World's first demonstration of persistent luminescence from organic materials set to unlock new, expanded uses

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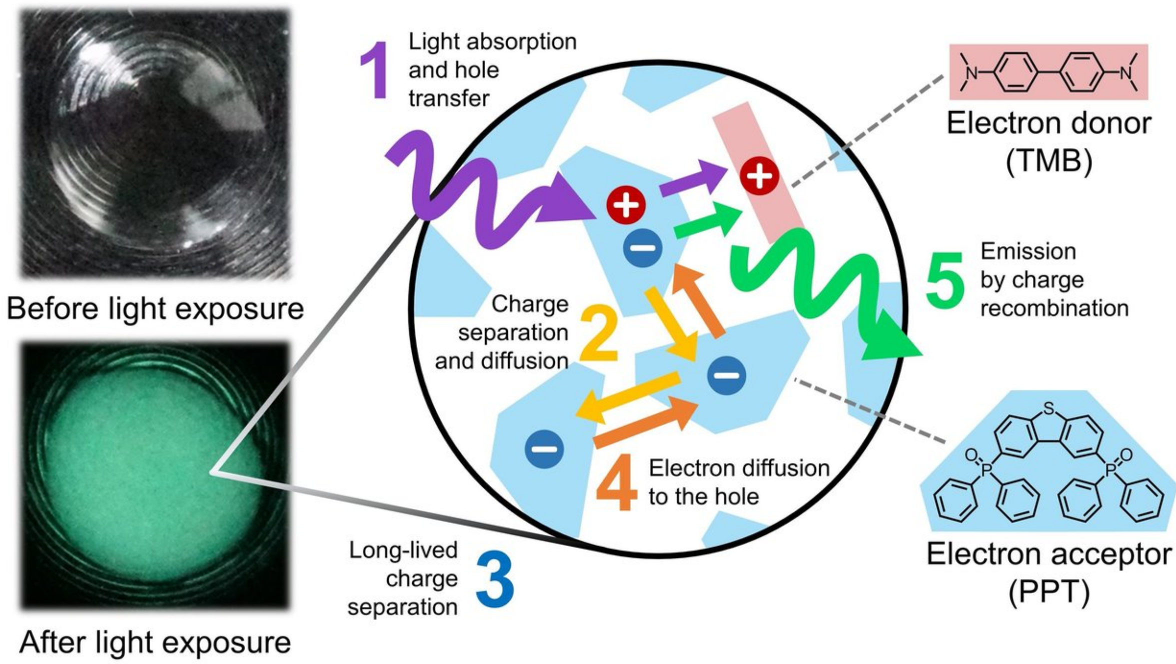


A circular film of glow-in-the-dark organic materials is shown in weak ambient light (top) and in the dark after exposure to ultraviolet light (bottom). Ultraviolet light was used to quickly accumulate energy and produce a strong glow, but the glow-in-the-dark effect can also be achieved by exposure with an ordinary white LED light. The film employs a mixture of donor and acceptor molecules to achieve this effect for the first time with organic materials. The process starts when an acceptor absorbs incident light energy, leading to the transfer of a positive charge, or hole, from the electron acceptor to an electron donor (1). The additional negative charge, or electron, on the acceptor then separates from the hole by hopping among other acceptors (2). The energy is now stored across a spatially separated electron and hole (3). The electron eventually moves back toward the hole (4), and light is emitted when the two come together (5). Some charges recombine quickly, but many can remain stored in the charge separated state for a long time (3), which leads to the glowing emission long after the excitation light is turned off. Credit: Ryota Kabe and William J. Potscavage Jr.

Glow-in-the-dark paints that have improved flexibility and transparency while also being cheaper and easier to manufacture are on the horizon courtesy of new research from Kyushu University. In a groundbreaking demonstration, light emission lasting more than one hour was achieved from organic materials, which are also promising for unlocking new applications such as in bio-imaging.

Based on a process called persistent luminescence, glow-in-the-dark materials work by slowly releasing energy absorbed from ambient light. Used in watches and emergency signs, commercial glow-in-the-dark materials are based on inorganic compounds and include rare metals such as europium and dysprosium. However, these materials are expensive, require high temperatures to manufacture, and scatter light—as opposed to being transparent—when ground into powders for paints.

Carbon-based organic materials—similar to those used in plastics and pigments—can overcome many of these disadvantages. They can be excellent emitters and are already widely used in organic light-emitting diodes (OLEDs). But achieving long-lived emission has been difficult, and the longest emission from organics under indoor lighting at room temperature was, until now, only a few minutes.

Researchers at Kyushu University's Center for Organic Photonics and

Electronics Research (OPERA) have now broken through this limit using simple mixtures of two appropriate molecules. In films formed by melting together molecules that donate electrons and ones that accept electrons, emission lasting for over an hour was demonstrated for the first time from organic materials without the need for intense light sources or low temperatures.

"Many organic materials can use energy absorbed from light to emit light of a different color, but this emission is generally fast because the energy is stored directly on the molecule that produces the emission," says Ryota Kabe, lead author on the paper reporting these new findings.

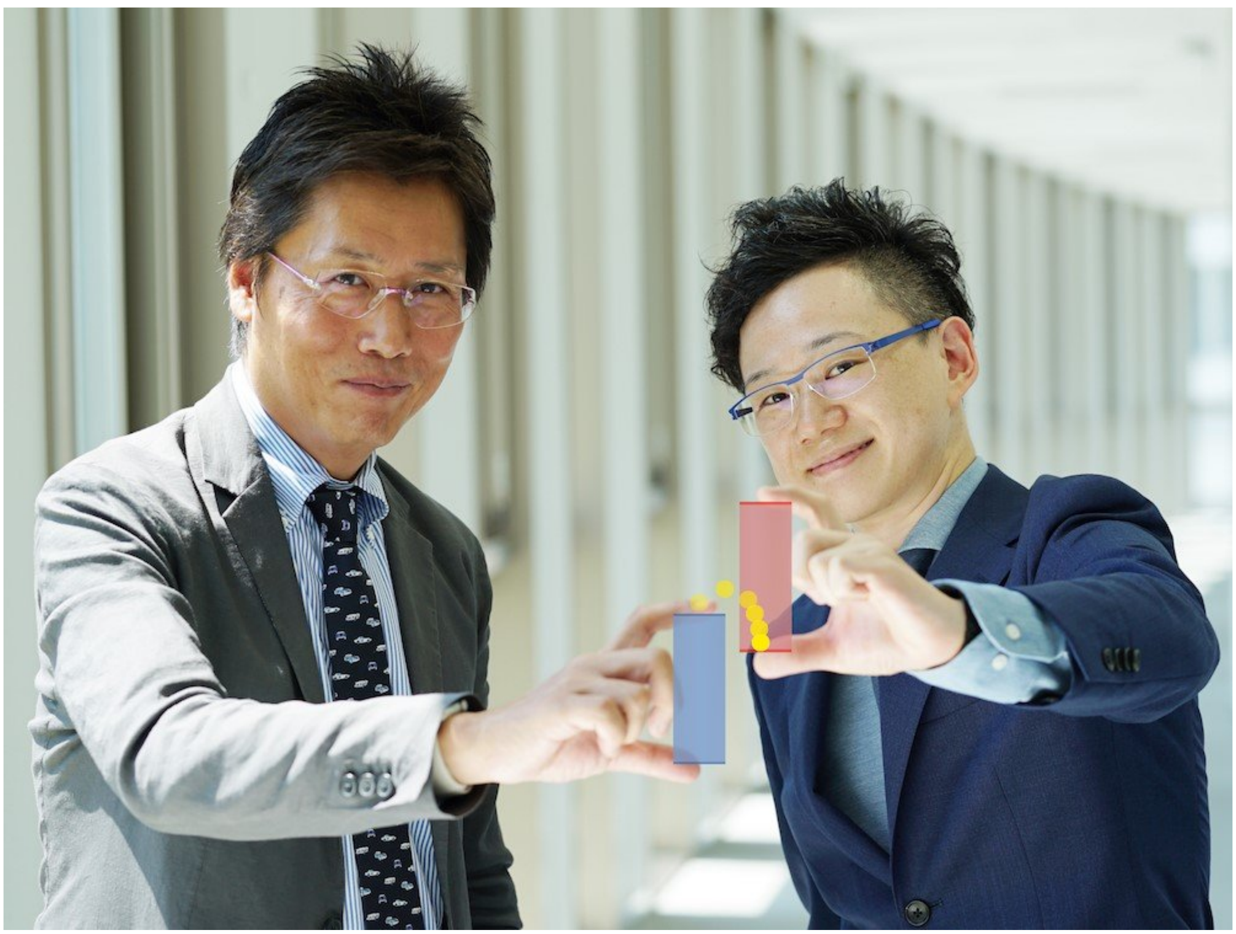
"By contrast, our mixtures store the energy in electrical charges separated over a longer distance. This additional step allows us to greatly slow down the release of the energy as light, thereby achieving the glow-in-the-dark effect."

In the mixtures, absorption of light by an electron-accepting molecule, or acceptor, gives the molecule extra energy that it can use to remove an electron from an electron-donating molecule, or donor. This transfer of an electron is effectively the same as a positive charge being transferred from the acceptor to the donor.

The extra electron on the acceptor can then hop to other acceptors and move away from the positively charged donor, resulting in separation of the charges. The separated charges gradually come back together—some slowly and some more quickly—and release their energy as light over the span of almost an hour.

The mixtures and processes are similar to what are found in organic solar cells and OLEDs. After building up separated charges like in a solar cell, the charges have nowhere to escape, so they eventually comeback together to emit light like an OLED. The key difference in the newly developed mixtures is that the charges can exist in a separated state for very long periods of times.

"With organics, we have a great opportunity to reduce the cost of glow-in-the-dark materials, so the first place we expect to see an impact is large-area applications, such as glowing corridors or roadways for added safety," says Chihaya Adachi, Director of OPERA.



Chihaya Adachi (left) and Ryota Kabe (right) of Kyushu University's Center for Organic Photonics and Electronics Research (OPERA) have developed the world's first glow-in-the-dark materials based on organic molecules. Light from the materials is produced when an electron transfers from an acceptor molecule to a donor molecule, which is represented by the diagram formed by their hands.

Credit: Center for Organic Photonics and Electronics Research

"After that, we can start thinking about exploiting the versatility of organic materials to develop glow-in-the-dark fabrics and windows, or even bio-compatible probes for medical imaging."

The first challenge to tackle on the road to practical use is the sensitivity of the process to oxygen and water. Protective barriers are already used in organic electronics and inorganic glow-in-the-dark materials, so the researchers are confident that a solution can be found. Concurrently, they are also looking into new molecular structures to increase the emission duration and efficiency as well as to change the color.

With efforts to solve these remaining issues underway, a new wave of glow-in-the-dark materials based on organics look poised to invigorate the area and expand their applications.

More information: Ryota Kabe et al, Organic long persistent luminescence, *Nature* (2017). DOI: 10.1038/nature24010

Provided by Kyushu University