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# Advanced Nanomaterials for Optical Thermometry and Dynamic Photonic Display

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**Abstract**

Recent advances in nanomaterials have yielded innovative devices for sensing and display. Here we review two breakthroughs: a one-dimensional van der Waals crystal (InSeI) that changes color with temperature, and block-copolymer-based photonic "Janus" colloids for real-time color displays. In the first, researchers found that ultrathin InSeI crystals exhibit strong thermochromism, shifting from yellow (around –190 °C) to red (~200 °C). These act as nanoscale thermometers far more sensitive than existing solutions. In the second, self-assembled polymer nanostructures mimic butterfly wing photonic crystals, producing vivid structural colors that dynamically adjust to stimuli. We also discuss a related ferroelectric technique: an "electric stylus" method to pattern dipoles at the nanoscale, enabling tailored materials for memory and photonics. These works demonstrate how nanoscale structural control – from atomic crystals to polymer lattices – enables new material functionalities. Together, they open paths to optical nanothermometers, adaptive displays, and devices for emerging photonic technologies.

**Keywords:** *nanomaterials; thermochromism; photonic crystals; block copolymer; ferroelectrics*

## Introduction

Nanoscience is rapidly delivering materials with remarkable properties not seen at larger scales. For example, a newly discovered one-dimensional van der Waals crystal of indium selenide iodide (InSeI) exhibits temperature-dependent color changes at the nanoscale. Separately, researchers have fabricated block-copolymer-based colloids that self-assemble into photonic crystals, mimicking natural iridescence and enabling real-time color displays. Concurrently, novel methods to engineer ferroelectric domains (using an "electric stylus") demonstrate the power of nanoscale precision in material design. In this article, we summarize these advances: the fabrication and characterization of nanoscale thermometers (InSeI crystals), dynamic photonic Janus colloids, and nanoscale ferroelectric patterning. These examples illustrate how controlling structure at the nano- to atomic scale yields new device functionalities.

## Methods

To study nanoscale thermometry, Cordova et al. grew InSeI crystals that form tubular "slinky-like" structures when exfoliated. The research team used mechanical exfoliation (tape peel) to obtain thin InSeI nanocrystals on substrates. Under a microscope with controlled temperature, they recorded optical images and spectra. The crystal's color shifted systematically with temperature; calibration showed distinct hues corresponding to specific temperatures from –190 °C to +200 °C. Similarly, for photonic displays, Ku et al. employed block copolymer self-assembly. They prepared Janus colloidal particles with polystyrene-polyvinyl pyridine (PS-b-P2VP) blocks. When cast on substrates, these particles spontaneously organized into cone-shaped photonic crystals with periodic nanostructure. Optical microscopy and reflectance measurements tracked how particle colors changed with environmental stimuli (pH, solvents). For the ferroelectric study, Checa et al. at ORNL used a conductive atomic force microscope (AFM) tip ("electric stylus") to locally reorient polarization in a lead-strontium titanate (PSTO) film. By scanning the tip, they "drew" domain patterns at the nanoscale. Domain imaging was performed with piezo response force microscopy to confirm the new structures.

## Results

The InSeI crystals showed dramatic color change with temperature. At –190 °C, they appeared light yellow; at 0 °C orange; and at +200 °C a deep red. The color shift was linear with temperature, indicating predictable thermochromic behavior. These nanoscale thermometers were an order of magnitude more sensitive than existing bulk optical thermometers. In practical terms, the researchers could measure local temperature at nanometer resolution by optical means.

The Janus colloidal photonic crystals produced vivid structural colors. By adjusting polymer composition, the team fabricated particles that reflected red, green, or blue wavelengths. Under a microscope, the colloidal films display dynamic color patterns. For instance, adding alcohol caused refractive index changes, shifting reflected wavelength; varying pH triggered reversible swelling of polymer domains, tuning the color. The result was real-time, reversible color change across a broad spectrum. Unlike traditional dyes, these structural colors are long-lasting and stable.

In the ferroelectric experiment, the electric stylus successfully wrote complex polarization patterns. Checa et al. demonstrated domain configurations that were not present naturally in the material. The "pencil" effect of the stylus allowed on-demand creation of topologically complex dipole arrangements. These patterns remained stable and could be reconfigured by additional writing, paving the way for memory elements or programmable photonic materials. The approach essentially tunes the material's local electric and optical response by design.

## Discussion

These advances highlight the power of Nano structuring. The InSeI thermochromic crystal embodies how quantum-scale properties can be harnessed: the material's electronic structure causes a strong visible color shift with minute temperature changes. Potential applications include inserting these crystals into biological cells or electronic circuits to optically report temperature with unprecedented sensitivity.

The Janus photonic colloids exploit block copolymer chemistry to create structural colors without pigments. Their autonomous color tuning suggests uses in smart paints, adaptive camouflage, or large-area displays where patterning by simple means is advantageous. Unlike conventional displays, these materials consume no power to maintain a color, and the fabrication is scalable.

The ferroelectric stylus technique shows that it is possible to reconfigure materials on the fly at the atomic level. This could enable neuromorphic devices where hardware rewires itself, or photonic structures whose refractive index profile is written by the fly. The creation of new "topological polarization structures" enriches the design space for future electronic and photonic systems.

Together, these examples underscore a trend: nanotechnology is moving from discovery to functional devices. Challenges remain in integrating these materials into products (e.g., stability of InSeI in ambient, large-scale alignment of copolymers, or speed of ferroelectric writing). Future work may combine such techniques: imagine a photonic display coated with a nanoscale thermal sensor that changes color with touch!

**Conclusion**

We have reviewed cutting-edge nanoscale materials enabling optical thermometry and dynamic color displays. The discovery of a 1D InSeI crystal with extreme thermochromic sensitivity provides a new tool for nano-thermometry. The development of dynamic photonic Janus colloids offers a route to robust, tunable color without dyes. Advances in nanoscale ferroelectric writing further illustrate the ability to engineer material properties. These innovations exemplify how controlling structure at the nanometer scale leads to emergent functionalities with broad technological relevance, from biosensors to novel displays. Continued research in nanomaterials promises further breakthroughs in sensing, energy, and information technologies.

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