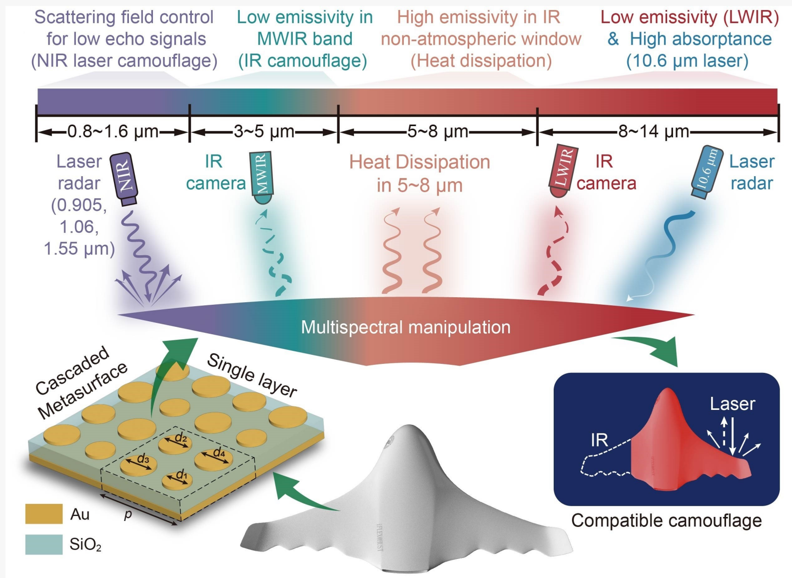
Single-Layer Ultrathin Metasurface Enables Multispectral Laser-Infrared Camouflage & High-Efficiency Thermal Management

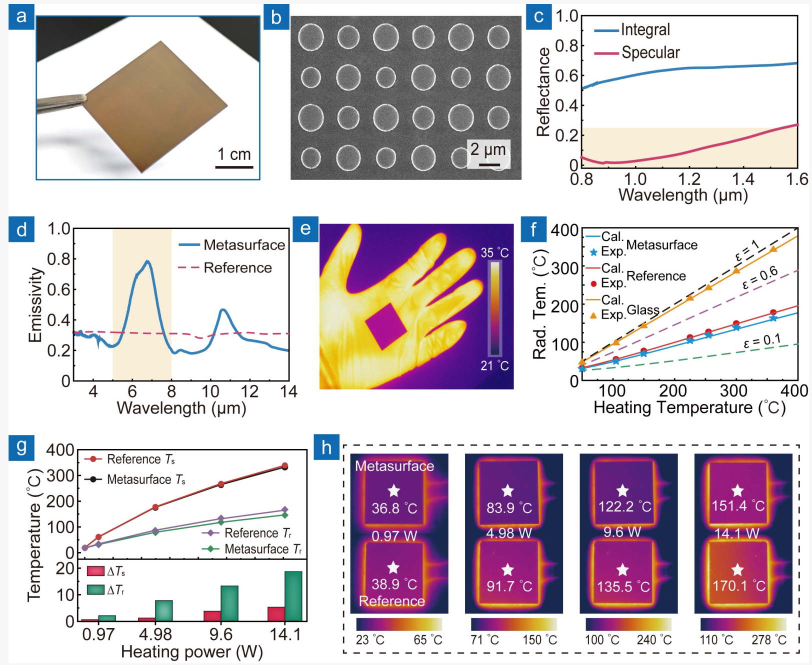
The proposed metasurface may trigger further innovation in the design and application of compact multispectral optical devices.



Implementation strategies for multispectral-compatible camouflage and schematic illustration of the metasurface.

CHENGDU, SICHUAN, CHINA, May 30, 2025 /EINPresswire.com/ -- The core of multispectral compatible camouflage technology lies in multispectral modulation, which requires the design of spectral characteristics based on the operational bands and principles of detectors. The intrinsic properties of natural materials depend on the inherent attributes of their microscopic components (e.g., molecules, atoms) and their arrangement, limiting their ability to modulate electromagnetic fields and making arbitrary tuning according to practical needs difficult. As a two-dimensional form of metamaterials, metasurfaces overcome the optical limitations of natural materials by designing artificial unit structures at a microscopic scale with periodicities between microscopic particles and operational wavelengths, enabling the modulation of macroscopic physical properties. Leveraging the metasurface's ability to flexibly control the amplitude and phase of electromagnetic waves, subwavelength structures can be designed on demand across different bands, providing critical support for the development of multispectral-compatible camouflage technologies. Ideal photoelectric camouflage materials must maintain compatibility with various detectors across the full spectrum while ensuring structural simplicity and ultrathin characteristics to reduce fabrication complexity and enhance practicality. However, a challenging contradiction exists between multifunctional multispectral integration and structural simplicity: whether in one-dimensional photonic crystals or metasurfaces, increasing the number of tunable bands often relies on multilayer stacking or complex configurations, significantly escalating design and fabrication difficulties.

Addressing the aforementioned challenges, a collaborative research team from the Hangzhou Institute of Technology (Xidian University) and Huazhong University of Science and Technology propose a single-layer metasurface design integrating cross-band modulation, multispectral camouflage, and broadband heat dissipation. This ultrathin metasurface can simultaneously achieves compatible modulation of near-infrared (NIR), mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) electromagnetic waves, providing a solution to decouple the contradiction between functional complexity and structural simplicity in multispectral camouflage materials.



Fabrication and characterization results of the metasurface.

The work, titled "Single-layer, cascaded and broadband-heat-dissipation metasurface for multi-wavelength lasers and infrared camouflage," is published in Opto-Electronic Advances (OEA) in early view section.

The research team introduced phase modulation into the traditional metal-dielectric-metal configuration of infrared camouflage materials, enabling coverage of additional camouflage bands without increasing structural complexity. The metasurface consists of horizontally cascaded resonant units of varying sizes, positioned above a middle silica dielectric layer and a bottom metal reflective layer. Figure 1 illustrates the proposed metasurface and its spectral modulation strategies across different bands: First, for incident near-infrared electromagnetic waves, the metasurface controls the phase of emitted waves by adjusting the thickness of the dielectric layer, constructing destructive interference in the reflected field to redirect energy toward non-specular directions, thereby suppressing LiDAR echo signals. Second, by precisely designing the dimensions of four resonant units, the metasurface achieves broadband high emissivity in non-atmospheric windows while maintaining low emissivity in thermal imaging windows through amplitude modulation. Finally, leveraging the unique abrupt change in the imaginary part of the refractive index of silica around the 10.6 μm wavelength, the metasurface enables narrowband absorption of 10.6 μm electromagnetic waves via non-local plasmonic resonance. Based on these strategies, this single-layer metasurface simultaneously modulates near-infrared, mid-infrared, and far-infrared electromagnetic waves, achieving multi-wavelength laser-infrared compatible camouflage and high-performance broadband thermal management.

Shan Jiang, an Associate Professor at Xidian University, Xi’an, China. His research focuses on metamaterials, metasurfaces, and flexible electronics. He has published over 30 papers as the first or corresponding author in prestigious international SCI journals such as Advanced Materials, ACS Nano, Advanced Science, and Innovation, including 3 ESI highly cited papers and more than 10 papers in the top-tier journals (Chinese Academy of Sciences, Q1). Additionally, he has authored an English monograph. He has led and participated in projects funded by the National Natural Science Foundation of China (NSFC), the National Key R&D Program, and JKW projects. He serves as a review expert for NSFC in the field of mechanical engineering, the Executive Associate Editor of Biomaterials and Biosensors, and an editorial board member of Cancer Insights. He is also a young editorial board member for journals such as Research, Rare Metals, Soft Science, and FlexMat, as well as a guest editor for SCI journals including Rare Metals and iScience.

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