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Dottorato di Ricerca in Ingegneria dell'Informazione
XII Ciclo – Nuova Serie

ABSTRACT
TESI DI DOTTORATO

A Study on Defects in Organic Semiconductors for Field Effect Transistors

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Anno Accademico 2012 – 2013

The understanding and the modeling of mechanisms involved in organic semiconductors are the aims of this Ph.D. thesis. In particular, the document focuses the attention on the role played by organic semiconductor defects on the electrical performance of organic-based field effect transistors. Critical issues are, indeed, the localized states related to the presence of structural defects and chemical impurities. They dominate the charge carrier transport in organic semiconductors and define the quality of interfaces occurring in the transistors.

Organic thin film transistors were fabricated with pentacene, a conjugated small molecule exhibiting p-type behavior, in combination with various polymeric gate insulators. The relationship between the electrical characteristics and the physical processes of the organic devices was investigated, along with a study of their electrical stability, essential to allow the adoption of organic transistors in practical applications.

Most of the unstable behaviors observed in the fabricated devices were justified by assuming a multiple trapping and release mechanism to occur, due to the high concentration of traps. Particular analyses of the physical properties of organic materials were presented, exploiting in detail the photo-excitation of charge carriers to produce hidden phenomena, which were used for the characterization of localized states. Thanks to this expedient, interesting results were obtained and, in particular, a novel analytical model describing the creation and annihilation dynamics of metastable defects induced in a pentacene film by an ultraviolet irradiation was developed. The evolutions of two types of induced defects, referred to as slow and fast defects, were reconstructed through the proposed equations. Induced defects were demonstrated to control the degradation and recovery kinetics of conductivity.

The physical mechanisms occurring in organic transistors at the semiconductor-insulator interface, where the conducting channel is formed, were studied through photocurrent and photocapacitance measurements and were revealed to dominate important aspects of device performance and stability under realistic atmospheric conditions. For this reason, specific equations were developed to model the combined effects induced by light irradiation and bias stress. The proposed model allowed a simultaneous study of the light effect on material structure, the trapping process of minority charge carriers at the insulator-semiconductor interface and the photoconductive efficiency in the organic semiconductor. Moreover, the new parameters introduced to describe the photoresponse evolution become characteristic figures of merit, fundamental to compare different organic devices by including information about the illumination time and the bias during measurements.

Finally, a significant contribution to the modeling of an organic thin film transistor was given through the development of a complete electrical model able to describe the dynamics of the various processes occurring in the organic device. By exploiting the potentialities of admittance spectroscopy in an organic based metal-insulator-semiconductor capacitor, an equivalent circuit was built and increasingly improved though the introduction of new components. Thus, every element was connected to each other through different relationships, each describing a single process in the device, including the diffusion of mobile ions, the dispersive transport in pentacene bulk, the trapping mechanism at the insulator-semiconductor interface and the contact resistance at the metal-organic interface. The simulation results showed that the proposed analytical equations are very effective in predicting the electrical behavior of organic devices. This model, suitable for device simulations, also provides an efficient parameter extraction method, useful to compare the device properties with respect to the geometries, the materials and the deposition conditions.