Design of Unidirectional Non-Hermitian Structure in the Near-Infrared Region

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The imaginary part of the refractive index of materials used in optical elements has traditionally been regarded as a factor that attenuates electromagnetic waves. However, recent studies have reported non-Hermitian control, which manipulates unique physical phenomena by appropriately utilizing the imaginary part of the refractive index. For example, previous research has demonstrated unidirectional light propagation in the visible region using multilayer structures composed of low-loss and lossy materials [1].

If unidirectional propagation can be realized in the near-infrared region included in sunlight, it could lead to the development of functional smart windows that block external infrared radiation while allowing internal infrared emission to pass through. However, unidirectional control based on non-Hermitian physics in the infrared region has not been reported to date.

Therefore, in this study, we designed and evaluated multilayer structures composed of materials exhibiting low and high loss characteristics to demonstrate unidirectionality based on non-Hermitian control in the near-infrared region, where solar irradiance is high.

In this study, graphite (C) and calcium fluoride (CaF_2) were selected as high- and low-loss materials with a large imaginary part of the refractive index in the infrared region. A multilayer structure was designed using the transfer matrix method to exhibit unidirectional absorption at a wavelength of 2 µm. The absorption spectra under forward and backward incidence for the designed structure are shown in Fig. 1(b). In the wavelength range of 1–3 µm, forward incidence yielded an absorption rate exceeding 90%, whereas backward incidence resulted in absorption below 60%, confirming that the designed structure exhibits unidirectional absorption in the near-infrared region.

To verify that this unidirectionality originates from non-Hermiticity, we calculated the wavelength-dependent generalized power spectrum $S_n\ (= T + \sqrt{R_f R_b})$ and its spectral derivative $dS_n/d\lambda$ (Fig. 1(c)). Around the exceptional point, exhibited a minimum and variation in the total power, while showed phase transitions. These results confirm that the observed unidirectionality arises from non-Hermitian effects.

Furthermore, Fig. 1(d) shows the magnetic field distributions at 2 µm. Under forward incidence, strong absorption was observed within the multilayer structure, indicating efficient field confinement and dissipation. In contrast, backward incidence resulted in interference within the structure, leading to partial reflection. Based on these findings, we conclude that by combining low- and high-loss materials with appropriate imaginary refractive index components, we successfully designed a multilayer structure exhibiting unidirectional behavior in the near-infrared region based on non-Hermitian control.

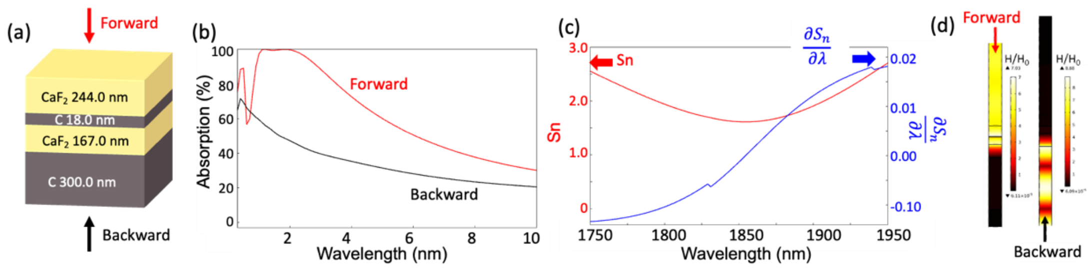

Figure 1(a) Schematic of unidirectional multilayer structure. (b) Calculated absorption spectra of the unidirectional structure under forward (red) and backward (black) light incidence. (c) Comparison between the generalized total power Sn (red) and its partial derivative spectrum (blue). (d) Magnetic field distributions calculated at a wavelength of 2 µm under forward and backward light incidence.

References

1. L. Feng, et al., Opt. Express, 22, 1760-1767 (2014).