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論 文 要 旨
THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

Chapter 1. background

The goal of organic electrical devices in the future can be imagined as flexible and printable. To achieve this, we should consider what kind of organic material, for example, single-crystal, poly-crystal, liquid-crystal, or amorphous, is promising semiconductor material for practical use. In this thesis, I expect that organic poly-crystal is the candidate, because it exhibits both high carrier mobility and thin film formability. However, organic-polycrystal usually has two troubles: first, random grain boundaries occur, which disturb carrier transport in the film. Second problem is difficulty in control of molecular orientation. It is serious problem because we must set the direction of molecular π-stacking along with the current flow direction. Here I focus on liquid-crystalline materials and their poly-crystalline phase: liquid-crystalline phase shows less random grain boundaries and molecular orientation controllability. Hence, we expect poly-crystal phase of liquid-crystalline materials can overcome the difficulty of the typical organic poly-crystals. The purpose of this thesis is to demonstrate availability of poly-crystal phase of liquid-crystalline materials in three organic devices, organic thin-film transistor, organic light-emitting diodes, and organic thin-film solar cells.

Chapter 2. device fabrication and measurement method

Here the detail of device fabrication processes and measurement method are described.

Chapter 3. organic thin-film transistor

In this chapter, organic thin-film transistor with poly-crystals of liquid-crystalline material was evaluated. The poly-crystal was fabricated with spin-coating technique under liquid-crystalline temperature; during spin-coating, the substrate, solution, and atmosphere were heated. Under this condition, at the beginning of the spin-coating, liquid-crystalline thin film was formed and then crystallized. Resulting poly-crystalline thin film was uniform, and molecules in the film sit perpendicularly to the substrate. The effect of random grain boundaries was evaluated by time-of-flight technique. We found that grain boundaries occurred but their direction was controlled, which meant the effect of grain boundaries on carrier transport was well suppressed. Indeed, thin-film transistor with the poly-crystals of liquid-crystalline material showed good characteristics, which field-effect mobility reached 0.14cm^2/Vs. This value is comparable to vacuum deposited one even though our device is fabricated by spin-coating. These results exhibit the superiority of the organic poly-crystals of liquid-crystalline materials.

Chapter 4. organic light-emitting diodes

In this chapter, poly-crystal of liquid-crystalline material is adopted to organic light-emitting diodes (OLEDs). Typical OLEDs have a multi-layered structure of organic amorphous materials and achieve high performance; however, their fabrication processes are complicated. For simply fabrication of the device, here I was focusing on glass cell structure which is usually used for liquid-crystal display. The liquid crystalline material was injected into the glass cell by capillary action under its isotropic phase. After the injection, the cell was cooled down to room temperature; hence resulting poly-crystals passed through its liquid crystalline phase naturally. To enhance the light emission and carrier injection, guest material was doped to the host liquid crystalline material as a recombination center. I compared the current-voltage (J-V) characteristics of poly-crystal of liquid crystalline material with that of non-liquid crystalline material. I found current density was two orders of magnitude higher in the liquid crystalline material. This difference was due to the difference of grain boundaries; the grain boundaries in the poly-crystal of liquid crystalline material were well controlled not to affect the carrier transport, therefore high current density was observed. Resulting maximum light emission was 65cd/m^2 which is much

smaller than that of multi-layered one. However, this result proves OLED driving is enable in the organic poly-crystalline phase which is promising to enhance the current density owing to its high carrier mobility.

Chapter 5. organic thin film solar cells

The efficiency of organic thin film solar cells has been drastically improved by adopting the bulk-heterojunction structure which has a random mixture of donor and acceptor materials. For further improvement of the performance, molecularly ordered structure in the mixed thin film is needed, because ordered structure enhances carrier transport from donor-acceptor interface to electrodes. The liquid crystalline materials are good candidate for realizing such an ordered structure because of their molecular orientation and aggregation controllability. In this chapter, I applied the poly-crystal of the liquid crystalline material to bulk-heterojunction solar cells. I selected a liquid crystalline donor of the diketo-pyrrolopyrrole derivative (DmPP-O12) which exhibits liquid crystalline smectic A phase from 108 to 121℃. The acceptor material was fullerene derivative ($PC_{61}BM$). It should be noted that during device operation at room temperature, the liquid crystalline DmPP-O12 is not in liquid crystal phase but in poly-crystal phase. The device structure was so called inverted structure of glass/indium tin oxide (ITO)/ZnO (50 nm)/DmPP-O12:$PC_{61}BM$ (2:1 w/w, 200 nm)/MoOx (5 nm)/Ag(100 nm). We found the power conversion efficiency (PCE) of the cell was improved from 0.035% to 1.2% by thermal annealing of 60℃ 30min. XRD patterns and polarization microscopy images showed the molecular orientation of the liquid crystalline donor material was changed from perpendicularly to the substrate into parallel, which was enhanced the carrier conduction of vertical direction. Besides, AFM measurement showed molecularly ordered structure occurred after annealing whose size is about 100nm. This phenomenon occurred only in the liquid crystalline material, not in the non-liquid crystalline material; hence these results are, as I expected, due to the molecular orientation and aggregation controllability of the liquid crystalline material. To evaluate the carrier collection in the cell, I suggested a new analysis method. Using this method, carrier collection efficiency was successfully evaluated, and I found the efficiency was 7 times higher after the annealing process. From these results, we think molecular orientation and aggregation controllability of liquid crystalline materials are effective to improve the power conversion efficiency of the organic thin-film solar cells.

Chapter 6. summary

In this thesis, I discussed the availability of the poly-crystal phase of the liquid crystalline material and demonstrated its usefulness in three organic electric devices, such as organic thin film transistor, organic light-emitting diode, and organic thin film solar cells. In the all cases, poly-crystalline phase of the liquid crystalline material is superior to the non-liquid crystalline material; hence the liquid crystalline materials are attractive materials for the semiconductor of organic electronic devices. For further improvement of the device performance, optimizations of the device structure and fabrication process are required.