Vacuum-deposited organic thin-film transistors based on dinaphthotetrathienoacenes

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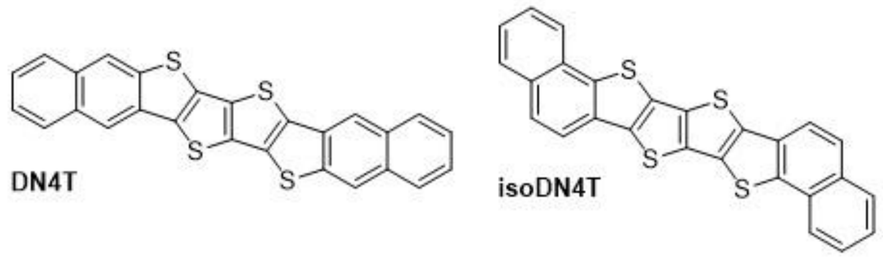
Introduction

In the last decades an interest for organic semiconductor films has been growing, due to their application in optical and electronical devices. Here we investigate the electrical performance of DN4T and isoDN4T, two large thienoacenes molecules, by fabricating thin-film field effect transistors (TFTs) through vacuum-sublimation. The structures-properties relationships of the two molecules are investigated using atomic force microscopy, X-ray diffraction along with charge-transport measurements, providing a detailed comparison of the semiconductor thin-film morphology, crystallinity and electrical performances as a function of the substrate temperature.The study contributes to a wider understanding of the relationship between the molecular structure and the charge transport with respect to the thin-film's crystal packing of large thienoacenes.



Materials and methods

TFTs were fabricated through thermal evaporation in high vacuum on highly doped silicon wafer substrates overgrown by atomic layer deposition with a 30 nm thick dielectric layer of Al_2O_3 which was treated with n-tetradecylphosphonic acid (TDPA) prior to the deposition of the semiconductors. Bottom-gate top-contact (BGTC) configuration was fabricated by thermal evaporation of gold with a typical thickness of ca. 50 nm using shadow masks. During the deposition, the substates were kept at temperatures ranging from 40 to 140°C with 20°C steps, respectively. The evaporation rate of 0.5 Å/s resulted typically film thicknesses of ca. 25 nm. The TFTs have a channel length (L) of 215 µm and a channel width (W) of 480 µm.

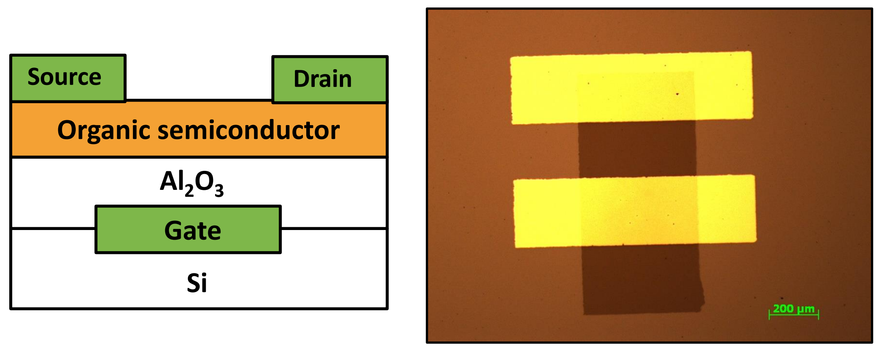
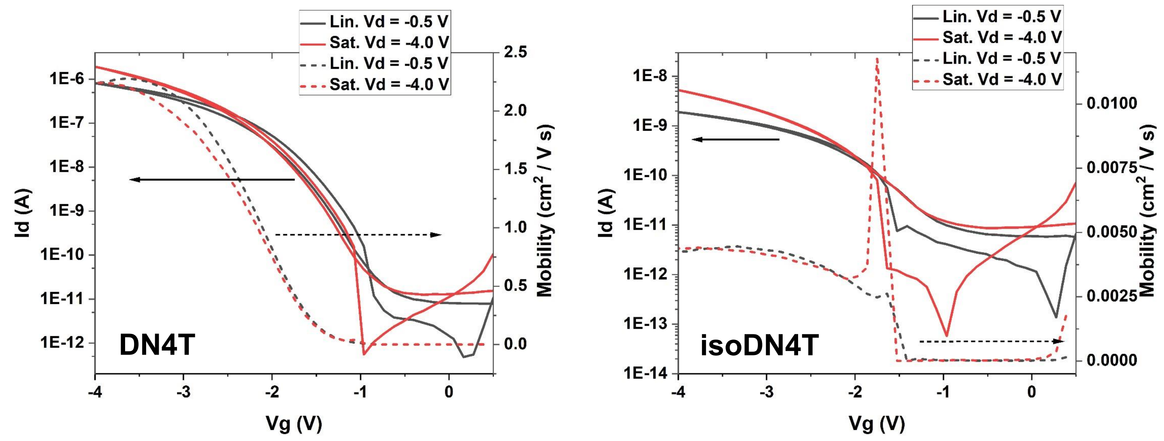


Illustration and optical microscope image of BGTC transistor

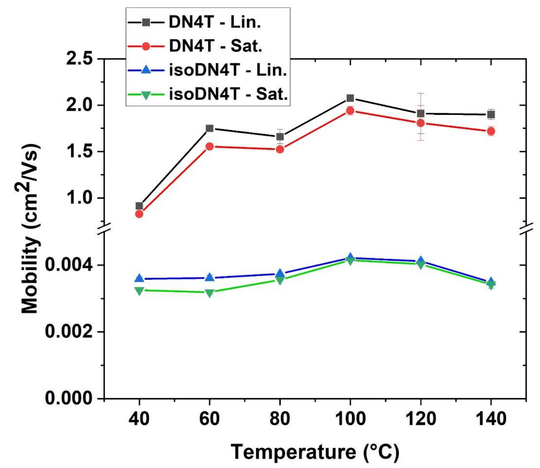
Results

❖ Electrical performances

DN4T based devices show a charge carrier mobility of 0.9 up to 2.1 cm^2/Vs for DN4T, depending on the substrate temperature along with an on/off current ratios (I_{ON}/I_{OFF}) of ~10^5-10^6, while isoDN4T devices gave rather poor performance with a mobility of 0.0029 up to 0.0042 cm^2/Vs and I_{ON}/I_{OFF} of ~10^2-10^3. The TFTs exhibit a threshold voltage between -1.8/ and -2.4 V and for both the isomers the highest charge carrier mobilities were found for devices deposited at a substrate temperature of 100°C.



Transfer characteristics of DN4T and isoDN4T at substrate temperature of 100°C



Mobility as a function of the substrate temperature for DN4T and isoDN4T TFTs

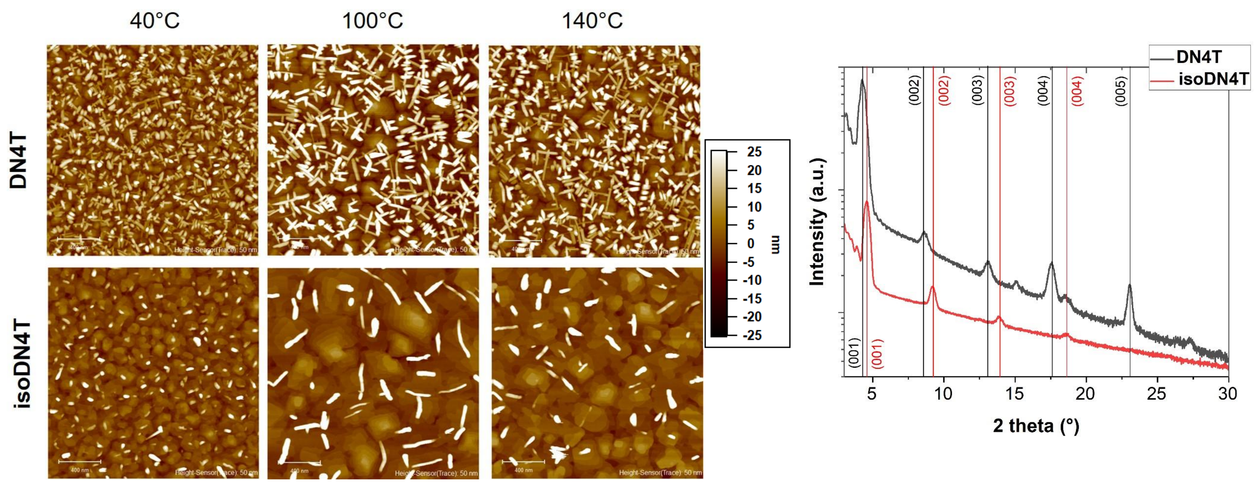
❖ Thin-film morphology and crystallinity

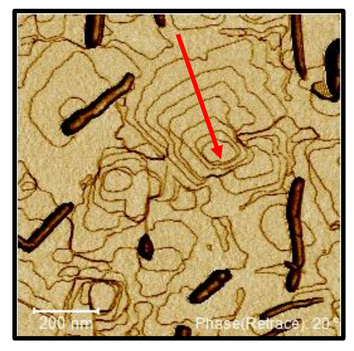
A terrace pattern covered by needle-shaped crystals arises from the images at all substrate temperatures. Particularly for DN4T, the quantity of these three-dimensional needle-shaped crystals is higher compered to isoDN4T samples. Remarkably:

- the longest grain diameter is achieved at a substrate temperature of 100 °C for both DN4T and isoDN4T samples
- the height of the terrace steps corresponds to the length of DN4T and isoDN4T, suggesting that in the crystalline films the molecules are oriented approximately upright with respect to the substrate. This observation is confirmed by XRD patterns.

Compound	Substrate T (°C)	Terrace height (Å)	Averaged d-spacing (Å)	Grain diameter (nm)
DN4T	40	20 ± 2		145 ± 30
	100	20 ± 1	20.2 ± 0.5	250 ± 60
	140	18 ± 2		200 ± 15
isoDN4T	40	18 ± 1		190 ± 30
	100	18 ± 2	19.2 ± 0.1	460 ± 75
	140	20 ± 2		320 ± 55

Extracted data from AFM and XRD characterization





Top on the left: AFM topography images of DN4T and isoDN4T at different substrate temperature (size of the images is 2×2 µm)
Top on the right: XRD patterns of DN4T and isoDN4T deposited at 100 °C.
Bottom on the left: enlargement of AFM material contrast image, which show the film terrace structure (size of the image is 1×1 µm)

Conclusions

- TFTs were fabricated using DN4T and isoDN4T through vacuum-sublimation
- The electrical performance are consistent with the already reported values for DNTT and isoDNTT,[1,2] confirming the analogy between the two system of thienoacenes
- isoDN4T gave rather poor performance compared to DN4T, confirming the structure-properties relationship and the computational calculations
- The thin-films were characterized through AFM and XRD, elucidating the crystalline arrangement

Acknwoledgement

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References:

1. Yamamoto, T., *J. Am. Chem. Soc.* **129**, 2224–2225 (2007)
2. Yamamoto, T., *BCSJ* **83**, 120–130 (2010)