0.0.1 Molecular and Nanoelectronics

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Electronic devices based on semiconductors formed by organic molecules are the focus of our research group. Transistors built from organic materials allow extreme cheap production as well as new applications like the use of bendable foils as transistor substrates. Furthermore, shrinking of spatial dimensions to the length scale of individual organic molecules (i.e. nanometer-scale) enables qualitatively new device concepts, like the monolayer transistor or molecular electronics devices. In the latter case individual molecules are used as transistors or diodes. Goal of the research is the understanding of the electronic transport mechanism in organic materials, at interfaces involved and across molecular junctions. This includes testing of new (molecular) device concepts and electronics at length scales below those of state-of-the-art silicon electronics.

Highlights Main advantages attributed to organic device concepts (organic radio-frequency information tags (RFID), organic solar cells, etc.) are the potentially very low productions costs, the low processing temperatures and the option for wet-chemical manufacturing. Due to the generally low carrier mobilities in organic materials organic devices are restricted to low-frequency applications so far. In 2006 in a systematic approach by shrinking the channel lengths of *organic field-effect transistors (OFET)* we were able to manufacture the *world-wide fastest polymer transistor* reported so far [3, 4]. The device realized in bottom-contact configuration based on the regio-regular polymer poly-hexylthiophene (P3HT, see Fig. 1) achieved a unity-gain bandwidth of 2 MHz at a low driving voltage of 10 V and a channel length of 480 nm. While these values wouldn't be a challenge for crystalline silicon devices they are extremely high for wet-chemically processable semiconductors. Furthermore, during this research work we could identify contact resistance at the metal-organic interface as main hindrance towards even higher frequencies predicted for lower channel lengths, e.g. for a 120 nm device shown in Fig. 1. While contact properties require for further optimization, MHz organic field-effect transistors will open new areas of applications. Their large-scale production will depend on upscaling of low-cost printing techniques, e.g. micro-contact printing or nano-imprint lithography.

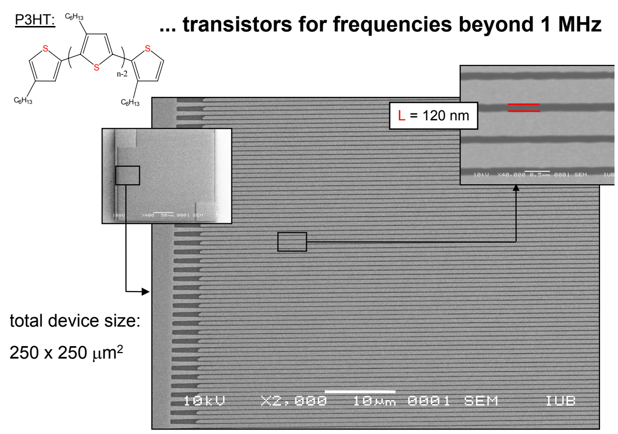

Figure 1: Polymer P3HT structure formula (upper left corner) and a top view of a L = 120 nm transistor structure prepared by e-beam lithography on an oxidized silicon wafer (main part). Light grey areas show the interdigitated gold electrodes (source & drain) and the dark areas are the SiO2 gate dielectric. The design allows for high current levels and small parasitic capacitances and is suitable to reach high frequencies.

Beside polymers also films consisting of small organic molecule can be utilized as active semiconductor compound in devices, as their are thiophenes or pentacene. Their crystalline ordering results in better defined systems and higher carrier mobilities. Main goal of the research is to understand and optimize contact properties and aging behavior, e.g. *almost ideal contact properties could be found for the system dihexyl-7-thiophene and gold.* A very fruitful cooperation was established in this area with the group of

Prof. Knipp (IUB) for pentacene-based devices [2].

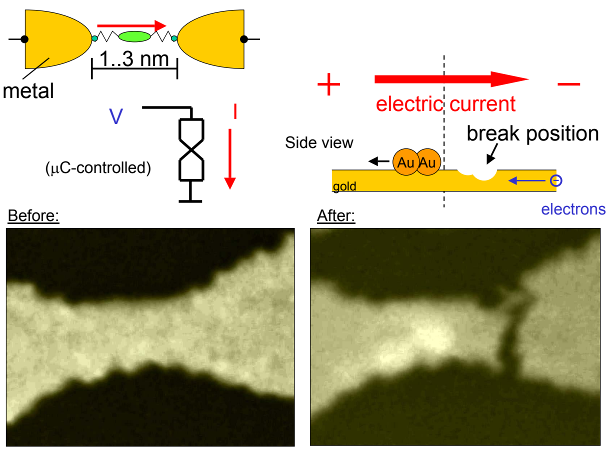

Figure 2: Molecular electronics: a contacted single molecule (upper part). Below the electromigration set-up and the principle of operation (pushing the gold atoms by electrons). The lower part shows scanning electron micrsocope (SEM) images of a gold nano wire (width ca. 100 nm) before and after the elctromigration process.

A further research highlight is the successful preparation of nano-sized electrodes (Fig. 2) to contact individual molecules utilizing an electromigration technique. In this approach an increasing electric current level is imposed on a lithographically defined gold nanowire until the wire breaks. Small gaps comparable to the size of individual molecules, i.e. $1 \cdots 3$ nm, can be realized via this technique. This approach was enabled by the development of self-made electronics including a fast microcontroller for realizing the feedback loop to control the applied voltage, which allows to stop this process at any time and gap size.

Organization

1. Organization committee: European Summer School on Biosensing with channels: faster, smaller, smarter, 2006, IU-Bremen.
2. Organization committee: Symposium Organic Thin Film Electronics: From Molecular Contacts to Devices (SYOE), 2007, DPG annual meeting, Regensburg.
3. Speaker of IUB graduate program Nanomolecular Science

Collaborations

1. *International University Bremen*
   Prof. Jürgen Fritz
   AFM-Analysis, Bio-Molecules
2. *International University Bremen*
   Prof. Dietmar Knipp
   Micro-Contact Printing, Organic Transistors
3. *International University Bremen*
   Prof. Arnulf Materny
   Lithographically designed SERS-Substrates
4. *International University Bremen*
   Prof. Stefan Tautz
   Organic Molecules at Surfaces, Molecular Electronics
5. *Universität Ulm*
   Prof. Peter Bäuerle
   Tailored Organic Molecules
6. *ISAS-Berlin*
   Prof. Norbert Esser
   Surface Optics at Self-assembled Monolayers
7. *Universität Bremen*
   Prof. Detlev Hommel
   Nano Lithography
8. *Universität Würzburg*
   Prof. Jean Geurts
   Characterization of Organic Transistors, Nano Lithography, Optical Analysis
9. *ICMAB, Barcelona, Spain*
   Prof. David Amabilino
   Tetrathiafilvalenes (TTF) Molecules for Organic Electronics
10. *Universidade do Algarve, Portugal*
    Prof. Henrique Gomes
    Electrical Analysis of Organic Transistors

11. *Nova Gorica Polytechnic, Slovenia*
    Prof. Gvido Bratina
    Time-of-Flight Analysis and Theoretical Simulations of Organic Devices

Grants

1. DFG, "Organic field-effect transistors: scaling behavior and interface properties" within Schwerpunktprogramm SPP 1121, "Organische Feldeffekt-Transistoren", Project WA 1039/2-1,2 (2004-2007)

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