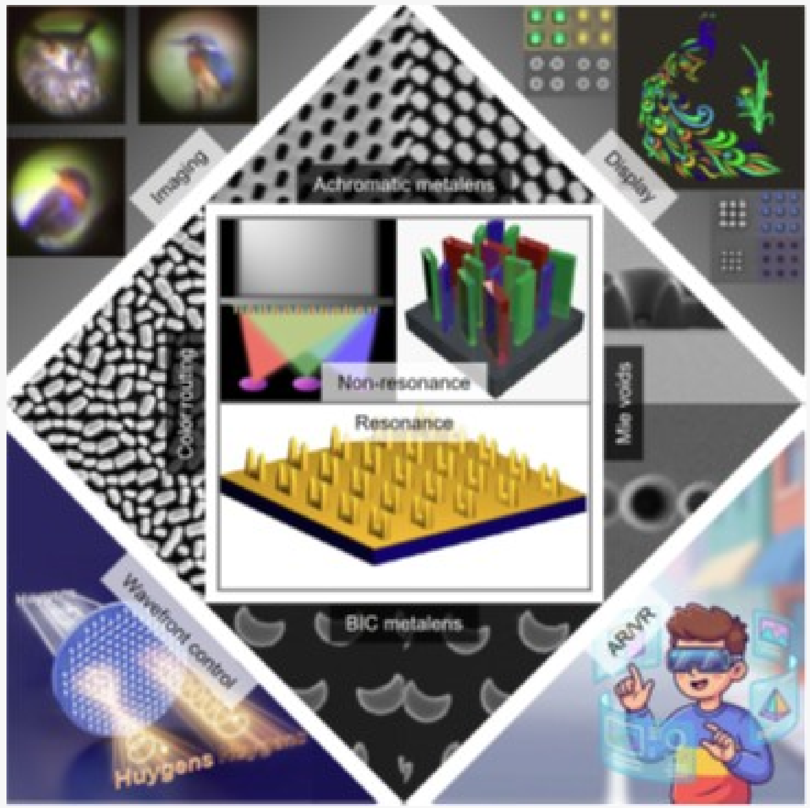
From 'Non-Resonance' to 'Resonance': How Meta-Devices Reshape Imaging and Display?

A comprehensive review of non-resonant and resonant metasurfaces for advanced imaging, color routing, and AR/VR displays

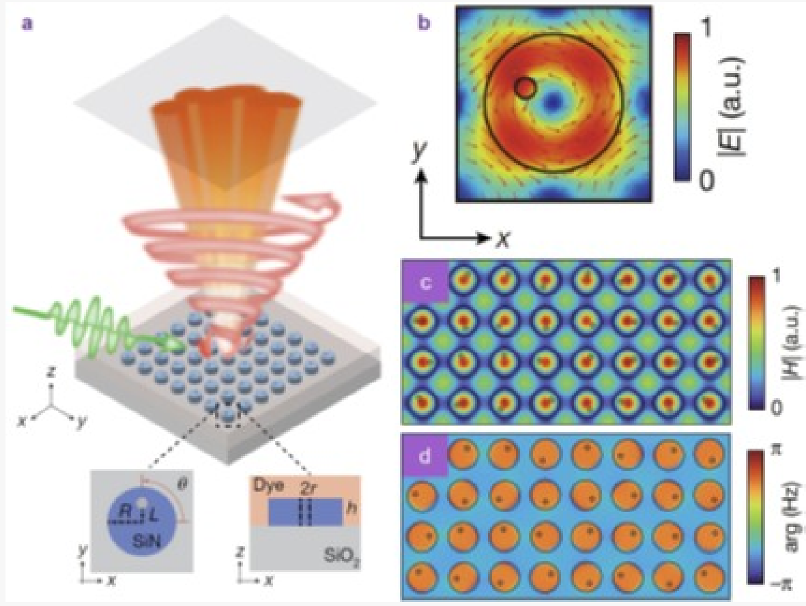


Overview of the hierarchical framework of non-resonant and resonant meta-devices, illustrating representative metasurface structures and their applications in achromatic metalenses, wavefront control, color routing, resonant imaging, structural color disp

CHENGDU, CHINA, July 31, 2026 /EINPresswire.com/ -- This review systematically bridges non-resonant and resonant metasurfaces, highlighting their complementary roles in shaping next-generation photonic devices. It covers physical mechanisms, key structures, and transformative applications in imaging, color routing, and displays. The fusion of both paradigms promises multifunctional, chip‑integrated meta‑devices.

Metasurfaces, composed of subwavelength artificial structures, have revolutionized optical imaging and display over the past decade. Traditional non‑resonant meta‑devices rely on geometric and propagation phases, enabling efficient, broadband, and achromatic functionalities, such as achromatic metalenses and full‑color structural color displays. However, they lack spectral selectivity, limiting their ability to meet the growing demand for multifunctional, high‑purity light-field control.

In recent years, resonant mechanisms—including bound states in the continuum (BIC) and local–nonlocal transitions (LNT)—have introduced a new paradigm. These resonant devices achieve ultra‑narrowband wavefront shaping, spectral decoupling multiplexing, and pixel‑level color routing while dramatically enhancing light–matter interaction. This review systematically charts the evolution from non-resonant to resonant meta-devices, showcasing their transformative potential in imaging, color routing, displays, and AR/VR systems. The integration of both mechanisms points toward a future of hybrid meta-optics with unprecedented versatility and performance.



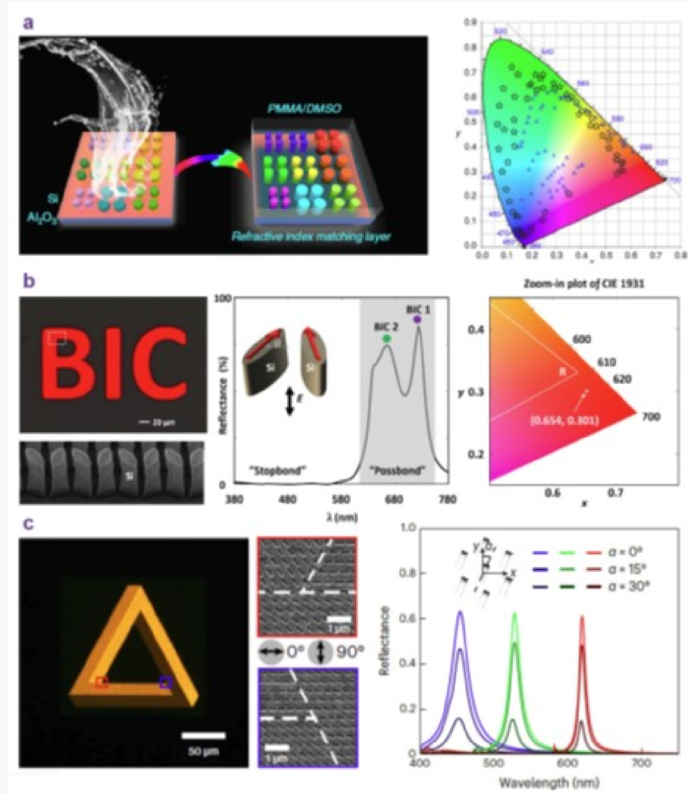
Schematic of a resonant metasurface-based meta-laser generating arbitrary wavefronts, with simulated electric and magnetic field distributions and a phase profile demonstrating localized–nonlocalized transition (LNT)-enabled quasi-bound states in the cont

Professor Din Ping Tsai's group at City University of Hong Kong was invited to publish a review in Opto-Electronic Science entitled "From non-resonance to resonant meta-devices: imaging, color routing, displaying, and beyond". The review was made available online on June 28, 2026. The article systematically summarizes the physical principles, typical structures, and application scenarios of non-resonant and resonant metasurfaces, and proposes that their fusion represents the future direction of next-generation multifunctional photonic devices.

The review first presents a hierarchical framework (Fig. 1) that maps the complete landscape from non-resonant to resonant meta-devices, organized into three layers: principles, structures, and applications. Non-resonant mechanisms (geometric phase, propagation phase, group delay, band engineering) are compared with resonant ones (LSPR, SLR, Mie resonance, BIC, LNT), linked to typical structures (achromatic metalens, color-routing metasurface, Mie cavities, resonant metalens), and their broad applications in imaging, displays, wavefront shaping, and AR/VR.

In resonant wavefront control and imaging, the review covers breakthroughs including multilayer nonlocal metasurfaces for multifunctional resonant wavefront shaping, nonlocal Huygens metalenses with Q-factors up to 10^4 via the generalized Kerker effect, and spin-multiplexed devices enabling simultaneous bright-field and edge-enhanced imaging. Quasi-BIC metasurfaces are also applied to terahertz single-pulse imaging, near-field sensing, and simultaneous spectral-polarization detection in the visible-to-near-infrared range. A representative highlight is the recently reported metalaser (Fig. 2), which uses LNT to excite quasi-BIC resonances, combining a high Q-factor (~3,700) with geometric phase control to directly emit narrowband laser beams with arbitrary wavefronts—such as focused spots, vortex beams, and speckle-free holograms—without external shaping optics. This work demonstrates the great potential of resonant mechanisms for integrated, programmable light sources.

In resonant structural color displays, the review summarizes advanced technical routes. For example, introducing a refractive-index-matching layer significantly narrows the resonance linewidth of high-contrast all-dielectric metasurfaces, achieving wide-gamut, high-saturation structural colors. Silicon nanoantennas based on quasi-BIC successfully solve the “Schrödinger’s red” problem by suppressing higher-order multipole resonances to obtain pure, bright red pixels. Furthermore, pixelated plasmonic metasurfaces with shallow nanocavities allow independent tuning of hue, saturation, and brightness, enabling lithographic-grade full-color nano-paintings with polarization-encrypted hidden information. Fig. 3 showcases representative results: (a) significant enhancement of color purity in silicon arrays via a refractive-index-matching layer; (b) quasi-BIC-driven “Schrödinger’s red” pixels and their reflection spectra; (c) full-color reproduction of famous paintings using plasmonic metasurfaces. These works collectively indicate that resonant mechanisms are driving structural color displays toward higher resolution, wider color gamut, and higher dimensional information capacity.



Representative resonant structural color approaches, including refractive-index matching for high-saturation structural colors, quasi-BIC silicon nanoantennas producing pure “Schrödinger’s red” pixels, and plasmonic metasurfaces enabling lithographic-grad

This review makes clear that non-resonant and resonant meta-devices are not substitutes but complementary. Future hybrid devices, merging broadband achromatic capability with high-Q spectral selectivity, combined with dynamic tunable materials and deep-learning inverse design, will unleash great potential in AR/VR, LiDAR, quantum photonics, and biosensing. Current challenges remain in large-area high-precision fabrication, modeling complex nonlocal effects, and CMOS-compatible integration.

Reference

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About Professor Din Ping Tsai from City University of Hong Kong
Professor Din Ping Tsai is the Chair Professor in the Department of Electrical Engineering at City University of Hong Kong. His research focuses on nanophotonics and optical physics. He has published about 400 papers in leading journals, including Science, Nature Nanotechnology, Nature Photonics, Physical Review Letters, Advanced Materials, and Nature Communications. He is a Fellow of multiple international societies, including COS, AAAS, APS, IEEE, Optica, SPIE, EMA, JSAP, and AAIA, and an Academician of APAM, IAE, and NAI. His honors include the SPIE Mozi Award and Clarivate Highly Cited Researcher recognition.

Siyi Ma
Institute of Optics and Electronics, Chinese Academy of Scie
+86 19136186296
oej_publishing@ioe.ac.cn
