga(In)As luminescence spectrum expands and shifts at a rate of approximately 0.4 nm/°C (figure 4(b)), and is much greater than the motion of the BR photonic band gap. Obviously, there is a certain
temperature range where the BR completely locks the leakage of luminescent radiation into the Ge subcell, as well as the range where the mirror is partially transparent and the light coupling in the Ga(In)As – Ge pair is broken. Thus, at different temperatures luminescent coupling will influence the photovoltaic characteristics of the solar cell in different ways.

![Figure 3](image1.png)

**Figure 3.** (a) The shifts of the reflectance spectrum (right and left edges) at various levels, and the corresponding temperature coefficients (the dimension is indicated in nm/°C). (b) Temperature dependencies of the BR reflectance spectrum width at levels 2, 3 (figure 2).

![Figure 4](image2.png)

**Figure 4.** (a) The temperature dependence of the Ga(In)As electroluminescence spectrum. (b) The shift (green and violet) and expand (blue and red) of the electroluminescence spectrum of the middle subcell. The points on the plot correspond to the experimental data, and lines are the approximation.

As is known [6], the reaction of the so-called “artifact photoresponse” in the shortwave spectrum on the spectral dependence of the external quantum efficiency of a narrower band gap subcell region is usually registered in the presence of luminescent coupling. One of the factors that directly affects the magnitude of such an artifact is the efficiency of optical coupling (i.e. the transparency of the medium located between the radiating and receiving subcells). In multijunction solar cells with BR, the photon structure contributes to the transparency of the intermediate medium. A strong optical mismatch between the mirror and the wide band gap subcell leads to the high coupling performance.
Accordingly, with the same external illumination (figure 5), the artifact is more pronounced when the level of optical matching is lower (at -170 °C, figure 5(b)).

![Graph showing spectral dependence of EQE and reflectance for different temperatures and light bias intensities.]

**Figure 5.** The spectral dependence of the external quantum efficiency of the GaAs-BR-Ge structure at different temperatures -100 °C (a), -170 °C (b) and the same level of external light bias intensity (the dimension is indicated in relative units). The red arrows correspond to the position of the electroluminescence peak for the Ga(In)As subcell.

### 4. Conclusion
Temperature studies of the spectral dependences of the external quantum efficiency, the reflectance coefficient for BR and electroluminescence have shown that by changing the temperature, it is possible to match the range of effective reflection of BR with the wavelength of the luminescent radiation, and almost completely lock this light within the GaAs subcell layers. In this case, a sharp decrease in the efficiency of optical interaction and a simultaneous decrease in the artifact photoresponse in the region of short wavelengths of the Ge subcell were registered.

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