Carrier Concentration Influence on Reflectivity Spectra of homoepitaxial DBR for Telecommunication Spectral Range

Helena Janowska, Anna Musiał and Grzegorz Sęk

Department of Experimental Physics, Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wrocław, Poland

Distributed Bragg Reflectors (DBRs) represent crucial components extensively utilized in photonics applications and telecommunication systems. DBRs find widespread application as forming optical resonators, e.g., in vertical cavity surface emitting lasers, or non-classical light sources based on quantum emitters boosting their extraction efficiency [1] and ensuring high directionality of emission. Quantum dots, as extensively demonstrated in prior studies [2-4], exhibit proficient performance when employed as the active region of such devices. DBRs are typically fabricated through epitaxial growth process, comprising alternating layers of different materials with distinct refractive indices. Through strategic selection of materials maximizing the refractive index contrast and their respective thicknesses, precise control over the resonant frequency of the microcavity and high reflectivity spectral range is achieved. Of particular significance is their application within the telecom spectral domain. Recently, an idea of homoepitaxial DBRs has been introduced with refractive index contrast achieved either by different porosity [5] or different doping of subsequent layers [6]. Using the same material with different carrier concentration for DBRs effectively solves the challenge of finding lattice-matched materials with high refractive index contrast which is a difficult task for some material systems like InP, where quaternary alloys need to be used for this purpose.

In our study, we aim to calculate the reflectivity spectra of selected DBR materials (e.g., BN, AlGaSb, Si) suitable for IR range, but instead of alternating layers of two different materials the design is based on varying carrier concentration. This will allow to verify potential of proposed DBR design [6] and to select most suitable material for a given application. As a result of three primary phenomena - bandfilling, bandgap shrinkage, and free-carrier absorption - the refractive index, and consequently the reflectivity spectra, rely on the carrier concentration in the material [7]. This characteristic can be altered through doping, interaction with external fields, carrier injection, and other means which can be explored as basis for engineering of DBR reflectivity spectra. The Transfer Matrix Method (TMM) is employed, which involves considering the electric field amplitudes during the propagation of an electromagnetic wave through the structure. This method encompasses propagation within materials characterized by refractive indices and thicknesses, as well as reflection and transmission at each interface. Light propagation throughout the structure can be represented as a 2D array - a transfer matrix [8]. The TMM was implemented in Python and utilized to compute the reflectivity spectra of the DBR. To incorporate the variable containing information about carrier concentration, we leverage its strong association with refractive index [7]. By integrating this relation into our program, we can study the sensitivity of the reflectivity spectrum to this parameter.

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