Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 634–635

F-8-1 (Invited)

Organic Solid State Lasers

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1. Introduction

Semiconductor lasers are widely used in modern science and technology. Compared to conventional inorganic semiconductors, organic semiconductors offer potential advantages with respect to low-cost processing and deposition on large-area flexible substrates. Hence, electrically driven lasers based on organic semiconductors will potentially find a wide range of applications. Optically excited lasing and amplified spontaneous emission has been observed in a wide range of semiconducting polymers, small molecules, as well as organic single crystals [1-3]. Moreover, amorphous or nearly amorphous organic and polymeric semiconductors have been very successfully employed in thin film organic light emitting diodes (OLEDs). Reduced luminescence efficiencies at high injection current densities, charge-induced absorption, and low charge carrier mobilities have been identified as major problems for electrically pumped OLEDs [2]. Mobilities in the order of 1 cm^2/Vs can be achieved in molecular single crystals (e.g. tetracene or α-sexithiophene (α-6T)) at room temperature. Moreover, reasonably high photoluminescence quantum yields have been reported for these single crystalline materials diodes. To ensure facile electrical contacts and balanced injection of electrons and holes we have used field-effect electrodes [4,5]. These properties altogether led to the demonstration of electrically-pumped stimulated emission in organic single crystals [4,5].

2. Experimental

Tetracene and α-6T single crystals have been grown from the vapor phase in a stream of inert gas [6]. Typical samples exhibit smooth faces of some mm^2 and thicknesses in the range from approximately 1 to 10 μm. Field-effect device structures were prepared on freshly cleaved crystal surfaces. Source and drain electrodes (Au for holes and Al for electrons, respectively) were thermally evaporated through a shadow mask defining a 25 μm channel length and several hundred μm channel width. An amorphous Al_2O_3-layer was sputtered onto the crystal resulting in a capacitance of C_i=50 nF/cm^2 between the gate electrode and the crystal. Finally, transparent Al-doped ZnO gate electrodes were deposited. A sketch of the device structures is shown in Figure 1.

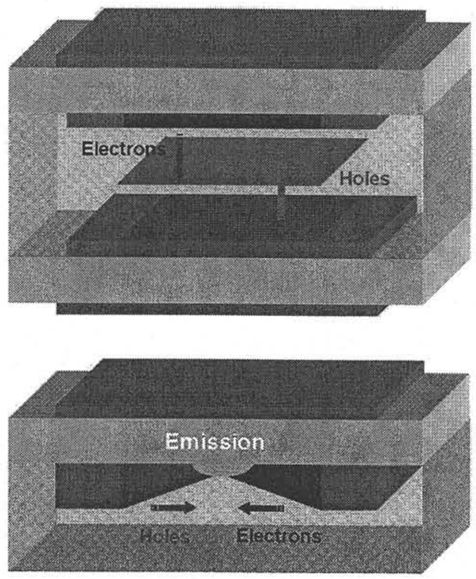

Fig. 1 Device structures for electrically-pumped stimulated emission in organic single crystals [4,5].

It has been recently demonstrated, that ambipolar charge transport, i.e. n- as well as p-channel activity, can be obtained in high-quality single crystal polyacene field-effect transistors (FETs) [7]. Hence, gate-controlled electrodes can realize efficient electron as well as hole injection, with the field-induced charge acting as a heavily doped 'contact' to the crystal. The injection efficiency can be tuned by the applied gate voltage leading to a balanced injection of electrons and holes.

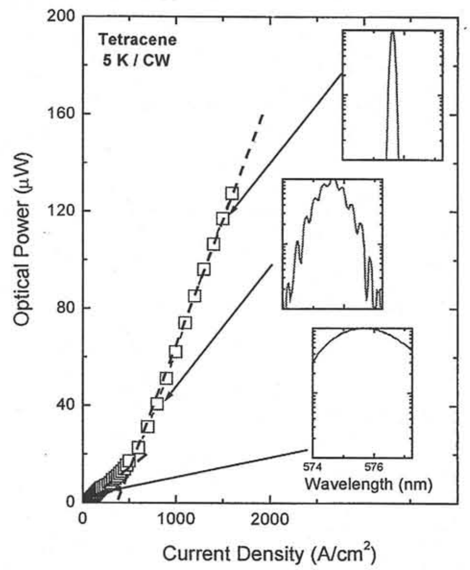

Fig. 2 Optical output power as a function current density through a tetracene single crystal. The insets show the evolution of the emission spectrum. A threshold for lasing of 400 A/cm^2 can be estimated.

3. Results and Discussion

Figure 2 shows the optical output power as a function of current density for electrical excitation of a tetracene single crystal at low temperature. A clear threshold for lasing of 400 A/cm^2 can be observed. The evolution of the emission pattern reveals single mode lasing at the highest excitation densities. Pulsed lasing has been demonstrated up to room temperature [4]. Similar results have been achieved for α-6T single crystals. The advantages of high-quality single crystals are a high mobility and low charge-induced absorption. A strong increase of the charge-induced absorption is observed for increased disorder in the material. Since these absorption bands can overlap with the optical gain regime, this could lead to the suppression of electrically-driven lasing in disordered materials.

4. Conclusions and Outlook

Electrically-driven stimulated emission in organic materials has been demonstrated in tetracene and α-6T single crystals. Future research will be directed towards two directions. Firstly, the preparation of high-quality thin films. So far we have demonstrated ambipolar transistor action in organic thin films. Further developments will focus on optimization of optical properties of polycrystalline materials as well. The second direction of research is related to new materials. For example, optically-pumped stimulated emission has been demonstrated for single crystals of various oligophenylenevinylenes.

Acknowledgements

This work was conducted in collaboration with Z. Bao, B. Batlogg, A. Dodabalapur, Ch. Kloc, S. V. Frolov, G. Hadziioannou, H. E. Katz, and R. E. Slusher.

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