論文の要旨

題目　Carrier Mobility Modeling of Organic MOSFETs for Circuit Design and Application to Organic Photovoltaics

(回路設計及び有機太陽電池への応用に向けた有機 MOSFET のキャリア移動度モデリング)

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In recent years, devices using organic semiconductor materials attract much attention because organic devices enable new product applications that could not be realized with conventional semiconductor materials. The major application areas are transistors for circuit, Organic Photovoltaic (OPV), Organic Electroluminescence (OEL). Features of organic devices are low-cost simple process by printing technology, flexibility, large area, and diversity of materials and functions. More and more researches that anticipate the future of organic electronics are being carried out actively in the world. However, there are many issues to be solved to enter the market and compete with conventional products. This research is motivated by such a situation and aims to find new applications of organic devices that can be accepted even in disadvantaged areas in the world such as non-electrified areas.

Firstly, OPV is focused to investigate the potential of OPV in the solar product market. Renewable energy has been introduced aggressively in the world and solar energy is widely used not only in developed countries but also developing countries due to the easiness of installing and its unlimited resource from the sun. At the end of 2017, cumulative introduction amount of solar power reached around 400 million kilowatt and became larger than that of nuclear power. In the countries of Asia, Africa and Latin America, there are still many non-electrified areas that are not connected to the power grid, and standalone small-scale solar home systems are utilized in such areas. This proves that solar power has the high convenience and versatility even in non-electrified areas. In this research, focusing on this small-scale solar home system, it is investigated whether OPV products match people's lives and needs in non-electrified areas. The obtained result tells that OPV is preferred to use as a private solar home system (PSHS). At the same time, technical issues of OPV and influences on their culture and society are highlighted. Possible solutions/approaches for those issues are discussed.

This research approaches to the lowness of energy conversion efficiency from a view point of circuit application. To make best use of organic material properties, it is important to integrate functions as much as possible on a sheet by flexible devices, which is conceptualized by NEDO (New Energy and Industrial Technology Development Organization) as flexible multi-functions device. In general, solar cells are connected in series and in parallel and balanced to keep sufficient voltage and current since generation voltage of the cell is determined by the magnitude of the photoelectric effect and current of the cell is dependent on cell area. Even for organic solar cell with low conversion efficiency, it is effective to increase the size of the panel and/or boost the voltage by a converter circuit. If the boost circuit can be configured with organic devices, organic solar cells and organic circuit can be formed on a flexible sheet together. Dickson charge pump DC-DC boost circuit is feasible for organic-based circuit because it can reduce the number of complicated passive elements such as inductors. However, there has been no standardized organic device model to design organic-based circuits. Therefore, the first priority in this research is to develop organic device model for circuit design. Compact device model for circuit design has been developed based on silicon material properties and device physics, and reliable device models are used in the circuit simulation or even in the system level simulation. It is known that organic devices have unique conduction mechanism and current characteristics different from silicon devices. This indicates that organic semiconductor properties and conduction mechanism must be described properly in the model to reproduce the device characteristics. Although some conduction mechanisms of organic semiconductor have been proposed as a carrier mobility model, all of these haven't been implemented in a complete device model. In other words, Compact organic device model: HiSIM-Organic that the author has engaged is the only one complete model that has decryptions of organic device physics.

This thesis consists of 7 chapters as follows. Chapter 1 overviews the history of inorganic and organic semiconductor and their developments. Three major electronic products; Transistor and circuit, EL, and PV are explained to compare features of inorganic and organic products. This clarifies the advantage of organic products and helps to consider new application areas. Chapter 2 includes a study on new product application of OPV in non-electrified areas carried with the support of "TAOYAKA program". This chapter starts with an outline of the global energy situation and the roles played by renewable energy, and continues to the needs survey conducted in the non-electrified villages in India. A possible solution is presented from a viewpoint of circuit application toward low energy conversion efficiency of OPV that was reconfirmed in the survey. Specifically, the suggested solution is to design DC-DC boost converter with organic devices and integrate into OPV sheet. Chapter 3 is to explain device physics of organic MOSFETs (OFETs). Both silicon MOSFETs and OFETs are explained to identify common and different points properly. Chapter 4 explains important techniques for OFETs fabrication and shows the process that the author had followed. The latter part describes the measurement method and the result to understand device characteristics that is particular to OFETs. Chapter 5 is focused on device modeling of OFETs. Basic concept of compact device model for circuit simulation: HiSIM is explained at first. HiSIM has been developed based on silicon MOSFET properties, therefore, the features of carrier transport in organic semiconductor has to be considered and described as a carrier mobility model. The process of describing the carrier transport of OFETs is shown step by step. Thereafter, temperature dependence is analyzed because device temperature is one of the most important parameters that determine device performance. Although OFETs show different temperature dependence from Si MOSFETs, it is sufficiently reproduced by developed model. It is discussed that OFETs have fast degradation phenomena which may deserve to be considered in the model. Chapter 6 is for operation verification of organic-based circuit. DC-DC boost converter (introduced in chapter 2) needs ring oscillator to be operated by pulse signal. Accordingly, oscillation frequency of measured and simulated data are compared to verify whether accurate prediction by developed model is available or not. Simulated frequency is close to the measured data, which indicates the developed model is reliable to be applied to the circuit simulation. Chapter 7 summarizes this research.