MATERIALS SCIENCE



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Iridescence-controlled and flexibly tunable retroreflective structural color film for smart displays

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Structural coloration is the production of colour by microscopically structured surfaces fine enough to interfere with visible light, sometimes in combination with pigments.

Iridescence (also known as goniochromism) is the phenomenon of certain surfaces that appear to gradually change color as the angle of view or the angle of illumination changes.

A **retroreflector** (sometimes called a retroflector or cataphote) is a surface that reflects radiation (light, usually) back to its source with a minimum of scattering. In a retroreflector the wavefront of the radiation is reflected straight back to the wave's source.





Introduction:

- Structural color materials rely on optimized structural designs instead of pigments or dyes to generate colors that stand out from the surrounding visual environment.
- They have attracted considerable scientific and industrial interest because of their unique ability to manipulate the flow of light, a number of striking optical effects, as well as a wide range of prospective applications in sensors, displays, optical or optoelectronic devices, coatings, and security labels.
- In recent years, although brilliantly diffuse structural colors have received increasing attention and can be achieved by mimicking the hierarchical periodic structures in Morpho butterflies and tarantulas the fabrication of such complex multilayer structures is generally time-consuming and costly to scale up for practical applications.
- Retroreflection is a specific type of reflection in which the incident light is reflected back toward the light source.
- In current retroreflective materials, glass bead-type or corner cube-type retroreflectors are widely used to provide a retroreflective function, and their coloration is achieved through an undercoating layer containing pigments or dyes.
- Incorporation of iridescent or non-iridescent structural coloration into retroreflector elements is an exciting prospect.
- Unfortunately, neither natural nor artificial materials that can efficiently produce retroreflective structural colors were reported.

In this paper:

- Report a retroreflective structural color film (RSCF) that can simultaneously display iridescent and non-iridescent vivid structural colors to observers at different viewing directions relative to the illumination direction, making it especially useful for smart traffic safety and advertisement display applications at night.
- In our approach, by partially embedding a monolayer array of polymer microspheres in the sticky polyacrylate layer of a transparent tape, a thin-film interference structure can be spontaneously formed at the microsphere/ polyacrylate interface due to interfacial debonding.
- The interferometric effect together with total internal reflection (TIR) that occurs respectively on the embedded and unembedded sections of the microsphere surface can lead to the structural coloration of retroreflected light.
- Moreover, because of the spherical symmetry of the microsphere, iridescent or noniridescent structural colors with wide viewing angles can be observed under coaxial or noncoaxial illumination and viewing conditions, respectively.
- These unprecedented optical properties allow traffic safety devices based on the proposed RSCF to serve as color-stable traffic signals for drivers and, simultaneously as color-changing indicators for pedestrians to warn them of approaching vehicles.
- RSCF-based display under fixed white-light illumination can present a flickering color signal that can be observed by moving observers, with no need for active displays.





Fig. 1. Fabrication and optical properties of the proposed RSCF. (A to D) Schematic illustration of the fabrication of an RSCF by transferring a monolayer array of PS microspheres from a substrate onto the sticky side of a transparent tape. (E) Typical cross-sectional SEM image of an RSCF assembled from 15-2 m PS microspheres, showing that the microspheres are partially embedded in the polyacrylate adhesive layer of the tape. (F) Photographs of the tape side (path I) and microsphere side (path II) of the RSCF under diffuse daylight. (G) Photographs of the tape side (path I) and microsphere side (path II) of the RSCF under diffuse daylight. (G) Photographs of the tape side (path I) and microsphere side (path II) of the RSCF under a white LED light source, showing a bright bluish green reflection color from the tape side. (H) Reflection optical micrograph of the RSCF observed from the tape side, showing a bluish green reflection circle from each microsphere. (I) Reflectance spectra measured from the tape and microsphere sides of the RSCF at normal incidence and reflection. Scale bars, 20 2m (E and H) and 1 cm (F and G).

Results and discussion:



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A) Schematic model of an interactive speed limit sign fabricated from RSCFs. (**B** to **F**) Photographs showing the flickering effect of a normally illuminated speed limit sign viewed from the side window of a moving vehicle that is passing by the sign from right to left.



Conclusion:



- Demonstrated a conceptually new type of RSCF that exploits a unique interferometric retroreflection mechanism of air-cushioned microsphere/polymer bilayer model.
- Neither synthetic nor natural structural color materials nor commercial retroreflective products reported to date have the unusual characteristics of our RSCF, i.e., a vivid color retroreflectivity, iridescent/non-iridescent color effects with wide viewing angles under different illumination and viewing conditions, and wide color tenability.
- These unprecedented optical properties and the versatile scalable fabrication method provide a straightforward solution for various large-area applications of robust and intelligent structural color films, such as smart display screens, anti-counterfeiting labels, indicators, smart coatings, and artistic decoration.
- This solution is particularly useful for enabling novel smart traffic signs that can deliver color-coded signals to drivers and pedestrians at night, and nighttime advertisement displays.



