Properties of Photonic and Plasmonic Resonance Devices

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Outline

• Introduction
• Guided-mode resonance bandpass filters.
• Broadband omnidirectional Si grating absorbers.
• Transmission resonances in metallic nanoslit arrays.
• Gain-assisted ultrahigh-Q SPR in metallic nanocavity arrays.
• Conclusion
Photonic Resonances in Periodic Thin Films

Thin-film interference

Guided mode by TIR

Guided-mode resonance

- Highly controllable with the pattern’s geometry.
- Spectral engineering by blending of multiple guided modes.
Guided-Mode Resonances in Dielectric and Semiconductor Thin-Film Gratings

Low index-contrast gratings

- High-Q, narrow band resonances.
- Primarily reflection peaks.
- Optical notch filters, biosensors, and so on.


High index-contrast gratings

- Both broadband + narrow-band effects.
- Versatile spectral engineering.
- Lossless mirrors/polarizers, flat microlenses, bandpass filters, broadband resonant absorbers, and so on.

[Ding and Magnusson, Opt. Express 12, 5661 (2004)]
Bandpass Filters: Theoretical

**Conventional multilayer**

**Single-layer GMR structure**

**Major advantages**
- Simple fab. processes (involves less fabrication errors).
- Stop-bands and pass-line are determined by geometry of the surface texture.
Bandpass Filters: Experimental

Performance Parameters

- Pass-line (peak): 0.4 nm FWHM, 83% efficiency.
- Stop-band: < 1% over 100 nm bandwidth.
- Angular tunability = 6 nm/deg.
Broadband Omnidirectional Absorbers: Theoretical

Planar absorber

\[ \alpha - Si:H \]

\[ SiO_2 \]

GMR absorber

15.5% fill factor

\[ \Lambda = 419 \text{ nm} \]

\[ 340 \text{ nm} \]

\[ 2000 \text{ nm} \]

\[ 30 \text{ nm} \]
Broadband Omnidirectional Absorbers: Theoretical

Resonant Light Trapping

(a) TM, \( \phi = 0^\circ \)

(b) TE, \( \phi = 0^\circ \)

Anti-Reflection Effect

unpatterned surface \( R_0 \)

patterned surface \( R_1 \)

(a) TM \( 120^\circ \)

(b) TM \( 120^\circ \)

(c) TE \( 120^\circ \)

(d) TE \( 120^\circ \)
Broadband Omnidirectional Absorbers: Experiment
Surface Plasmon Resonances in Metallic Nanostructures

• Collective oscillation of surface free electrons.

• Deep subwavelength confinement:
  - Metallic metamaterials.
  - Optical communication with nanoscopic objects.
  - Quantum optical effects.

• Highly lossy due to ohmic damping.

• Primarily absorption and transmission resonances. (↔ Photonic resonances)
Extraordinary Optical Transmission

Extraordinary Optical Transmission


“Negative role of surface plasmons in the transmission of metallic gratings with very narrow slits”

Destructively interfere

Fabry-Perot resonance of slit guided mode

\[ k_0 \text{Re}(n_{\text{eff}})h - \text{arg}(r_{12}) = m\pi \]

SPP resonance condition

\[ \lambda_{SP} = \frac{\Lambda}{m} \left[ \text{Re}\left\{\frac{\varepsilon_2}{1 + \varepsilon_2}\right\}^{1/2} \right] \pm \sin(\theta) \]
Surface and Cavity Plasmonic Resonances in Metallic Nanoslit Arrays

Analytic Theory RCWA

$T_a$, Lossless ($\epsilon_M'' = 0$)

$T_b$, Lossy ($\epsilon_M'' = 0.01$)

$\lambda (\Lambda)$

$T (\text{RCWA})$

$T (\text{Analytic Theory})$

$q = 1, 2, 3, 4, 5$

$d (\Lambda)$

$\rho_D + \rho_{sp} = \rho_{in}$

$\eta_{in}$

$\eta_{ex}$

$\tau = \tau_{sp} + \tau_D$

$\text{CM}$

$\text{SPP}$

$\text{Metal}$

$\text{Slit}$

$\text{Metal}$

$\text{To External Plane Wave}$
Toward Ultrahigh-Q Metallic Nanocavity Resonances

- $|\rho_\text{in}|^2$
- $|\tau|^2$

- $k = 0$
- $k = -2.26 \times 10^{-3}$

- $\lambda_{AR}$

- $|E_z/E_0|^2$

- $T$

- $T$

- $q = 5$
- $q = 4$
- $q = 2$
- $q = 3$ (missing)

- with optical gain in the dielectric host
Conclusion

• Demonstrated optical bandpass filters and broadband absorbers based on high-index contrast subwavelength waveguide gratings.
• Explained complex resonance effects in metallic nanoslit arrays with a simple model of an optical cavity with Fano-resonant reflection boundaries.
• The theory predicts efficient room-T ultrahigh-Q plasmonic nanocavity resonances with the externally amplified intracavity feedback mechanism.
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Publications with these works: