

ELECTRICAL PROPERTIES OF PENTACENE FILMS OBTAINED BY PULSED LASER DEPOSITION

G.Wisz¹, I.Virt¹, M.Kuzma¹, P.Sagan¹, T.Ya.Gorbach² and P.S.Smertenko²

¹Institute of Physics, University of Rzeszow, Rejtana 16a, 35-309 Rzeszow, Poland

²Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, Prospect Nauki 45, Kiev 28, 03028 Ukraine

Received: December 10, 2009

Abstract. ITO covered glass was used as a substrate for the laser epitaxy of pentacene (C₂₂H₁₄) films. A different orientation of the substrate with respect to the pentacene plasma plume was applied. Thin films of pentacene were deposited using a YAG:Nd³⁺ laser with a second harmonic ($\lambda = 532$ nm). The electrical properties of the structures were analyzed on the base of the current-voltage characteristics. The current-voltage characteristics are explained in relation to the molecular structure properties of the pentacene films as well as the pentacene/contact, pentacene/substrate interface. The carrier transport mechanisms for different interfaces and structures are presented.

1. INTRODUCTION

Organic films fabrication offers a possibility of low weight, mechanical flexibility and low cost production of electronic devices. In a wide group of various organic semiconductors, the pentacene (C₂₂H₁₄) is one of the most promising candidates for organic thin film transistors due to its high field effect mobility [1-3]. Despite the important role of pentacene in the up to date organics semiconductor research, very little is known about the carrier transport mechanism and the nature of metal/pentacene contacts. The type of the internal device structure, especially the molecular short and long range order of pentacene layers affects strongly its functional properties. Therefore, the understanding of the processes of growth that permit finding a way to control and optimize the structure is the basis of the technology development. The structural properties strongly depend on the substrate type, on its surface properties, growth conditions and the production method.

We propose a pulsed laser deposition (PLD) method as an alternative method of obtaining pentacene layers on a cold substrate [4-8]. This method provides a high degree of flexibility in the used materials, geometrical arrangements, and adjustment of the growth parameters. Different conditions of growth result in different mechanisms of layer growth, different organic/inorganic interface properties and different energy level alignment. For growth of an organic material on inorganic substrates, we have an additional possibility to form different types of interfaces with respect to the arrangement of molecules in the first monolayer [9]. In the case of a pentacene layer, different types of pentacene/substrate interfaces result not only in different molecular structures but lead to a modified energy-band structure and the carrier transport mechanism as well. In this work the influence of the ITO/glass substrate surface orientation with respect to the plasma plume propagation direction on the

Corresponding author: G. Wisz, e-mail: gwisz@univ.rzeszow.pl

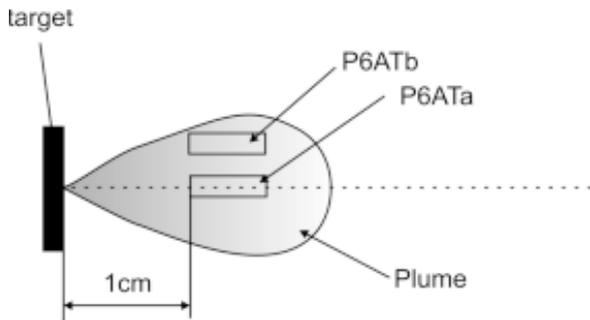


Fig. 1. Substrate orientation in respect to the plasma plume.

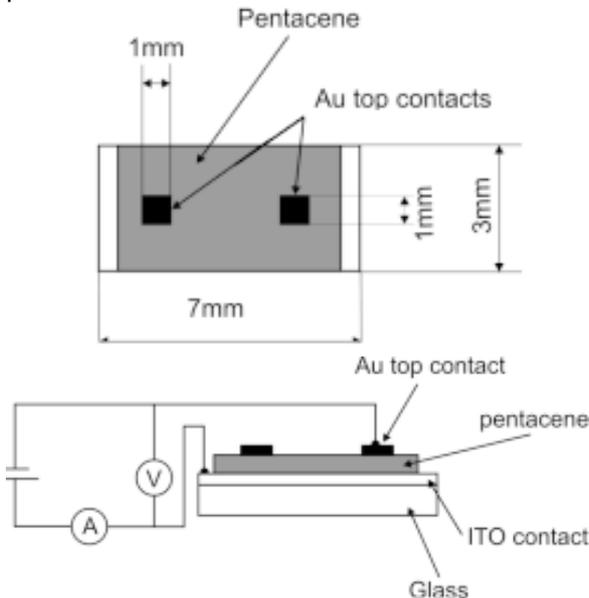


Fig. 2. Sample structure and contact configuration: a) top view, b) sandwich configuration.

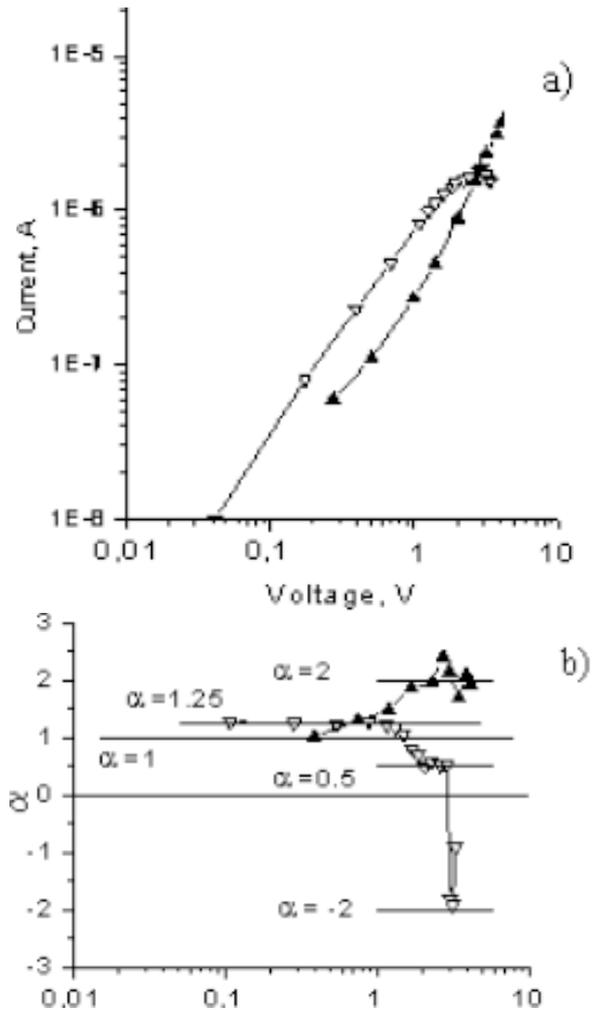


Fig. 3. I - V characteristics of P6ATa sample for forward (Δ) and reverse direction (\blacktriangle) and their slope α (b).

pentacene films properties was investigated by the current voltage characteristics analysis.

2. EXPERIMENTAL DETAILS

Two kinds of ITO/pentacene/Au device structures were studied in this work. Pentacene films were obtained by the PLD method using a YAG: Nd³⁺ laser with a 532 nm (II harmonics) wavelength, 40 ns pulse time and a fluence of the range of 930 mJ/cm². The glass covered by ITO sheet (Aldrich) was used as a substrate. The ITO sheet resistance was 20 Ω . The layers were deposited in a vacuum chamber equipped with a PFEIFFER TMH/U 071 turbomolecular pump providing a vacuum of 10⁻⁶ hPa. Finally, a gold top contact was prepared by thermal evaporation through a shadow mask. The pentacene layers were about 50-70 nm in thickness. The I - V characteristics were measured for two samples

(P6ATa, P6ATb) obtained in one technological cycle for the geometrical arrangement presented in Fig. 1. The device structure details, the contact configuration and the measurements setup are presented in Fig. 2. The current voltage characteristics were measured at room temperature. The fine structure of the I - V characteristics was determined by a differential approach [10,11]. The main procedure of this approach was to determine a differential slope of the current-voltage characteristics (CVC) on a Log-Log scale according to the formula $\alpha = d \log I / d \log V = (dI/I) / (dV/V)$. Such processing shows special ranges of the CVC behavior, e.g. the Ohm's law will be represented by $\alpha = 1$, the space charge limited currents (SCLC) regime will show $\alpha = 2$, and so on [11-16]. In other words, $I \sim V^\alpha$.

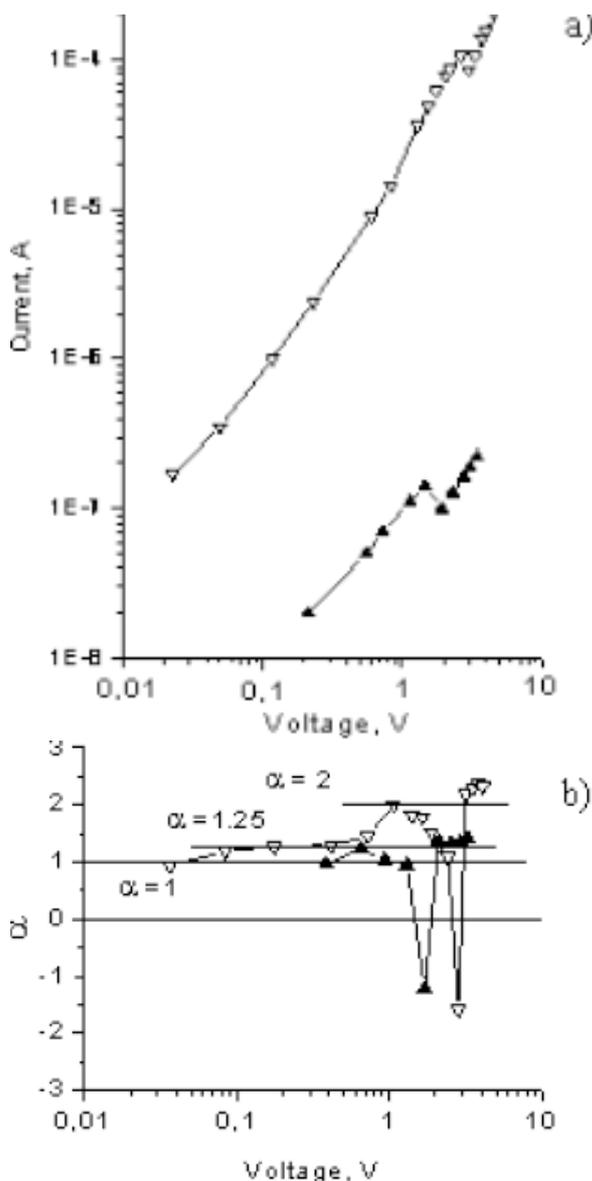


Fig. 4. *I-V* characteristics of P6ATb sample for forward (Δ) and reverse direction: (\blacktriangle) and their slope α (b).

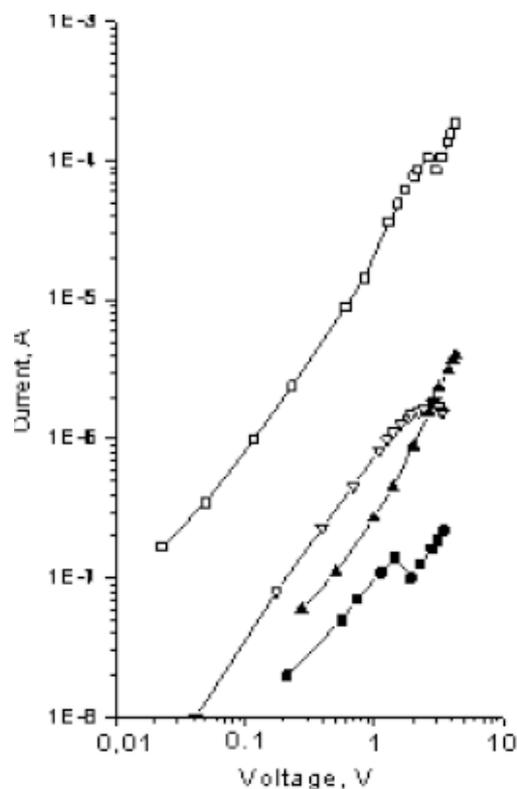


Fig. 5. Comparison of *I-V* characteristics of P6ATa (Δ , \blacktriangle) and P6ATb (\square , \blacksquare) samples - forward (Δ , \square) and reverse direction (\blacktriangle , \blacksquare).

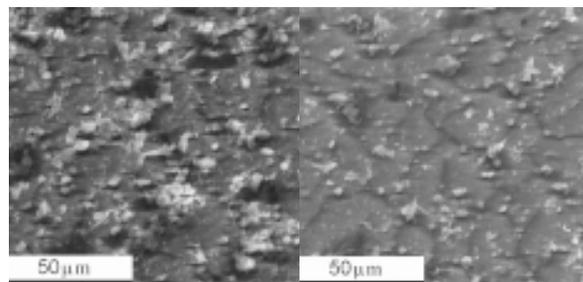


Fig. 6. SEM images of P6ATa and P6ATb sample surface.

Table 1. Conductivity of samples in forward and reverse directions at $V = 1$ V for P6ATa and P6ATb devices.

Sample	Forward		Reverse		I_F/I_R
	I , A	σ , $\Omega^{-1} \text{ cm}^{-1}$	I , A	σ , $\Omega^{-1} \text{ cm}^{-1}$	
P6ATa	1.0×10^{-6}	7.0×10^{-10}	3.5×10^{-7}	2.4×10^{-10}	2.86
P6ATb	2.0×10^{-5}	1.0×10^{-8}	1.0×10^{-7}	5.0×10^{-11}	200

3. RESULTS AND DISCUSSION

The CVC of the P6ATa sample are shown in Fig. 3. The Ohm's law can be seen at low voltages in the reverse direction. The forward direction shows $\alpha =$

1.25. Up to now, there has been no theoretical explanation of such behavior. An experimental CVC observation of different structures may lead to a conclusion that such type of behavior can be seen in amorphous structures and in some organic ma-

terials [17-21]. The behavior with $\alpha \geq 2$ can be seen for the P6ATa device at higher voltages, more than 1 volt in the reverse direction. This points out to the injection behavior [12]. In [22] the authors show that it is the SCLC regime with an exponential trap distribution. According to this model, charge carriers move through the material by hopping from trap to trap. The charge carriers may be trapped by chemical impurities or structural defects. Another interesting CVC feature is the presence of negative difference conductivity (NDC) with $\alpha \approx -2$. The switching to this mechanism goes through the rectification law ($\alpha = 0.5$).

The behavior is strongly different for the second P6ATb device (Fig. 4). The conductivity in the forward direction is two orders higher than for the reverse one. Both curves have a part with $\alpha = 1.25$. However, it is only the curve in the forward direction that has an injection region with $\alpha \geq 2$ and all curves have a small part of the NDC. Conductivity σ in both cases can be evaluated according to the equation $\sigma = I \times L / (V \times S)$, where L is the pentacene film thickness, S is the contact area. These data are summarized in Table 1 for the P6ATa and P6ATb devices (with parameters $L_a = 7 \times 10^{-6}$ cm, $L_b = 5 \times 10^{-6}$ cm, $S = 0.01$ cm²) at $V = 1$ V. It can be seen from Table 1 that the rectification factor for P6ATb is approximately 100 times higher than that of P6ATa. Fig. 5 illustrates a comparison of CVC for both samples deposited at various conditions. The conductivity in the forward direction is higher for P6ATb and lower for the reverse direction in respect of the P6ATa sample. Fig. 6 presents SEM images for samples P6ATa and P6ATb. The surface morphology of these samples shows the following features. There are randomly distributed particles 3-5 μ m in size. A different layer growth mode can be noticed. The lower growth rate, due to a lower plume flux density for sample P6ATb, leads to a decrease in the number of inhomogeneities and the formation of a much smoother surface of the layer. On the contrary, crystallites, 5 μ m in size, with sharp boundaries are easily visible at the surface of the P6ATa sample. In both cases grains having a size in the range of 40-60 μ m are also visible.

4. CONCLUSIONS

A pulsed laser deposition technique was developed for epitaxy of pentacene films. The difference in the electrical properties was recognized to be dependent on the substrate orientation with respect to the pentacene plasma plume. A fine structure of current voltage characteristics determined by a dif-

ferential approach included the following peculiarities of the I-V behavior with differential slope $\alpha = 1; 1.25; 2; 0.5; -1; -2$. The different electrical properties of the device were in a close relation to the crystal structure of the layers.

REFERENCES

- [1] W.J.E. Northrup // *Phys. Rev. B* **66** (2002) 121404-1.
- [2] A.R. Volk, R.A. Street and D. Knipp // *Phys. Rev. B* **66** (2002) 195336-1.
- [3] M. Hong, B.S. Kim and Y.U. Lee, *SID International Symposium* (PUBLISHER???, 2005).
- [4] Y. Kawamura, K.Z. Toyoda and S. Namba // *Appl., Phys. Lett.* **40** (1982) 374.
- [5] T. Ya. Gorbach, M. Kuzma, E. Sheregii, P.S. Smertenko, S.V. Svechnikov and G. Wisz // *Appl. Surface Science* **96-98** (1996) 881.
- [6] J.M. Maud, A.J. Salih and J.M. Marshall // *Synthetic Metals* **102** (1999) 986.
- [7] D.B. Chrisey, A. Pique, R.A. McGill, J.S. Horwitz, B.R. Ringeisen, D.M. Bubb and P.K. Wu // *Chem. Rev.* **103** (2003) 553.
- [8] G. B. Blanchet, C. R. Fincher and I. Malajovich // *J. Appl. Phys.* **94** (2003) 6181.
- [9] F. Schreiber // *Phys. Stat. Sol. (a)* **6** (2004) 1037.
- [10] T. Ya. Gorbach, P.S. Smertenko, S.V. Svechnikov, M. Kuźma, G. Wisz and R. Ciach // *Applied Surface Science* **154-155** (2000) 495.
- [11] P. Smertenko, L. Fenenko, L. Brehmer and S. Schrader // *Advantages in Colloid and Interface Science* **116** (2005) 255.
- [12] M.A. Lampert and P. Mark, *Current Injection in Solids* (Academic Press, New York, 1970).
- [13] A. N. Zyuganov and S. V. Svechnikov, *Contact-injection phenomena in semiconductors* (Naukova dumka, Kiev, 1981).
- [14] S.M. Sze, *Physics of semiconductor devices* (John Wiley and Sons, Inc., New York, 1981).
- [15] M. Pope, *Electronic Processes in Organic Crystals and Polymers* (Oxford University Press, New York, 1999).
- [16] R. Ciach, Yu.P. Dotsenko, V.V. Naumov, A.N. Shmyryeva and P.S. Smertenko, *Solar Energy Materials & Solar Cells* **76/4** (2003) 613.
- [17] L.I. Bereginisky, Nan-Ihn Cho, Jin-Ho Oh, P.S. Smertenko, S.V. Svechnikov and

- S.I.Vlaskina, In: *New Photovoltaic Materials for Solar Cells* (Cracow, 1996), p.43.
- [18] L.A.Ivashchenko, G.V.Rusakov, P.S.Smertenko, S.V.Svechnikov and S.I.Vlaskina, In: *New Photovoltaic Materials for Solar Cells* (Cracow, 1996), p.54.
- [19] N.A.Davidenko, L.I.Fenenko, A.A.Ishchenko, G.P.Olkhovik and P.S.Smertenko // *Functional Materials* **7***4*(1) (2000) 664.
- [20] N.A.Davidenko, L.I.Fenenko, A.A.Ichtchenko, M.Kuzma, P.S.Smertenko and S.V.Svechnikov // *Synthetic Metals* **122**/1 (2001) 173.
- [21] S. Svechnikov, P. Smertenko, N. Guba, L. Grebinska, L. Fenenko and V. Pokhodenko // *Mol. Cryst. Liq. Cryst.* **361** (2001) 119.
- [22] V.S.Reddy, S.Das, S.K.Ray and A.Dhar // *J.Phys.D:Appl.Phys.* **40** (2007) 7687.