【Grant-in-Aid for Specially Promoted Research】

Organic semiconductor lasers aimed at low lasing threshold

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Purpose and Background of the Research

●Outline of the Research

Organic semiconductors have been developed by the interdisciplinary forces of device engineering, organic chemistry, and solid-state physics. 30 years ago, it was difficult for anyone to predict that devices based on organic ultra-thin films such as 100 nm would overcome stability issues and reach the practical application. However, significant progress has been made in materials and device process technologies for forming pinhole-free, uniform organic thin films, which has enabled highly reproducible ultra-thin film formation and has also greatly advanced the exploration of optoelectronic properties of organic thin films. The practical application of OLEDs (organic light emitting diodes) has demonstrated that organic molecules have the performance to transcend the academic framework and to endure as a practical material. There is no doubt that this development has been supported by the detailed mechanism elucidation of the processes from charge injection, transport, and charge recombination. In this study, we will advance the elucidation of basic science and technology from the development of new materials to device properties to realize organic semiconductor lasers (OSLDs) as an extension of OLEDs.

● Establishment of OSLD Science

OSLDs have the potential to greatly advance the science of organic semiconductors, including exciton deactivation processes at high current densities of up to 1 kA/cm^2, electronic conduction mechanisms, and new developments in organic laser molecules and optical resonator structures, raising a wide range of fields from organic material chemistry to device physics and engineering to a higher stage.

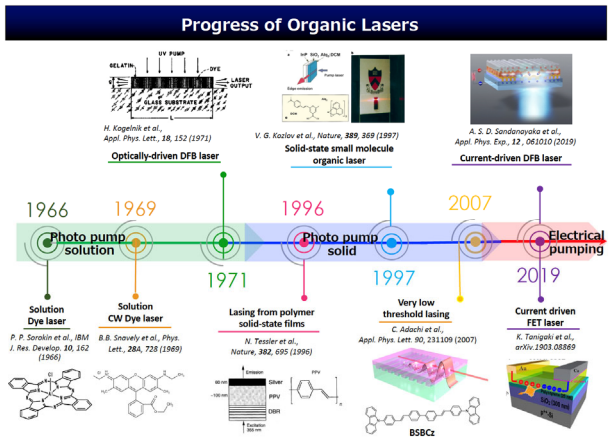

Fig. 1: Development of OSLD from photo to electrical excitation.

In particular, in the design of organic laser molecules, we expect to create ultra-low threshold laser materials under current excitation by developing fluorescence, phosphorescence, and TADF materials. It is also important to convert the large number of triplet excitons produced under current excitation to laser action, which requires the realization of a fast spin conversion process of triplet excitons to singlet excited states in less than a few hundred ns.

These studies are expected to advance the clarification of the detailed mechanism of spin conversion. Furthermore, the degradation mechanism of OSLDs under high current density should be clarified from the viewpoint of the exciton dissociation mechanism as well as the advancement of organic thin film aggregation structures that can withstand high current densities. In particular, research on film stabilization and oriented polarization by controlling fine amorphous structures is expected to open up a new academic field of organic amorphous structures.

●Elucidation of Organic CT Phenomena

The core science of organic thin film device research can be summarized as the precise control of intra- and intermolecular CT interactions of organic molecules. In all elementary processes from charge injection to charge transport, and from exciton generation to deactivation, precise control of the strength and weakness of CT interactions leads to the expression of functionality. We would like to summarize the CT phenomena and break through the challenges of OSLDs.

Expected Research Achievements

OSLDs need to inject a high current density of 1 kA/cm^2 into organic thin films, which is beyond the conventional knowledge, and under OSLD drive, in addition to exciton-exciton deactivation, exciton-charge (polaron) interactions, and exciton quenching process must be overcome. Moreover, spontaneous orientation polarization (SOP) during organic thin film formation may also play a significant role in exciton quenching and is the main cause of the strong internal electric field and exciton deactivation due to SOP. Under such extreme conditions (strong electric field, high exciton density, and high current density), we will establish a detailed mechanism to form an inversion population and achieve laser oscillation while actively suppressing exciton deactivation, leading to a "complete understanding of the molecular exciton deactivation process". In order to make OSLDs a practical and reliable technology, a significant reduction of the laser oscillation threshold is indispensable.

In the development of new laser molecules, we will develop fluorescent molecules with radiation rate constants exceeding k_r >10^{10} s^{-1} and TADF molecules with fast inverse intersystem crossing velocities (>10^8 s^{-1}), challenging issues that will be "breakthroughs" for next-generation luminescent molecules. We will also deepen our understanding of the intramolecular spin conversion process.

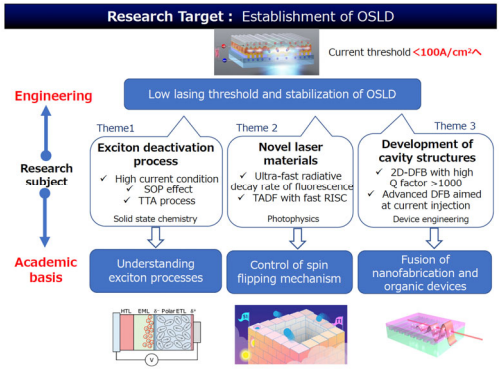

Fig. 2: Research subjects of OSLDs.

At the same time, we will work on the advancement of optical resonator structures. We are currently working to develop new optical waveguide-type resonator structures such as cylindrical, spiral, and two-dimensional lattice structures, and to construct a DFB structure embedded under the electrode to facilitate current excitation. We will construct a device structure that leads to the integration of organic devices and microfabrication.

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