Light-Intensity Distributions in Distributed-Feedback Resonators

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Introduction

Numerous models have been developed to model the performance of Bragg gratings and distributed-feedback (DFB). The coupled-mode theory [1] is an approximated formalism that has been extended in various ways to better approximate specific configurations. Alternatively, the characteristic-matrix approach [2] provides exact solutions, at the expense of larger computing efforts. Equally exact, but avoiding the matrix formalism, is the impedance method [3]. By use of these theories, frequently reflection and transmission curves of Bragg gratings and DFB resonators without propagation losses have been calculated. In some cases, either propagation losses have been included or light-intensity distributions at the Bragg wavelength have been modelled. These theories, though accurate, often prove cumbersome to implement.

Using a recursive method based on the circulating-field approach [4] we calculate the exact reflection and transmission curves and light-intensity distributions in DFB resonators with propagation losses.

Recursive circulating field approach

The circulating-field approach has previously been applied to single Fabry-Pérot resonators [5]. It can straight-forwardly be extended to the situation of a multiple Fabry-Pérot-resonator structure. The relationships between the electric fields in the double-Fabry-Pérot resonator of Figure 1 are

$$E_{circ,1} = it_1 E_{inc} + r_1 e^{-i\phi_1} e^{-\alpha_{loss}/2} E_{b-circ,1}, \quad E_{b-circ,1} = r_2 e^{-i\phi_1} e^{-\alpha_{loss}/2} E_{circ,1} + it_2 e^{-i\phi_2} e^{-\alpha_{loss}/2} E_{b-circ,2}$$

$$E_{circ,2} = it_2 e^{-i\phi_1} e^{-\alpha_{loss}/2} E_{circ,1} + r_2 e^{-i\phi_2} e^{-\alpha_{loss}/2} E_{b-circ,2}, \quad E_{b-circ,2} = r_3 e^{-i\phi_2} e^{-\alpha_{loss}/2} E_{circ,2}$$

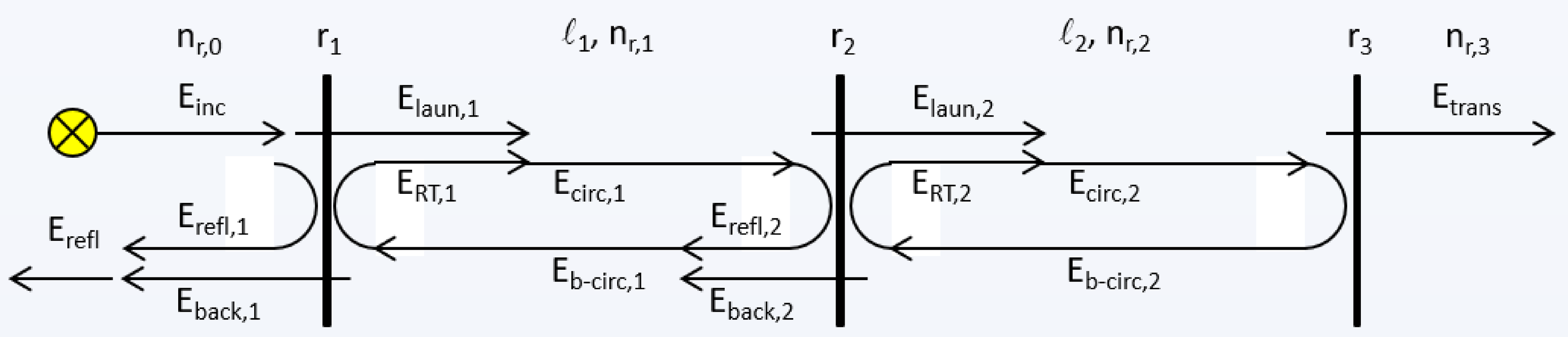

Figure 1. Double Fabry-Pérot resonator with relevant electric fields E; inc: incident; refl: reflected; laun: launched; circ: forward-circulating; b-circ: backward-circulating; RT: round-trip; trans: transmitted.

These equations can be exploited to describe the electric-field distributions of a structure with N consecutive Fabry-Pérot resonators. As long as there is no light launched from the other end of the multi-resonator structure, the electric fields for all resonators are given by

$$\frac{E_{circ,j}}{E_{circ,j-1}} = \frac{it_j e^{-i\phi_{j-1}} e^{-\alpha_{loss}/2}}{1 - r_j r_{j+1} e^{-i2\phi_j} e^{-\alpha_{loss}} - r_j it_{j+1} e^{-i\phi_j} e^{-i\phi_{j+1}} e^{-\alpha_{loss}} \frac{E_{b-circ,j+1}}{E_{circ,j}}}$$

$$\frac{E_{b-circ,j}}{E_{circ,j-1}} = \left(r_{j+1} e^{-i\phi_j} e^{-\alpha_{loss}/2} + it_{j+1} e^{-i\phi_{j+1}} e^{-\alpha_{loss}/2} \frac{E_{b-circ,j+1}}{E_{circ,j}} \right) \frac{E_{circ,j}}{E_{circ,j-1}}$$

By applying these equations recursively, the exact electric-field distribution along the grating can be found.

Number of films	4485	Low eff. refractive index	1.6049715
Bragg wavelength	1.5500e-06 m	Grating length	1.0818413 cm
High eff. refractive index	1.6079535	Phase-shift position	0.5409207 cm

Table 1:DFB grating parameters

Results

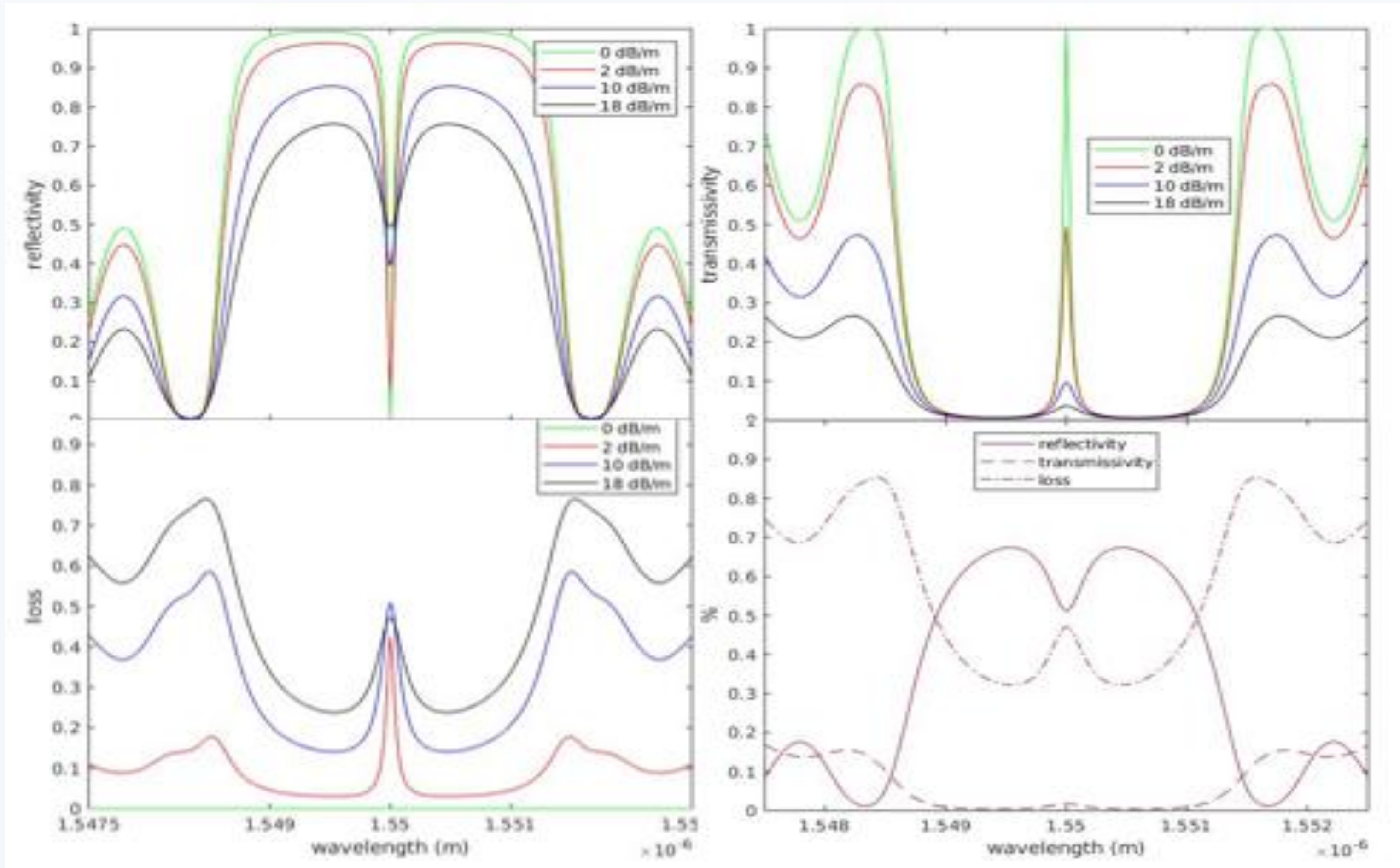

Figure 2. (Top left) Reflectivity, (top right) transmissivity, and (bottom left) loss curves for different propagation losses (legend). (Bottom right) Reflectivity, transmissivity, and loss curves for a propagation loss of a_{loss} = 26 dB/m

The output curves of a DFB grating with the design parameters of Table 1 are shown in Figure 2. At the resonant wavelength, the reflectivity increases and the transmissivity decreases significantly with increasing losses, indicating a loss of resonance. At low propagation losses, the highest loss occurs at the Bragg wavelength, but as the propagation losses increase, the highest loss now occur at either end of the stopband.

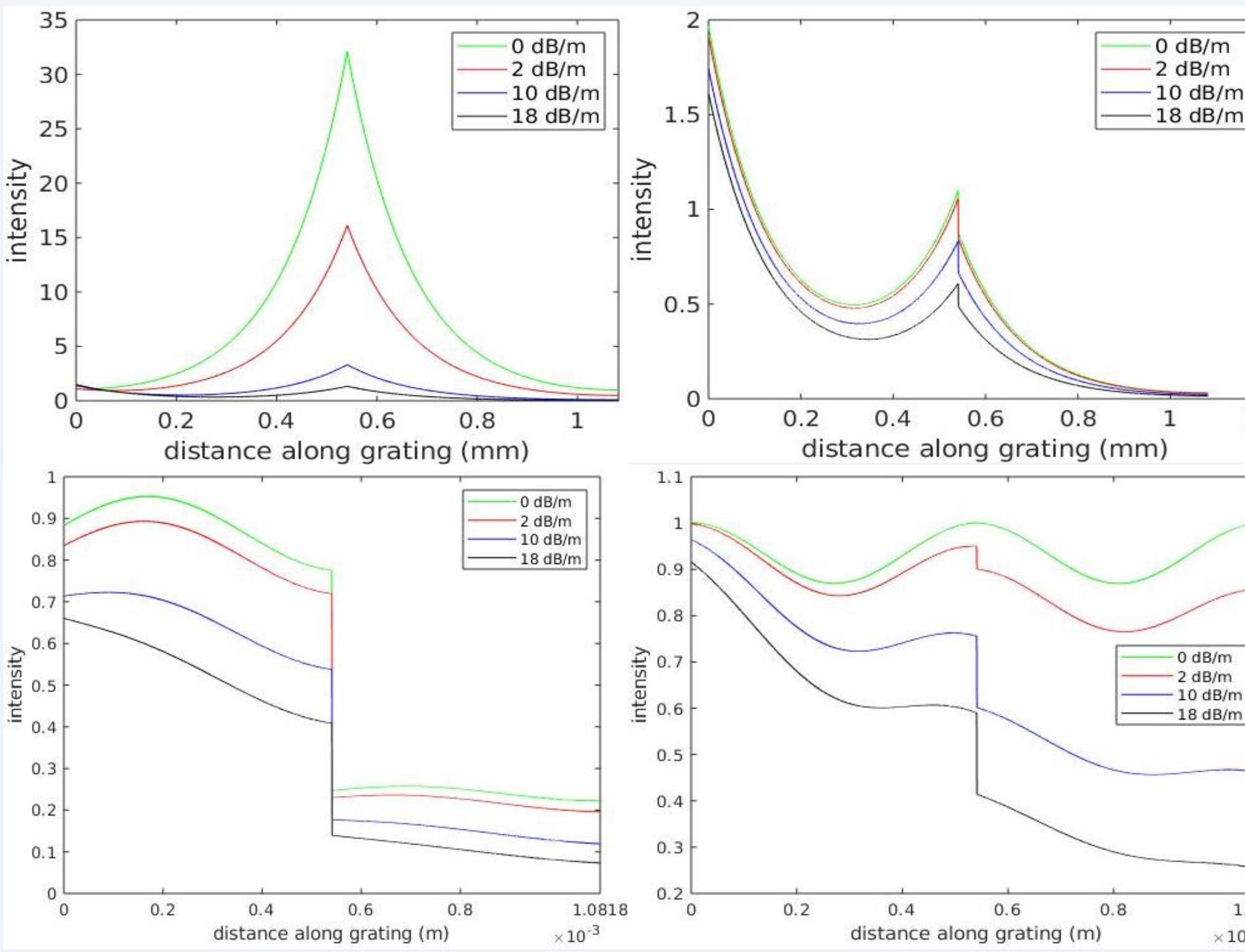

Figure 3. Intensity distribution versus grating position for different wavelengths: (top left) λ = 1.5000×10^{-6} m (= Bragg wavelength), (top right) λ = 1.5498×10^{-6} m (bottom left) λ = 1.5487×10^{-6} m, and (bottom right) λ = 1.5484e×10^{-6} m (= wavelength of first zero reflection), for different propagation losses (legend).

The intensity distribution exhibits an intensity jump as we move further away from the Bragg wavelength and displays oscillatory behavior at wavelengths far away from the Bragg wavelength, as can be seen in Figure 3.

Conclusion

We have presented a simple, straight-forward method, based on the recursive calculation of single Fabry-Pérot resonators, to calculate the exact intensity distributions within a DFB resonator. Uniform propagation losses have been considered. The resulting output and loss curves, as well as the intensity distribution along the resonator axis have been calculated and their behavior studied. These results will help predict the performance of DFB lasers.

References

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