## Deep Level Transient Spectroscopy Study of Pentacene Diode\*

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Organic semiconductors based devices [1, 2], such as thin film transistors [3, 4] and light emitting diodes [5] are in the focus of the research for the last decades for many promising applications in electronics or photonics. Although the mobility (as a main parameter required for applications) is comparable with amorphous hydrogenated silicon, fabrication of the high mobility devices is still difficult. Hence, study of the charge propagation through the organic devices is one of main challenges of present applied physics. In contrast to inorganic semiconductors organic materials have different mechanical, optical and partially also electrical properties. However, electronic devices based on the organic molecular material exhibit similar behavior as an inorganic one; hence, the name organic semiconductor is used [1]. On the other hand, low charge carrier mobility reported by many research groups can classify these materials as dielectrics, i.e., materials in which the thermodynamic equilibrium is not established. In addition, due to not well-defined difference the designation "semi-insulators" was proposed [6]. Hence, charge transport is studied in detail to reveal microscopic transport mechanism.

On the other hand, there is an energy band diagram representation of the charge trapping in solids. The localized levels created between highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) are assigned to the charge trapping phenomenon. It was reported that the origin of these levels dwells in imperfections of the crystal structure or in the chemical modification of organic semiconductor molecules [7, 8]. The former one is related to the crystal size, while the latter one represents, e.g., oxidation, which is common for organic materials [9]. In other words, there are molecular crystal defects and single molecule defects. The chemical defects are investigated for their simple generation by the ambient atmosphere. In addition, the traps study is important for both the understanding of device physics and electric field distribution in organic semiconductor devices [10].

Even though there are many advantages of organic semiconductors, there are still problems with high concentration of defects and the charge trapping phenomena. Therefore, there is a need to study the origin of the defects as well as their properties.

The deep level transient spectroscopy technique (DLTS) is a versatile method used for investigation of emission processes from defects in semiconductors. The standard DLTS method is a high-frequency transient capacitance thermal scanning method, where an electrical excitation pulse causes the capacitance transient effect in the potential barrier of the semiconductor [11]. By monitoring capacitance transients produced by pulsing the metal-semiconductor junction (Schottky diode) at different temperatures, a spectrum is generated which exhibits a peak for each deep level. The height of the peak is proportional to the trap density, its sign allows to distinguish between majority and minority traps and the position on the temperature axis leads to the determination of the fundamental parameters governing thermal emission and capture (activation energy - enthalpy of ionisation and cross section). However, this method is not widely used for organic semiconductors due to many ambiguities in the energy structures of these materials.

There are many organic semiconductors suggested for applications. However, as a reference material is usually used pentacene due to well-known structural and electrical properties.

In these experiments, gold/pentacene/aluminium sandwich diode structure has been employed. Emission processes has been investigated by the DLTS technique using the Fourier analysis. This modification of standard DLTS method – Deep Level Transient Fourier Spectroscopy (DLTFS) is a

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digital DLTS system that records the whole capacitance transients and analyses them using the Fourier transform analysis.

The pentacene films (260 nm) sandwiched between Au and Al electrodes have been used in this study as a Schottky diode. The Au contact provided an Ohmic contact, while Al represents the Schottky barrier electrode. The electrical measurements were carried out in the temperature range from 80 to 300 K using the BIORAD DL8000 measuring system equipped with Fourier transform analysis of the measured capacitance transients. The emission processes in Au/pentacene/Al Schottky diode structure has been investigated under various experimental conditions. The obtained DLTS spectra, were evaluated using the Fourier transform analysis with the "Direct auto Arrhenius single level evaluation" option with minimal class for evaluation of 40.

Recorded capacitance transients showed non-exponential decay. This is caused by the emission processes of multiple traps. The three hole-like deep energy levels with activation energy of 0.34, 0.42, and 0.61 eV has been determinated from Arrhenius plot. Furthermore, the energy distribution standard deviation of 0.072 eV has been estimated from current-voltage characteristics. The capture cross-sections of each deep energy level has been estimated using effective mass obtained from simulations reported elsewhere [12]. The activation energy 0.34 eV is in good agreement with previous reports and illustrate capabilities of DLTS for organic semiconductors [7, 13].

This contribution demonstrates the application of DLTS technique with Fourier analysis as a method suitable for organic semiconductor study and illustrates its capabilities.

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