Next-Gen Eco-Friendly Color-Changing Crystals: IIT Indore's Leap Towards Sustainable Innovation

Researchers at IIT Indore have made significant strides in developing environmentally friendly materials for thermochromic applications, eliminating the need for toxic lead-based compounds. Lead (Pb), a hazardous heavy metal, poses serious environmental and health risks due to its ability to contaminate soil and water. While lead-based materials have long been used in various applications, their harmful effects have led to a shift toward safer alternatives.

Perovskites, a special class of materials found both in nature and synthesized in laboratories, have gained immense research attention due to their remarkable optical and electronic properties. Scientists have successfully created a more complex version of perovskites known as halide double perovskites, which can be tailored to exhibit different characteristics based on their chemical composition. These materials are widely used in solar cells, LEDs, scintillators, and photodetectors. When subjected to external factors like pressure, temperature, or electric fields, they undergo structural and chemical changes, altering their optical and electronic behavior.

One of the most exciting properties of these materials is thermochromism- the ability to change color in response to temperature variations. This characteristic has vast applications in smart wearables, temperature indicators, medical devices, architectural designs, and even defense technology. However, most existing thermochromic materials rely on lead-based halide perovskites, which have drawbacks such as slow response times, poor stability, and environmental toxicity, making them unsuitable for widespread use.

To overcome these challenges, a research team at IIT Indore's Department of Physics, led by **Prof. Preeti A. Bhobe** along with PhD student **Bikash Ranjan Sahoo**, has successfully synthesized millimeter-sized single crystals of lead-free $Cs_2NaFeCl_6$ double perovskites. They achieved this using a cost-effective solvothermal method under controlled cooling conditions. These newly developed crystals exhibit a remarkable and reversible color change—from yellow at low temperatures (-173°C) to brown at higher temperatures (about 200°C). The stability of this transformation remains intact even after multiple heating and cooling cycles, withstanding temperatures up to 400°C. This research is financially supported by the Department of Science and Technology (DST), Government of India and benefited from the India-DESY Germany collaboration.

To understand the mechanism behind this thermochromic behavior, the researchers conducted advanced studies using temperature-dependent X-ray diffraction and X-ray absorption spectroscopy. Their findings revealed that the key factors driving this color

change include charge localization around iron atoms, structural tilting within the crystal, a decrease in the material's band gap with rising temperatures, and strong electron-phonon interactions.

Prof. Suhas Joshi, Director of IIT Indore, emphasized, "The development of lead-free thermochromic perovskites marks a major advancement in material science, as these non-toxic alternatives have the potential to revolutionize future technologies. By understanding the principles of thermochromism, researchers are paving the way for safer and more efficient materials that could impact various fields, from healthcare to climate-responsive architecture".