Leaky-mode Resonance Properties of Periodic Lattices and Their Applications

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Subwavelength periodic photonic crystal slabs and waveguide gratings exhibit strong resonance effects. For periodic elements with weak dielectric-constant contrast, strong surface-localized fields with high Q-factors are found. As the modulation amplitude increases, the Q-factor falls and the resonant spectra broaden. These guided-mode resonance effects arise when an incident electromagnetic wave is coupled by a second-order grating to a leaky waveguide mode supported by the thin-film system. Such resonance effects can be applied to implement new photonic devices. For example, optical reflection (bandstop) filters with narrow spectral linewidths can be realized since the coupling of the external wave into the leaky, reradiated mode occurs over narrow parametric ranges. Resonant bandstop optical filters with high efficiencies (~98%) and narrow lines (~1 nm) have been experimentally verified in the near-IR spectral region. New resonant biosensors can be developed based on these concepts.

This paper provides analytical, numerical, and experimental results elucidating the nature of resonant leaky modes associated with periodic refractive-index lattices. It is shown by numerous simulations that single-layer subwavelength periodic leaky-mode waveguide films with binary profiles can be applied to fashion optical elements that provide a remarkably broad variety of spectral characteristics. These sparse elements even with one-dimensional periodicity can function as new types of narrow-line bandpass filters, polarized wideband reflectors, polarizers, polarization-independent elements, and as wideband antireflectors. The work presented addresses fundamental phenomena essential for development of subwavelength leaky-mode resonant device technologies. The associated physical properties are explained in terms of the photonic band structure and its relation to the structural symmetry of the elements. The interaction dynamics of the leaky modes at resonance contribute to sculpting the diverse spectral bands observed by numerical simulations. The leaky-mode spectral placement, their spectral density, and their levels of interaction are shown to be fundamentally important in understanding device operation. These results demonstrate potentially new dimensions in optical device design and may provide complementary capability with thin-film optics.

In addition to applications in the photonic band, it is of interest to consider applicability of guided-mode resonance effects in lower frequency spectral regions. For example, devices operating in the THz region are potential candidates. Thus, computed results are presented to illustrate key properties of resonant THz elements such as spectral profiles and resonance efficiencies with respect to the structural parameters defining the device.