Environmental sensing, Bioimaging, Smart devices

Visualizing ions through the power of boron

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Abstract

In this study, we developed novel sensor molecules capable of highly sensitive detection of fluoride and other anions using long-wavelength light. These molecules utilize the ambipolar characteristics of phenazaborine, a trivalent organoboron compound, resulting in a red-shift in both color and emission wavelength upon binding to fluoride ions. This property allows straightforward visual detection of anions in solution, with color and emission changes indicating the presence of fluoride. When embedded in plastic films, these molecules also enable tunable emission across a wide range from green to red. Unlike conventional sensors that depend on high-energy wavelength shifts, our approach achieves detection in the low-energy spectrum. Additionally, we successfully applied phenazaborine derivatives as emissive materials in organic light-emitting diodes (OLEDs), where fluoride ions induced a further red-shift in emission wavelength. These findings highlight promising applications for ultra-sensitive anion detection, bioimaging, and advanced display technologies, with potential uses in environmental monitoring, healthcare, and safety fields.

Background & Results

Fluoride and other anions pose significant health and environmental risks, emphasizing the need for rapid, precise detection methods. Traditional detection techniques depend on high-energy, short-wavelength shifts, which limit their applications. To address these limitations, we designed a novel anion sensor based on the ambipolar properties of phenazaborine, allowing detection through low-energy wavelength shifts. By pairing phenazaborine with an electron-deficient aromatic compound (i.e., dibenzophenazine), the sensor efficiently detects anions at long wavelength light. In solutions containing fluoride ions, the sensor shifts from green to orange in color, enabling clear, sensitive visual detection. Moreover, incorporating these molecules with fluoride ions into plastic films enabled emission tuning from blue to near-infrared, expanding potential applications. Experimental and theoretical analyses confirmed that fluoride ions alter the molecule's electronic state, promoting thermally activated delayed fluorescence (TADF). In the solid state, TADF was observed alongside room-temperature phosphorescence (RTP) and triplet-triplet annihilation (TTA), highlighting fluoride's role in modulating photophysical properties. These findings suggest that the developed molecules are highly suitable as efficient organic light-emitting materials for OLED devices. OLED performance evaluations demonstrated that adding fluoride ions improves device efficiency and enables controlled emission color tuning. This progress opens opportunities for further advancements in OLED technology, with optimization of molecular design and device structures paving the way for versatile applications.

Significance of the research and Future perspective

The sensor molecules developed here offer a significant advancement by enabling high-sensitivity anion detection at long wavelengths. Unlike traditional short-wavelength sensors, our approach facilitates early detection of hazardous substances, potentially reducing health risks. The solid-state red TADF properties make these molecules promising candidates for next-generation displays and safety monitoring devices. When applied to OLEDs, they enhance device efficiency and emission control, offering broad potential as display materials and innovative emissive components. Continued optimization in molecular design and device architecture could establish these molecules as foundational in emissive technologies and environmental sensing solutions.

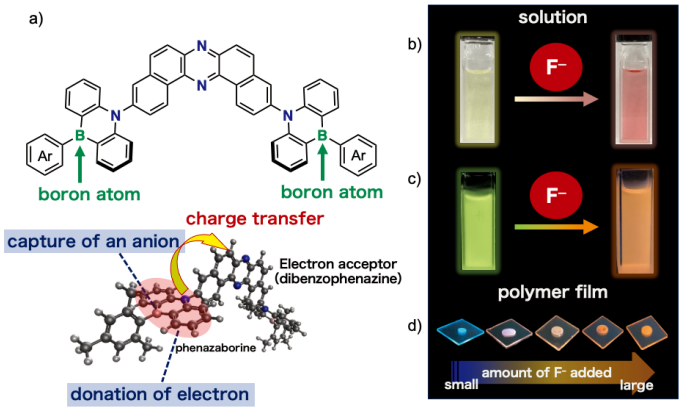

Fig. 1 The a) chemical structure of the developed sensor molecule, b) color change of the solution when fluoride ions are added, and c) luminescence color change when fluoride ions are added.d) the luminescence of polymer film prepared by adding fluoride ions.

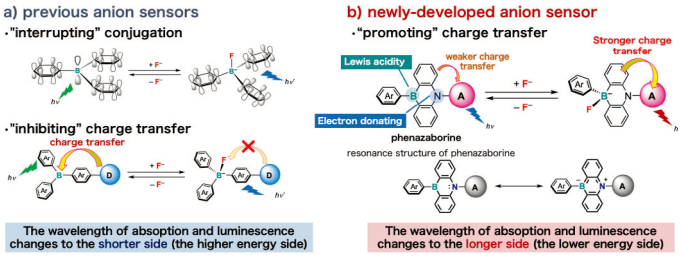

Fig. 2 a) conventional anion sensor molecules and b) anion sensor molecules developed in this study

Patent
Treatise
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URL http://www.chem.eng.osaka-u.ac.jp/~minakata-lab/ytakeda/

Keyword fluoride ion, boron, chemical sensor, luminescence, element strategy