photonics

MDPI

Supplementary Material:

One DBR micromirror includes an alternating sequence of two material layers of different refractive index. Always, two neighboring layers define a 1D grating period of the optical thickness of half of the wavelength in the medium. In most of the cases, each individual layer in the DBR stack has a thickness of $m\lambda_i/4$ (m=1, 3, …) where λ_j is the material wavelength in the respective material j (λ is the vacuum wavelength). By performing transfer-matrix simulations, the reflectance can be calculated as a function of wavelength for different number of DBR periods and different absorption coefficients α in the different materials Note that the spectral variation of the absorption α=$\alpha(\lambda)$ has to be included. The inset in Fig. SM1 depicts the spectral reflectance for a SiO_2/Si_3N_4 DBR micromirror for 12 periods, individual quarter wave layers in the DBR and an absorption of α=0. The big black arrow indicates the maximum spectral reflectivity R_{max} at λ=1.55 µm at the center of the stopband inside the reflectance spectra which have been obtained on the basis of theoretical model calculations using transfer matrix method. In the main diagram of Fig. SM1 the maximum spectral reflectivity R_{max} at λ=1.55µm is depicted for SiO_2/Si_3N_4 and InP/air-gap DBR micromirrors as a function of the number of periods p. For InP the residual absorption of InP is taken into account. Since the photon energy corresponding to the wavelength λ=1.55µm is far below the InP bandgap, there is nearly no difference between the undoped, p-doped and n-doped InP. In addition, the maximum spectral reflectivity R_{max} at λ=1.55 µm is calculated for SiO_2/Si_3N_4 DBR micromirrors for different absorption values α=0, 0.1, 0.3, 1, 3, 10, 20, 100cm^{-1}. The technological fabrication process plays a crucial role which absorption values can be obtained at the end. A value between 20 and 10 cm^{-1} is already a very good value for the amorphous Si_3N_4 and SiO_2. However, is absorption loss for photon energies below the bandgap is much lower and only depends on the band structure of these extreme high-quality crystalline materials. Figure SM1 displays an R_{max} strongly increasing with the number of periods, however, saturating larger number of periods. Note that the saturation level of the maximum reflectance strongly increasing with decreasing loss. The stopband represents the large region of high spectral reflectivity – it is the plateau-like structure in the spectrum in the inset. Note that, in addition, the spectral reflectance strongly grows with an increasing refractive index contrast Δn between the neighboring layers in the DBR.

In Fig. SM 1, for the dielectric SiO_2/Si_3N_4 system at λ=1.55 µm we have about, n_{Si3N4}=1.94, n_{SiO2}=1.47, Δn=0.47 and consider α_{Si3N4} = α_{SiO2}=20 cm^{-1} providing a maximum reflectivity of R_{max} exceeding 99.8% for p≥14 for α_{Si3N4} = α_{SiO2}=15 cm^{-1}. However, 99.8% cannot be reached for α_{Si3N4} = α_{SiO2}=20cm^{-1} since R_{max} already saturates at 0.997. To further increase the refractive index contrast Δn, studied InP/air-gap structures on InP substrates have been studied (λ=1.55 µm, n_{InP}=3.167, n_{Air}=1, Δn =2.167, n_{InP}=3.4 cm^{-1}) yielding R_{max} = 0.9998 for p=4 and enables $Rmax$ already to surpass 99.8% if only more than three periods are used.

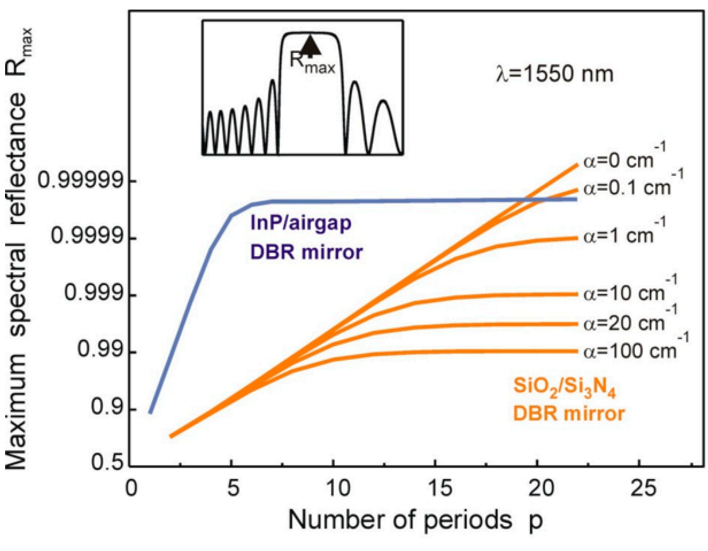

Figure S1. Theoretical model calculations of the maximum spectral reflectance R_{max} of DBR micromirrors at λ=1.55µm as a function of the number of periods for different optical absorption. Inset: simulated optical DBR reflectance spectrum defining R_{max}.