4
Single-interface lossless modes in ϵ_r'-μ_r' parameter space

Tables

Item	Topic	Chapter 3	Chapter 4	Chapter 5	Chapter 6	Chapter 7
1	Interfaces	1	1	2	1	2
2	Types	ENG,DNG	DPS,ENG,DNG,MNG	DPS,ENG,DNG,MNG	ENG	ENG
3	ϵ_r, μ_r	complex	real	real	complex	complex
4	Dispersion	yes	no	no	no	no
5	Free β	yes	yes	yes	yes	yes
6	Loaded β	yes	no	no	yes	yes
7	Configuration	O,K	free	free	O,K	G
8	$\mathcal{R}$	yes	no	no	yes	yes
9	G–H	yes	no	no	no	no
10	E and H	no	yes	yes	yes	yes
11	s_z	no	yes	yes	yes	yes
12	s_x	no	no	no	yes	yes
13	η	yes	no	no	yes	yes
14	v_{ph} and v_{group}	yes	no	no	no	no
15	Charge density	no	no	no	yes	yes

Table 2.10. List of topics investigated in chapters 3-7.

Item	Topic	Chapter 4
1	Interfaces	1
2	Types	DPS,ENG,DNG,MNG
3	ϵ_r, μ_r	real
4	Dispersion	no
5	Free β	yes
6	Loaded β	no
7	Configuration	free
8	$\mathcal{R}$	no
9	G–H	no
10	E and H	yes
11	s_z	yes
12	s_x	no
13	η	no
14	v_{ph} and v_{group}	no
15	Charge density	no

Table 4.1. List of topics investigated in this chapter.

Medium		ϵ_i	μ_i	n_i	r_i	ϕ_i (deg)
Cover	c	2.25	2.25	2.25	3.18198	45.
Substrate	s	3.0625	3.0625	3.0625	4.33103	45.

Table 4.2. The parameters ϵ_i, μ_i and n_i, and the magnitude of the vector, r_i, and its angle, ϕ_i, for the DPS-type substrate and DPS-type cover. These parameters are used to generate all the media types discussed in this chapter.

Medium	DPS	ENG	DNG	MNG
Cover	r_c, ϕ_c	$\pi-\phi_c$	$\pi+\phi_c$	$2\pi-\phi_c$
Substrate	r_s, ϕ_s	$\pi-\phi_s$	$\pi+\phi_s$	$2\pi-\phi_s$

Table 4.3. The sets (r_s,ϕ_s) and (r_c,ϕ_c) used to generate all the media types discussed in this chapter.

β_{TE}	$DPS_{sub.}$	$ENG_{sub.}$	$DNG_{sub.}$	$MNG_{sub.}$
DPS_{cover}	0	0	0	4.69043
ENG_{cover}	0	0	4.69043	0.
DNG_{cover}	0	4.69043	0	0
MNG_{cover}	4.69043	0	0	0

Table 4.4. The solutions of β_{TE} for the 16 media pairs. The valid solutions are those whose magnitude is larger than the refractive indices given in Table 4.2.

Types	DPS/MNG	DNG/ENG
δ_{TE}	4.11553	4.11553
γ_{TE}	5.6017	5.6017

Table 4.5. The decay constants, δ_{TE} and γ_{TE}, for the DPS/MNG-type and DNG/ENG-type structures.

β_{TM}	$DPS_{sub.}$	$ENG_{sub.}$	$DNG_{sub.}$	$MNG_{sub.}$
DPS_{cover}	0	4.69043	0	0
ENG_{cover}	4.69043	0	0	0
DNG_{cover}	0.	0	0	4.69043
MNG_{cover}	0	0	4.69043	0

Table 4.6. The solutions of β_{TM} for the 16 media pairs. The valid solutions, whose magnitude is larger than the refractive indices presented in Table 4.2.

Types	DPS/ENG	DNG/MNG
δ_{TM}	4.11553	4.11553
γ_{TM}	5.6017	5.6017

Table 4.7. The decay constants, δ_{TM} and γ_{TM}, for the DPS/ENG-type and DNG/MNG-type structures.

Mode	Types	*a*	*b*
TE	DPS/MNG	201534.	
TE	DNG/ENG	201534.	
TM	DPS/ENG		534.956
TM	DNG/MNG		534.956

Table 4.8. The normalization constants of the fields for the TE mode, *a*, using Eq. (2.189) and for the TM mode, *b*, using Eq. (2.195).

Figures

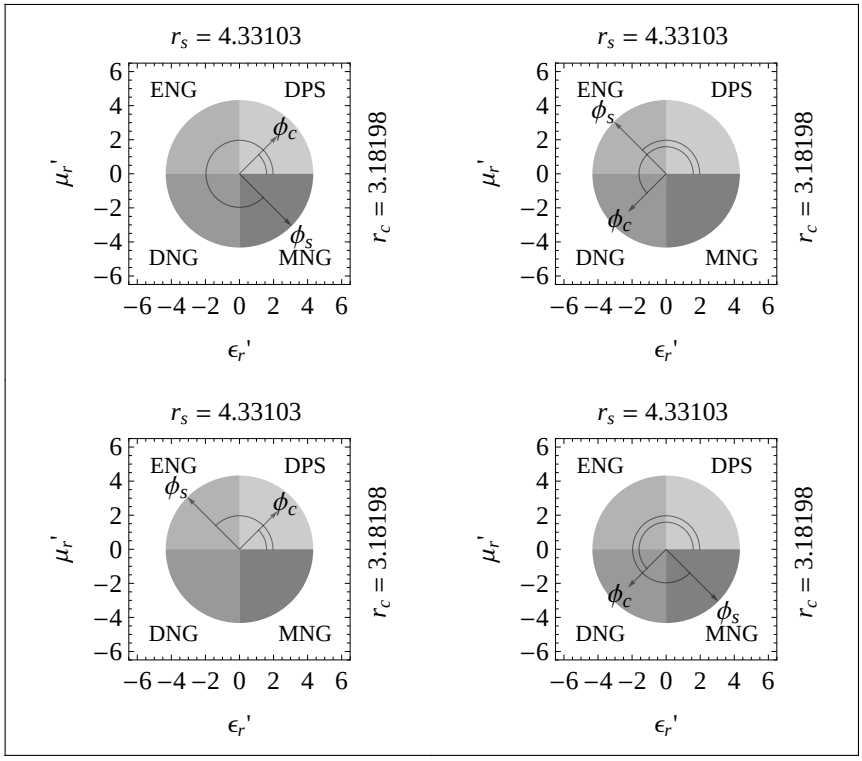

Fig. 4.3. The four media-type pairs that support a single-interface mode, presented in an ϵ_r'-μ_r' parameter space. These pairs consist of the following structures: (top left) DPS/MNG-type, (top right) DNG/ENG-type, (bottom left) DPS/ENG-type and (bottom right) DNG/MNG-type.

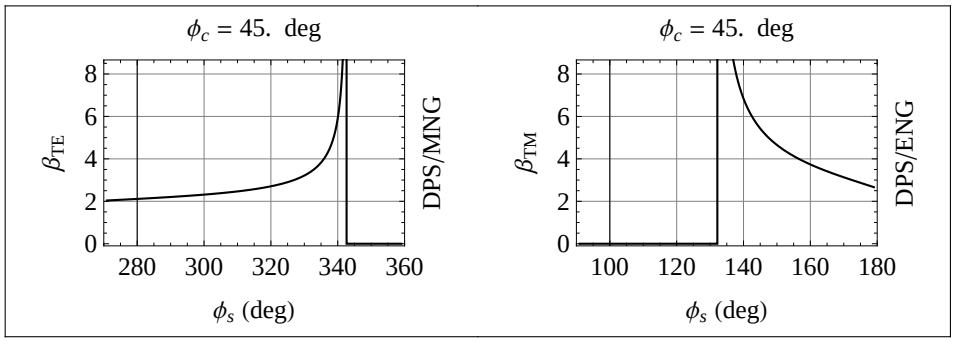

Fig. 4.4. The solutions of single-interface (left) TE and (right) TM modes, β_{TE} and β_{TM}, respectively, in terms of the angle ϕ_s. Here, the cover is DPS-type while the substrate, characterized by ϕ_s, is (left) MNG-type and (right) ENG-type.

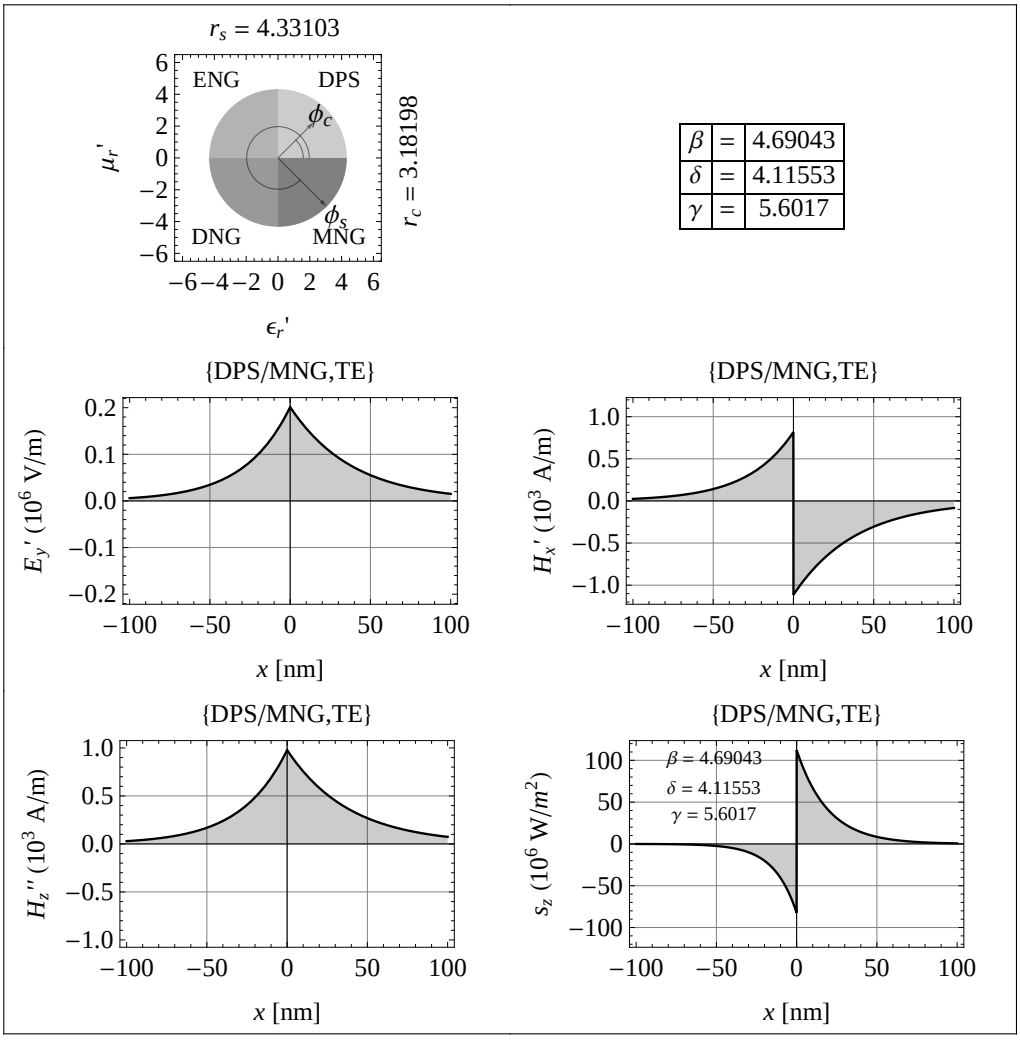

Fig. 4.6. The complete solution of the TE mode belonging to the DPS/MNG-type structure: (top left) the presentation of the structure in an ϵ_r'-μ_r' parameter space, (top right) the propagation constant, β, and the decay constants in the cover and substrate, δ and γ, (center left) E_y', (center right) H_x', (bottom left), H_z'', and (bottom right) s_z. Note that for the substrate $x < 0$ and for the cover $x > 0$.

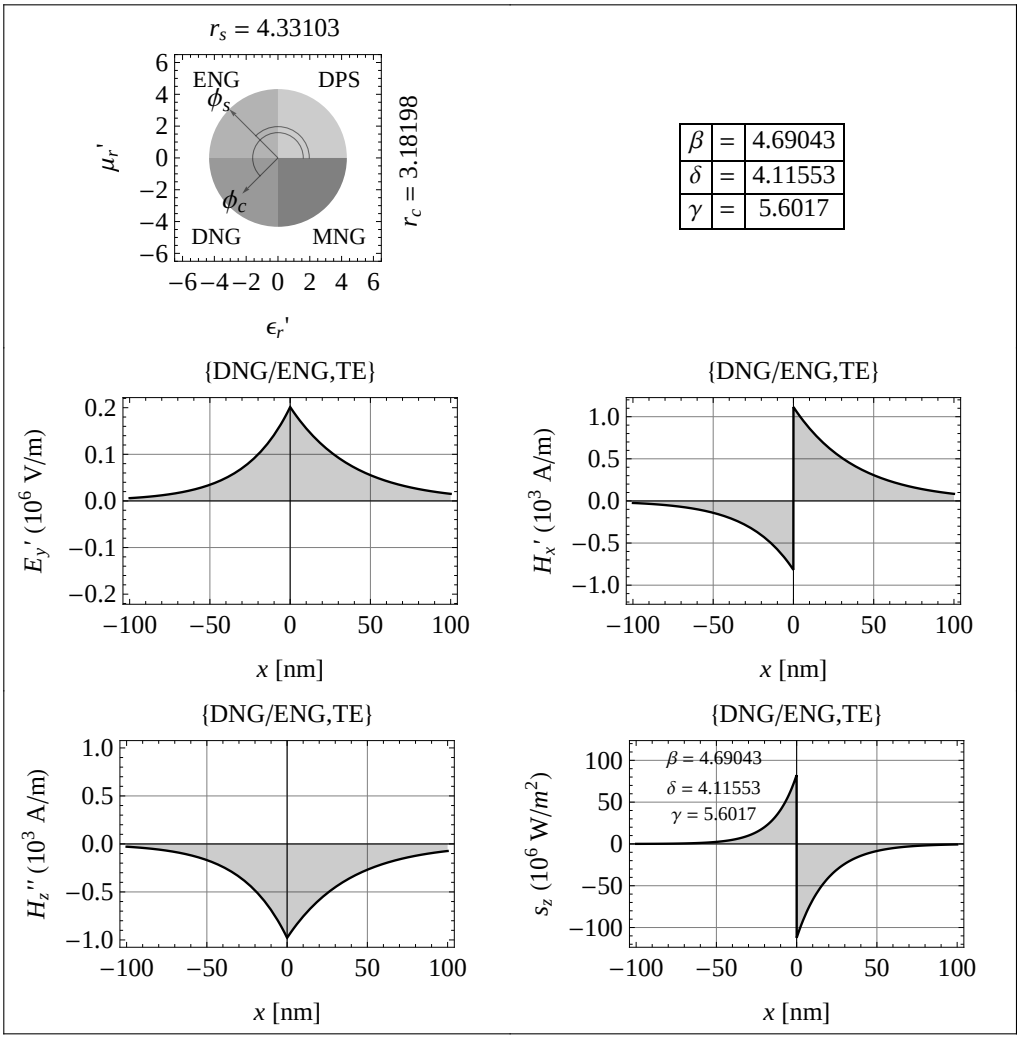

Fig. 4.7. The complete solution of the TE mode belonging to the DNG/ENG-type structure: (top left) the presentation of the structure in an ϵ_r'-μ_r' parameter space, (top right) the propagation constant, β, and the decay constants in the cover and substrate, δ and γ, (center left) E_y', (center right) H_x', (bottom left), H_z'', and (bottom right) s_z.

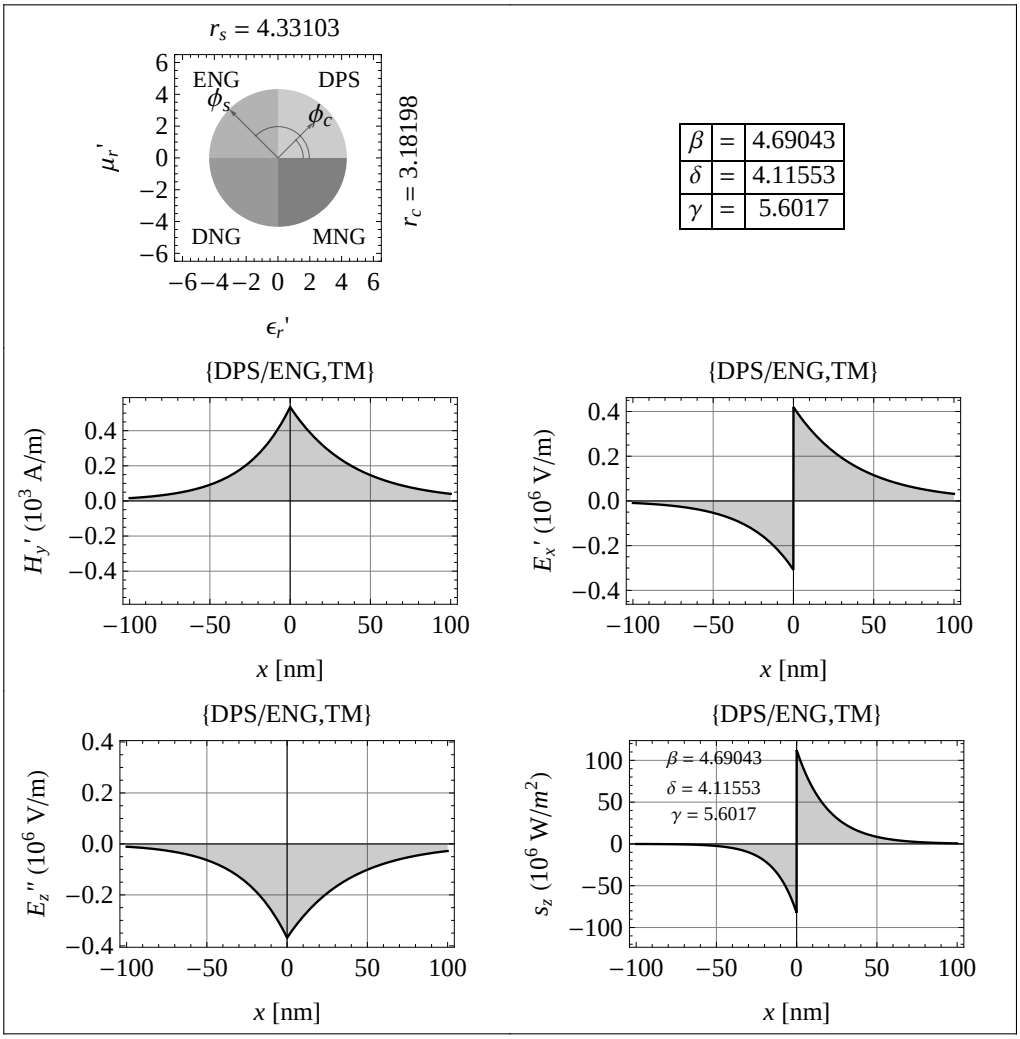

Fig. 4.8. The complete solution of the TM mode belonging to the DPS/ENG-type structure: (top left) the presentation of the structure in an ϵ_r'-μ_r' parameter space, (top right) the propagation constant, β, and the decay constants in the cover and substrate, δ and γ, (center left) H_y', (center right) E_x', (bottom left) E_z'', and (bottom right) s_z.

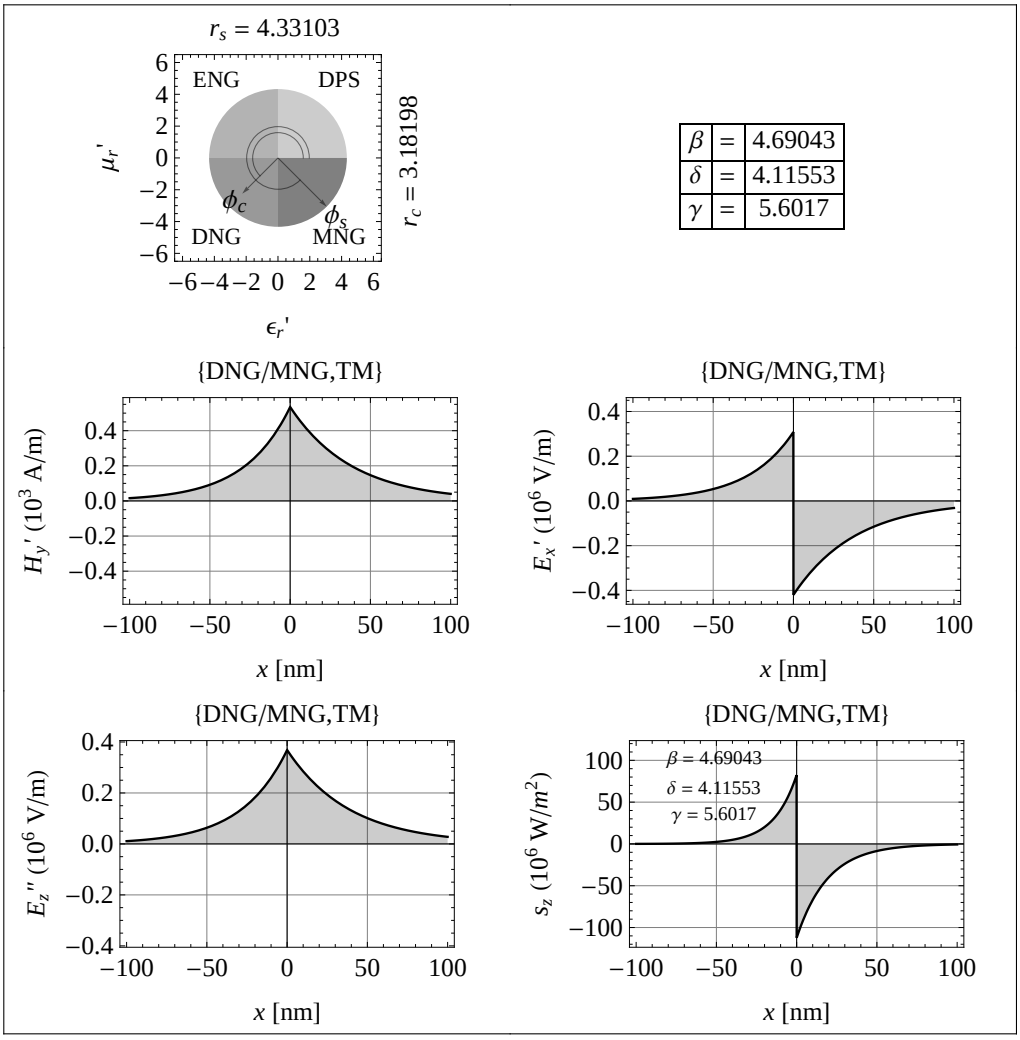

Fig. 4.9. The complete solution of the TM mode belonging to the DNG/MNG-type structure: (top left) the presentation of the structure in an ϵ_r'-μ_r' parameter space, (top right) the propagation constant, β, and the decay constants in the cover and substrate, δ and γ, (center left) H_y', (center right) E_x', (bottom left) E_z'', and (bottom right) s_z.

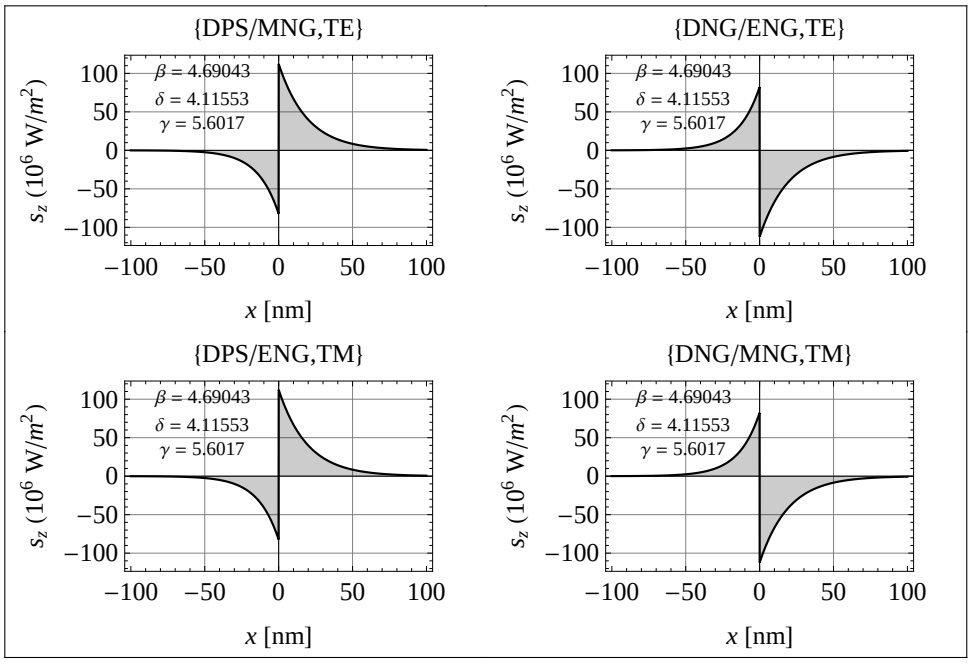

Fig. 4.10. Comparison of the local power flow, s_z, in the substrate ($x < 0$) and cover ($x > 0$) for the (top left) DPS/MNG-type, (top right) DNG/ENG-type, (bottom left) DPS/ENG-type and (bottom right) DNG/MNG-type. Here, the two figures at the top and at the bottom belong to the TE and TM modes, respectively. Note that in each case s_z in the cover and substrate point in the opposite direction.

Exercises

(1) Table 4.1 includes only a partial list of the topics included in Table 2.2. Try addressing all the rest of the topics using the model metamaterial of this chapter.

(2) Discuss the meaning of electric and magnetic charge density waves in the DPS/MNG-, DNG/ENG-, DPS/ENG and DNG/MNG-type structures in the context of a metamaterial.

References

[1] I. V. Shadrivov, A. A. Sukhorukov and Y. S. Kivshar. Guided modes in negative-refractive-index waveguides. *Phys. Rev. E* 67 (2003) 057602.

[2] M. J. Adams. *An Introduction to Optical Waveguides* (Wiley Interscience, 1981).