a-Ge and *a*-Si as dielectric mirror materials for long-wavelength optoelectronic devices: a comparative study

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Dielectric mirrors are key components in a number of optoelectronic devices, e.g. vertical-cavity surface-emitting lasers (VCSELs)[1], low-threshold edge-emitting lasers[2], subwavelength ultrabroadband mirrors[3] and modulators[4] which require very high reflectivity (R > 95%) with low optical losses. In fact, this type of mirrors, such as, distributed Bragg reflectors (DBRs) or Bragg mirrors are composed of stacking alternating thin layers of two different dielectric materials with high and low refractive index. The mirror materials must be chosen in a way that the refractive index contrast, Δn of the constituent materials becomes as high as possible and at the same time the absorption loss becomes very low to reach sufficient reflectivity with a minimum number of layers and interfaces.

In this study, the optical characteristics of e-beam evaporated and non-hydrogenated *a*-Si and *a*-Ge are determined in the mid-infrared (MIR) wavelength regime and then the comparison between these two materials for their use as dielectric mirrors are presented. As a part of the investigation, these materials are at first evaporated by e-beam on quartz glasses and then reflection, transmission and photothermal deflection spectroscopy (PDS)[5] measurements were carried out. Finally, the values of the refractive index and the absorption coefficient are extracted from these measurement data.

While designing VCSELs in the mid-infrared wavelength regime, one has to deposit highly reflective (R > 99%) dielectric Bragg mirrors in order to reach laser operation. Among conceivable materials, *a*-Si and *a*-Ge with high refractive indices are potential ones against low refractive index material, e.g. SiO_2. When *a*-Si against SiO_2 is used in dielectric mirrors above 2 µm, one can obtain approximately Δn ~ 2.0, since the refractive index of *a*-Si is about 3.5 for photon energy of 0.57 eV. An even higher index contrast, Δn ~ 2.9 can be achieved by using *a*-Ge against SiO_2 in this wavelength regime, because *a*-Ge shows a very high refractive index of approximately 4.4 below 0.6 eV. But when the optical absorption losses of these materials above 2 µm are considered, then *a*-Si is proven to be better. As a matter of fact, *a*-Ge introduces a larger insertion loss than *a*-Si that limits their use in devices based on transmission. Numerically, the absorption coefficient (α) value of *a*-Ge above 2 µm remains more than one order of magnitude higher than *a*-Si. For example, at a wavelength of 2.7 µm, *a*-Ge exhibits α = 380 cm^{-1} whereas α = 28 cm^{-1} in case of *a*-Si.

Fig. 1 shows the measured and simulated reflection spectra of a 3 pair *a*-Si/SiO_2 DBR and *a*-Ge/SiO_2 DBR on GaSb, where air is the incident medium. Despite of the strong optical losses of *a*-Ge but large index contrast of *a*-Ge/SiO_2, the calculated peak reflectivity of a 3 pair *a*-Ge/SiO_2 at λ = 2.6 µm is 99.2%, which is slightly lower than a 3 pair *a*-Si/SiO_2 DBR. In addition, *a*-Ge could be material of interest as a high index material to reach smaller reflectivity with fewer layer pairs.

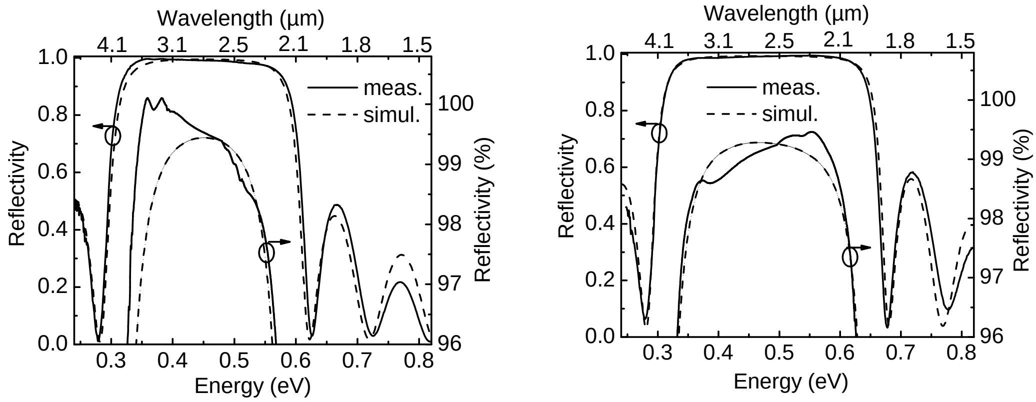

Fig. 1. Reflectivity spectra of a 3 pair *a*-Si/SiO_2-DBR (left) and 3 pair *a*-Ge/SiO_2-DBR (right) designed for maximum reflectivity at 2.6 µm. The simulation (dashed line) fits well to the measurement (solid line), hinting that the measured n and α values of these materials are accurate. The deviations close to the maximum are measurement artefacts and result from the combination of two curves measured with two different detectors.

References

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