



Application Note AN-FET-001

Characterization and performance studies of field-effect transistors (FETs) using µStat-i 400

In recent years, field-effect transistors (FETs) have become more commonly used as a sensing platform for a multitude of electrochemical and biological applications.

These devices are promising bioelectronic transducers that allow both low-potential operation and stable potentiometric measurements. FETs are now seen as an attractive alternative to using conventional electrochemical detection systems in the scientific community.

This Application Note gives in-depth guidance about how to operate Metrohm DropSens bipotentiostat devices for the characterization of FETs and their use as transducers. A single µStat-i 400 device, a small and portable bipotentiostat and galvanostat, is used to demonstrate the following experiments.

INTRODUCTION

When field-effect transistors (FETs) are properly functionalized with appropriate biorecognition elements such as antibodies or enzymes, they are shown to offer a unique platform for real-time, specific, and label-free transduction of biochemical events. For example, properly functionalized FETs can detect the presence of gases, ions, and viruses, and even monitor cell growth in real-time.

These FET-based biosensors work with an electric field that modulates charge carriers through a semiconductor material. Such biosensors can directly convert specific biological interactions directly into electrical signals without the need of an electroactive label.

INSTRUMENTATION AND SOFTWARE

The Metrohm DropSens µStat-i 400 was used for the purpose of showing how to connect accessories and perform experiments with FETs. This instrument is a portable bipotentiostat and galvanostat that can work wirelessly or be connected to a computer by USB cable. The instrument is controlled by the DropView 8400 software, a dedicated and easy-to-use intuitive software that allows users to perform electrochemical measurements and view the obtained graphical signal in real time.

Metrohm DropSens also offers the AUFET30 (Figure 1a), a gold electrochemical transducer fixed to a plastic substrate. This platform is designed in a coplanar arrangement integrating all electrodes (drain-source channel and gate) in a single piece for the easy fabrication of FETs. This configuration always ensures the same separation distance is kept between the electrodes and provides an easy modification of the channel with the semiconductor material. The drain-source channel is an interdigitated system of six bands in each electrode. The width of the bands' gap is 30 µm, while the length of the bands is 270 µm. The gate electrode is a square electrode (9 mm^2) and is placed 2 mm from the drain-source channel.

The dedicated connector BIDSCFET (Figure 1b) was designed for AUFET30 to easily connect to any instrument. Here, AUFET30 is shown in the slot located on the front side of this connector, while in the rear there are four female banana connectors that match the colors of the male banana connectors of the provided cables for an intuitive setup.

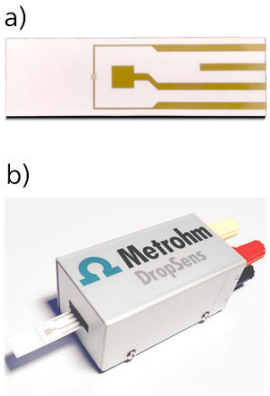


Figure 1. a) AUFET30 platform for the fabrication of FETs. (b) BIDSCFET connector.

FET connection

A I-BICABSTAT cable connector is included with the bipotentiostat / galvanostat µStat-i 400. This cable has 5 male banana connectors labelled as described in Figure 2.

In order to perform experiments with FETs, different connection arrangements are described depending on the desired experimental application.

Red – (WE1)

Red – (S)

Yellow – (XWE2)

Black – (A)

Blue – (R)

Green – (≒)

Figure 2. Labels for the 5 different banana connectors

Connection for FET characterization

During FET characterization, drain-source current (I_{D-S}) is commonly evaluated by sweeping drain-source voltage (V_{D-S}) at different steps of gate-source voltage (V_{G-S}). Therefore, the arrangement of the connections is as follows:

- XWE2 (yellow) banana connector is connected to the gate electrode.
- R (blue) and A (black) banana connectors are connected to the source electrode.
- WE1 (red) and S (red) banana connectors are connected to the drain electrode.

In order to carry out the characterization, several *LSV+AD* experiments are performed while varying V_{G-S}. During the experiment the graphics display area plots two curves simultaneously: a blue one corresponding to I_{D-S} *vs* V_{D-S} and a red one corresponding to I_G *vs* V_{D-S}. After performing the different LSV+AD experiments, the graphics display area shows a plot similar to the one in Figure 3.

The blue lines show the linear relationship between I_{D-S} and V_{D-S} obtained at different V_{G-S} ranging from -0.40 V to +0.40 V. The linear dependence for the evaluated device confirms that the ohmic contact is kept between the gold electrodes of the drain-source channel and the underlying semiconductor film.

Once the connections have been made, select the *LSV+AD* technique in the DropView 8400 software. The parameters of the experiment can be set up in the parameter windows of the software.

- Ebegin: initial value for V_{D-S}
- Eend: Final value for V_{D-S}
- E2: Gate voltage V_{G-S}

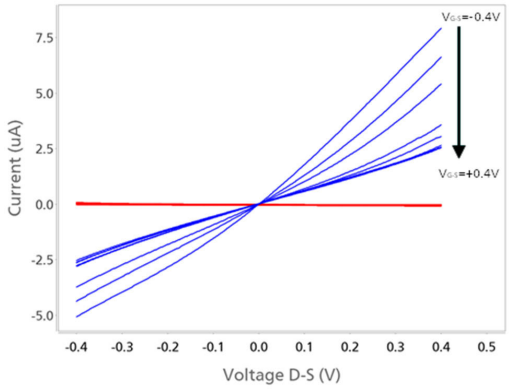


Figure 3. Plot of ID-S (blue) and IG-S (red) versus VD-S obtained at different VG-S with the DropView 8400 software.

Connection for transfer curves I-V: sweep gate-source voltage applying fixed voltage in drain-source channel

In order to obtain the typical transfer curves, the drain-source current (I_{D-S}) is registered at a fixed voltage while V_{G-S} is swept. After characterization (Figure 3), a large variation in I_{D-S} values can be observed depending on the applied V_{G-S} at a V_{D-S} of +0.40 V. For that reason, this V_{D-S} value (+0.40 V) has been selected to perform the following transfer curves experiment. The operating procedure is very similar to the previous description, but the connections must be made as described below.

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- WE1 (red) and S (red) banana connectors are connected to the gate electrode.
- R (blue) and A (black) banana connectors are connected to the source electrode.
- XWE2 (yellow) banana connector is connected to the drain electrode.

After starting the experiment, the graphics display area shows two curves simultaneously: a red one corresponding to named transfer curve I-V (I_{D-S} *vs* V_{G-S}), and a blue one related to leakage current (I_{G-S} *vs* V_{G-S}) (Figure 4).

Once the connections have been made, select the *LSV+AD* technique in the DropView 8400 software. The parameters of the experiment can be set up in the parameter windows of the software.

- Ebegin: initial value for V_{G-S}
- Eend: final value for V_{G-S}
- E2: drain-source voltage

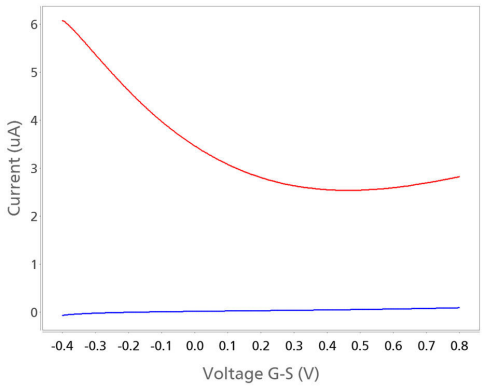


Figure 4. Plot of transfer curve I-V (ID-S, red line) and leakage current (IG-S, blue line) versus VG-S obtained with the DropView 8400 software.

Connection for continuous measurements

For some applications, it is necessary to perform measurements in continuous mode, because once the optimum parameters have been selected a fixed voltage is applied between gate and source, and another fixed voltage is also applied to the drain. In this case, the operational setup is the same as the one used for the transfer curves. However, in this situation a different technique is employed. *Amperometric Detection* is selected in the DropView 8400 software. In the parameter windows of the software, select «2» as the number of channels (Figure 5a). Subsequently, click the Multichannel parameter tab inside of the parameter window (Figure 5b), then set the gate-source voltage in channel 1 and drain-source voltage in channel 2. After starting the experiment, the graphics display area will show two curves, a red one and a blue one related to I_{D-S} *vs* time and I_{G-S} *vs* time, respectively.

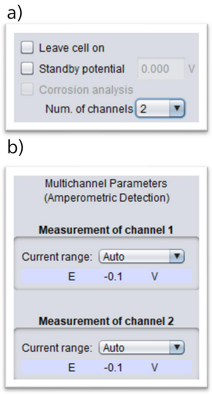


Figure 5. a) Section of the parameter window in DropView 8400 where the number of channels must be selected. (b) The Multichannel parameter tab within the parameter window where E of channel 1 corresponds to VG-S and E of channel 2 corresponds to VD-S.

CONCLUSION

Metrohm DropSens bipotentiostats allow users to simultaneously display the gate-source and drainsource currents in a unique figure, meaning that the transfer curve I-V and the leakage current can be obtained for each experiment. The same protocol written in this Application Note can be followed with the µStat 400.

In addition, AUFET30 is an electrochemical transducer for the easy development of FETs. Together with the dedicated connector BIDSCFET it facilitates adaptation to any bipotentiostat to perform reliable measurements with higher sensitivity than conventional three-electrode electrochemical cell setups.

CONTACT

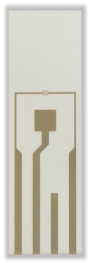
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CONFIGURATION



Stat-i 400 Bipotentiostat/Galvanostat/Impedance Analyzer (EIS)

µStat-i 400 is a portable BiPotentiostat/Galvanostat/Impedance Analyzer (EIS) that can be applied for Voltammetric, Amperometric, Potentiometric and EIS measurements and can be used with one- or two-working electrodes configuration. Li-ion Battery powered, it can be easily connected to a PC via USB and wireless.



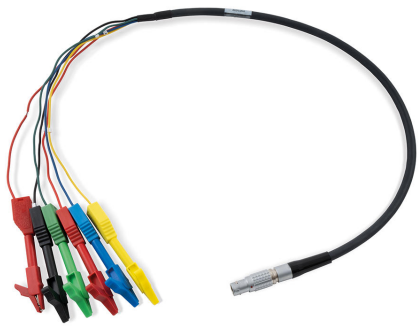
Flexible Gold Field-Effect Transistors with coplanar gate

Disposable flexible devices for Field-Effect Transistor (FET) are made of gold onto plastic substrate. These electrodes are useful to obtain sensing phases.



Connector for Field-effect transistor Electrodes

Boxed connector that acts as an interface between ref. AUFET30 electrodes and any kind of potentiostat



Stat Cable connector for Stat-i 400 and conventional electrodes

µStat Cable connector for µStat-i 400 and conventional electrodes