

Molecular Organic Self-Assembled Monolayers Function as Field-Effect Transistors

Due to their low cost, nanometer-scale dimensions, and potential for self-assembly, molecular organic materials may someday replace their conventional, inorganic counterparts in electronic and optoelectronic devices. Working toward this objective, researchers from Lucent Technologies in Murray Hill, N.J. have fabricated field-effect transistors (FETs) based on self-assembled monolayers (SAMs) of molecular, organic insulator/semiconductor heterostructures (σ - π SAMs) by attaching π -electron moieties on insulating molecules (σ bonded).

In the January 7 issue of *Applied Physics Letters*, J.H. Schön and Z. Bao report the preparation of FETs based on σ - π SAMs, that demonstrate large in-plane conductance variations with applied gate voltage, high mobilities at room temperature, and high on/off ratios. The σ - π SAMs were formed on highly doped Si substrates (see Figure) through a three-step process including the self-assembly of a vinyl-terminated monolayer of tertadecyl-1-enyltrichlorosilane (TETS, $\text{SiC}_{13}(\text{CH}_2)_{12}\text{CH}=\text{CH}_2$), subsequent oxidation of the vinyl end groups resulting in $-\text{COOH}$ end groups and pyrene methanol, and an esterification reaction between these end groups and the methanol. In the researchers' FETs, the molecules' alkyl chains acted as the gate insulator, and the π -electron moieties acted as the active semiconductor. Gold electrodes were

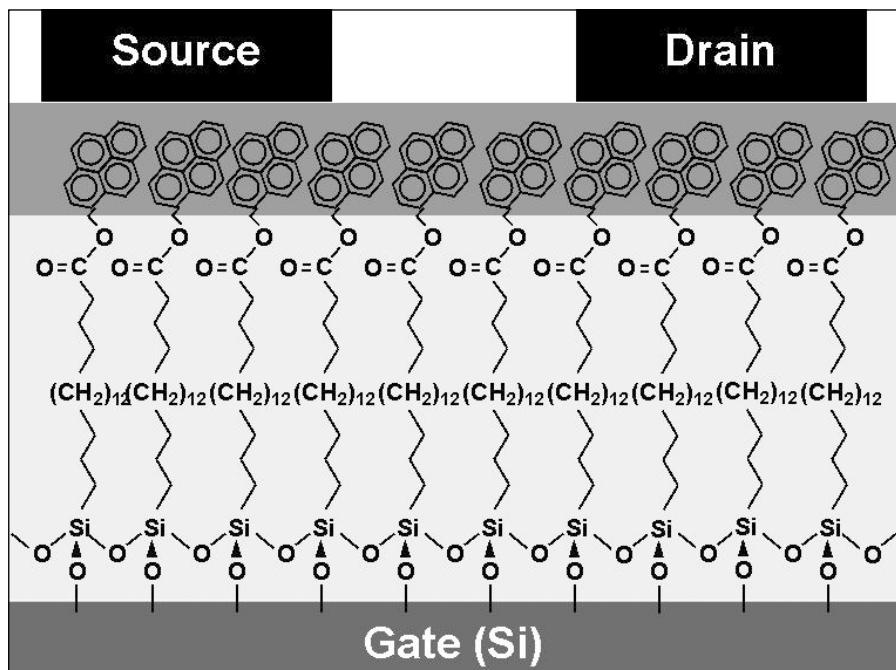


Figure. Structure of the σ - π self-assembled monolayer field-effect transistor (σ - π SAM FET). The silane is grafted on the highly doped silicon substrate, which also serves as the gate electrode. The conjugated pyrene moieties are attached to the silane by esterification of the SAM. Two gold source and drain electrodes are thermally evaporated through a shadow mask. Reprinted from *Appl. Phys. Lett.*, January 7, 2002, **88**. Copyright 2001 American Physical Society.

evaporated through a mask at 100 K onto the σ - π SAMs to define channel lengths of 25 μm , and contacts were formed using Pt wires and eutectic InGa. By applying a neg-

ative voltage to the gate electrode, or the Si substrate in this case, the researchers were able to modulate the in-plane conductance of the devices by more than 5 orders of magnitude. They measured room-temperature mobilities of up to 0.05 $\text{cm}^2/\text{V s}$ and achieved on/off current ratios that exceeded 10^5 . They also discovered that the mobility was thermally activated with an activation energy of 45 meV, a behavior that they attribute to defects, disorder, and domain boundaries in the SAMs. Additionally, since the channel length can be controlled by varying the SAM thickness, Schön and Bao were able to use SAMs to pattern transistors with ultrashort (2 nm) channel lengths. For these nano-FETs, a current modulation of 3 orders of magnitude and a room-temperature mobility of $2\text{--}3 \times 10^4 \text{ cm}^2/\text{V s}$ were achieved.

"Our results reveal that different groups of the same molecule can be used as the gate insulator and the active organic semiconductor," said Schön, "which is a step toward realizing molecular-scale transistors."

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