2-5-13. Magneto-Optical Materials

Overview

In 1945, Faraday discovered that the plane of polarization of linearly polarized light rotates when it passes through a material in the presence of a magnetic field (Fig. 1). This phenomenon, known as Faraday rotation, is employed in various applications, such as optical isolators. Recently, macrocyclic aromatic molecular systems have attracted attention as promising materials exhibiting large Faraday rotations. The Faraday effect on luminescent transitions has also been investigated to expand potential applications.

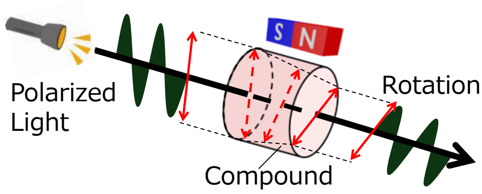

Figure 1. Illustration of Faraday effect.

Current Status and Frontiers

The rotation angle of the polarization plane due to the Faraday effect can be expressed as "V (Verdet constant) × H (magnetic field) × L (length of the optical path)." The development of materials with large Verdet constants enables the construction of miniaturized and integrated optical devices. According to classical theory, achieving a large V requires a transition with a high oscillator strength and degenerate initial (or final) states with large total angular momentum (or spin/orbital angular momentum).

Magnetic garnet single crystals have long been known to exhibit strong Faraday rotations in the visible and near-infrared ranges. The d and f orbitals derived from metal ions, as well as the π-electron orbitals, possess orbital angular momentum (Fig. 2). Thus, highly symmetric macrocyclic aromatic molecules with large π−electron orbital angular momentum and high oscillator strength also exhibit significant Faraday rotation. Recently, porphyrin and phthalocyanine derivatives have been shown to exhibit Verdet constants comparable to those of magnetic garnet crystals. Phthalocyanines on ferromagnetic substrates impart magnetic hysteresis at room temperature and demagnetize the substrate under light irradiation (Ishii et al.). Organic materials with facile processing and tunable wavelengths will promote the development of molecular magneto-optical materials.

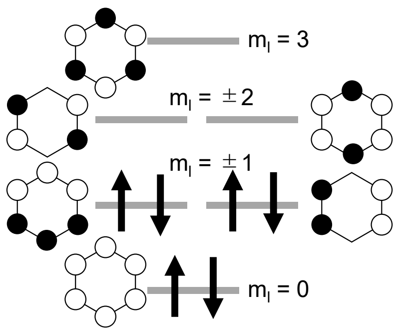

Figure 2. π-Electron orbitals of benzene

Compounds designed with large Verdet constants are also related to the quantum anomalous Hall effect. The Hall effect has been realized in topological insulators with magnetic properties. When low-energy light (in the terahertz range) irradiates a compound exhibiting the Hall effect, the rotation angle of the polarized light is quantized by the physical constant of the electromagnetic interaction (fine-structure constant). Topological insulator thin films (8 nm, 1.5 K) provide the Faraday rotation of 0.15 degree (Tokura et al). The rotation angle per unit thickness is two orders of magnitude greater than those of conventional Faraday materials.

The Faraday effect in the luminescent transitions, known as magnetic circularly polarized luminescence (MCPL), produces an emission intensity difference between left- and right-circularly polarized light (Fig. 3). Although this phenomenon was discovered more than 50 years ago, recent studies have focused on compounds exhibiting strong MCPL for applications such as OLEDs in magnetic fields (Imai et al.). Optical switching based on large MCPL signals through the aggregation of macrocyclic aromatic molecules has also been demonstrated (Ishii et al.).

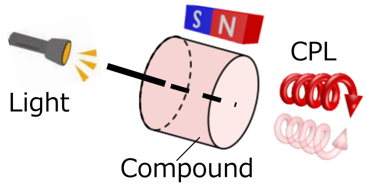

Figure 3. Illustration of MCPL phenomenon

References

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Future Perspectives and Directions

Issues that need to be addressed and resolved within the next 10 years: The future requires the discovery and development of new guiding principles capable of achieving a strong Faraday effect, and development of the molecular magneto-optical materials.

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