Supporting Information

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Convergence, numerical error, and conservation of energy

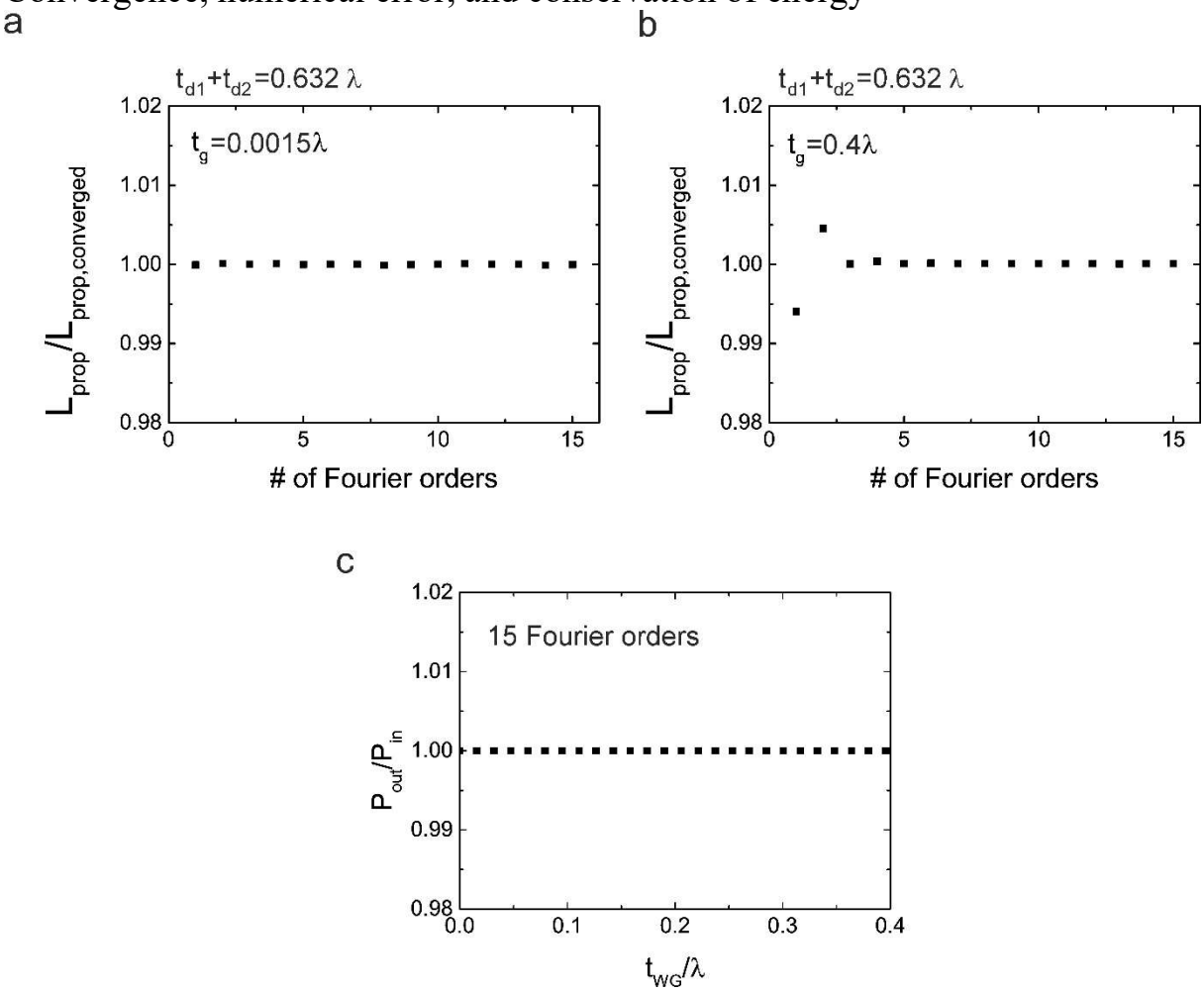

Figure S1. (**a,b**) The convergence of L_{prop} as a function of the number of Fourier orders at the smallest ($t_g = 1.5 \cdot 10^{-3}\ \lambda$) and thickest grating layer thicknesses $t_g = 0.4 \cdot 10^{-4}\ \lambda$; (**c**) energy conservation for various grating thicknesses at 15 Fourier orders. For all values, the energy is conserved, confirming the stability of the simulation.

Figure S1a,b show the convergence of the calculated propagation lengths as a function of the number of Fourier orders. A value of 1 means that the 0, 1, and -1 orders are taken into account. At the thinnest values of $t_g = 1.5 \cdot 10^{-3}\ \lambda$ (Figure S1a), we found that the calculated values immediately converge. This is a common characteristic of RCWA simulations. The relative numerical error on the largest values of L_{prop}/λ was found to be in the order of 10^{-3}. At

otherwise fixed parameters and for significantly thinner thicknesses than considered in this study (below an atomic layer thickness in the visible range), this relative numerical error increases and makes the simulation numerically unstable (relative error above 0.1) below an estimated value of $t_g = 0.8 \cdot 10^{-5}\ \lambda$.

On the other hand, the thickest considered grating layer $t_g = 0.4\ \lambda$ provides larger optical distances and, therefore, requires more Fourier orders to converge (Figure S1b). Here, we found convergence with a relative error below 10^{-3} above 5 Fourier orders. This fast convergence is common for RCWA calculations with TE polarization. To securely exclude any instabilities in the simulation, we used 15 Fourier orders.

As an additional stability check, we calculated the ratio of the outgoing power with respect to the incoming power P_{out}/P_{in}. As the proposed geometry is loss-free, a value of 1 indicates energy conservation, as can be seen in Figure 1c for various values of t_g/λ using 15 Fourier orders.

Impact of an asymmetric grating profile

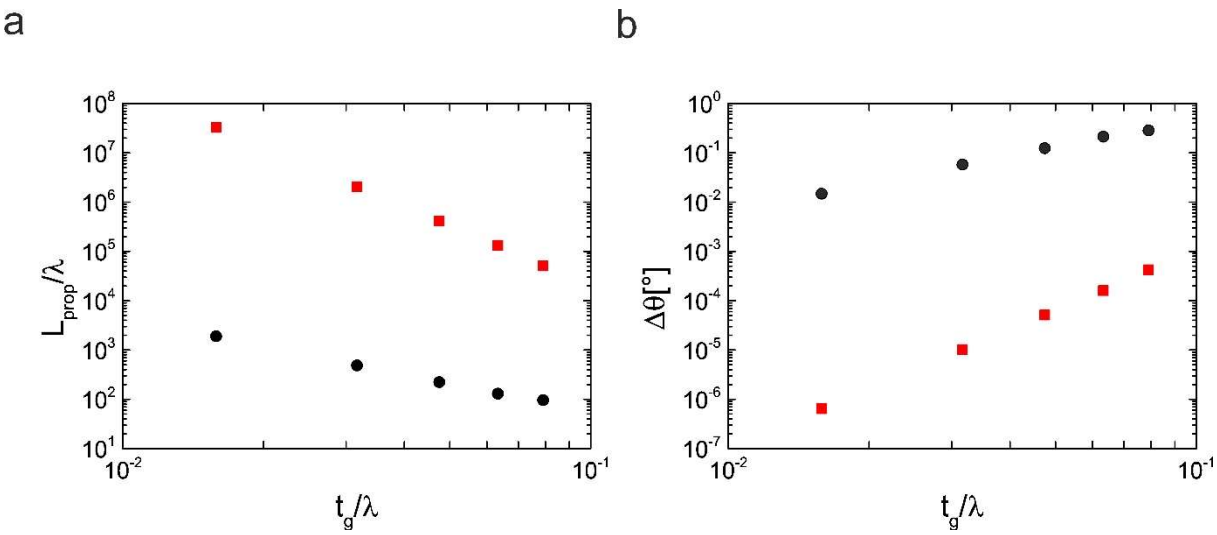

Figure S2. (**a,b**) L_{prop}/λ and $\Delta\theta$ as a function of t_g/λ for a waveguide grating with a blaze grating geometry and otherwise identical parameters as in Figure 3. The black and red dots indicate the TE_0 and TE_1 modes for $\chi_{gp} = 1.0$, respectively.

To show that the concept at hand is not strictly limited to perfectly symmetric gratings, we simulated the characteristics of L_{prop}/λ and $\Delta\theta$ as functions of t_g/λ using a blazed grating as defined in Figure S2. Similarly to the results in Figure 4, the TE_1 mode shows significantly larger values of L_{prop}/λ in comparison to the TE_0 mode.

Lossy grating geometry

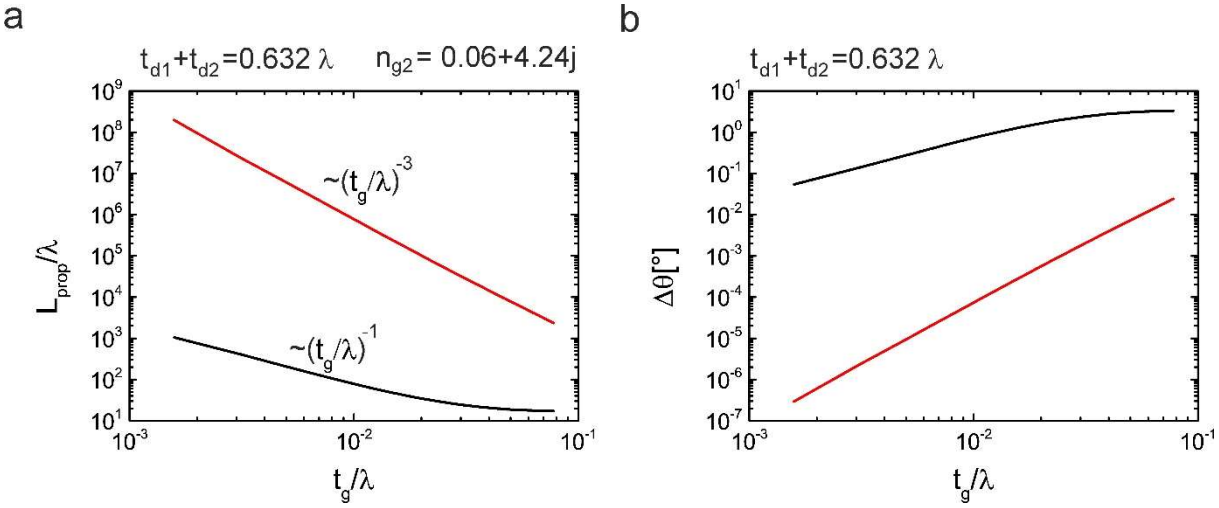

Figure S3. (**a,b**) L_{prop}/λ and $\Delta\theta$ as functions of t_g/λ for a waveguide grating with a lossy grating ($n_{g1} = n_{d1}$ and $n_{g2} = 0.06 + 4.24j$) and otherwise identical parameters as in Figure 3. The black and red lines indicate the TE_0 and TE_1 modes for $\chi_{gp} = 1.0$, respectively.

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To provide evidence for the claimed proportionalities of $\frac{L_{prop}}{\lambda} \propto t_g^{-3}$ (TE_1 mode) and $\frac{L_{prop}}{\lambda} \propto t_g^{-1}$ in the presence of loss (e.g., metals), we simulated a waveguide grating containing a grating with $n_{g1} = n_{d1}$ and $n_{g2} = 0.06 + 4.24j$. Both proposed proportionalities can be observed in Figure S3a. They occur as a result of dominant Ohmic losses in comparison to radiative losses.

Effect of period changes on the TE_1 mode at $\chi_{gp} = 1.0$

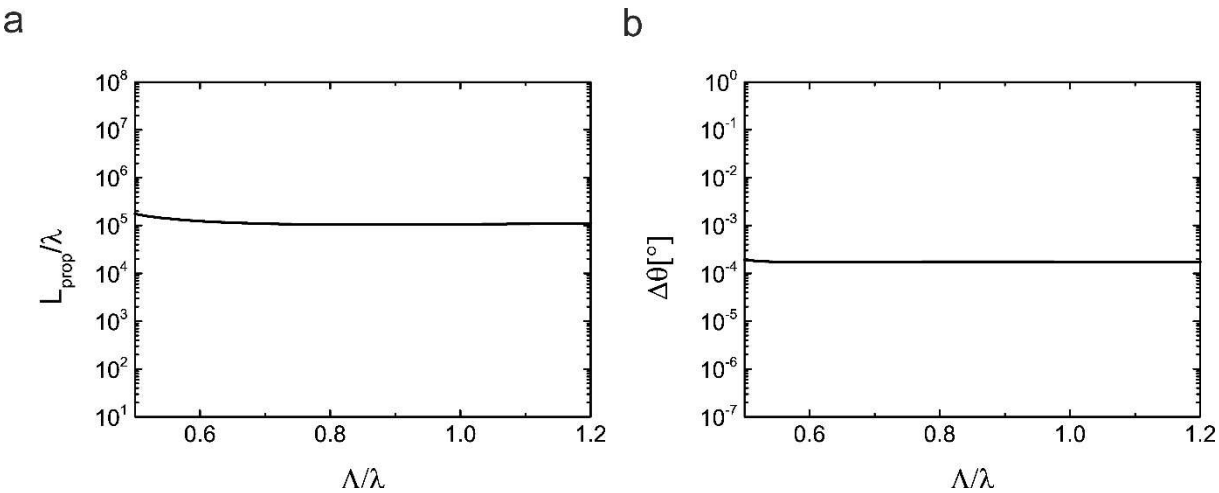

Figure S4. (**a,b**) L_{prop}/λ and $\Delta\theta$ as a function of Λ/λ for a waveguide grating with otherwise identical parameters to the geometry in Figure 3 for $\chi_{gp} = 1.0$.

To estimate the effect of period variations on L_{prop}/λ and $\Delta\theta$, we simulated their values as functions of Λ/λ. We observed that a change in the period has almost no effect on both quantities as long as diffraction into free-space is possible with respect to the momentum of the diffracted waves.