International Conference ONLINE
★ February 23-24, 2021 ★

Transition metal dichalcogenide monolayers as gate controlled field emitters

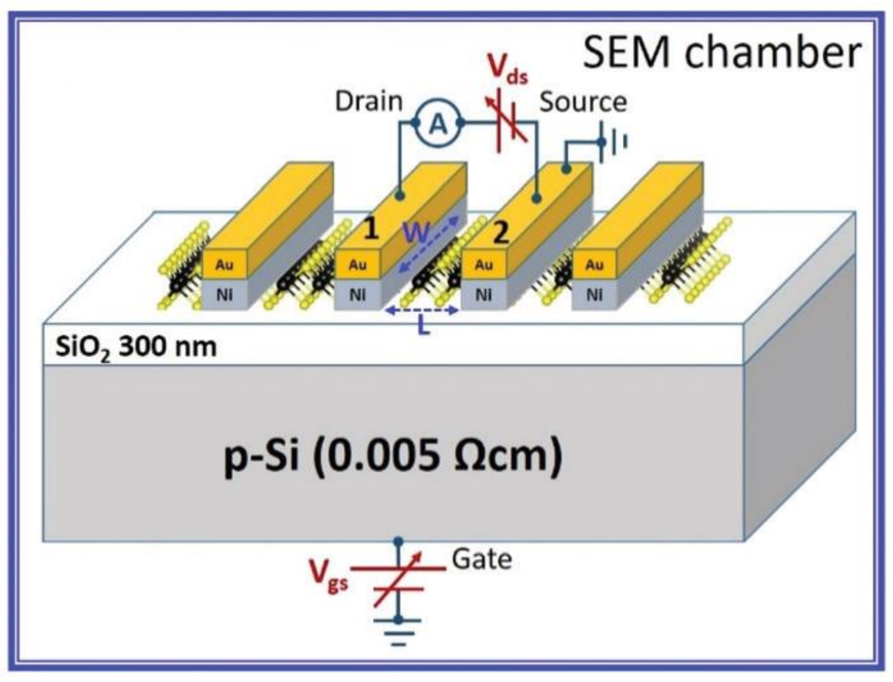
Enver Faella[1,2], Aniello Pelella[1,2], Alessandro Grillo[1,2], Maurizio Passacantando[3], Marika Schleberger[4], Niall McEvoy[5] and Antonio Di Bartolomeo[1,2]

[1]CNR-SPIN Salerno, via Giovanni Paolo II, 132, Fisciano (SA), Italy
[2]Physics Department, University of Salerno, via Giovanni Paolo II, 132, Fisciano (SA), Italy
[3]Dept of Physical and Chemical Science, University of L'Aquila, and CNR-SPIN, via Vetoio, L'Aquila, Italy
[4]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Lotharstrasse 1, Duisburg D-47057, Germany
[5]AMBER & School of Chemistry, Trinity College Dublin, Dublin 2, Ireland

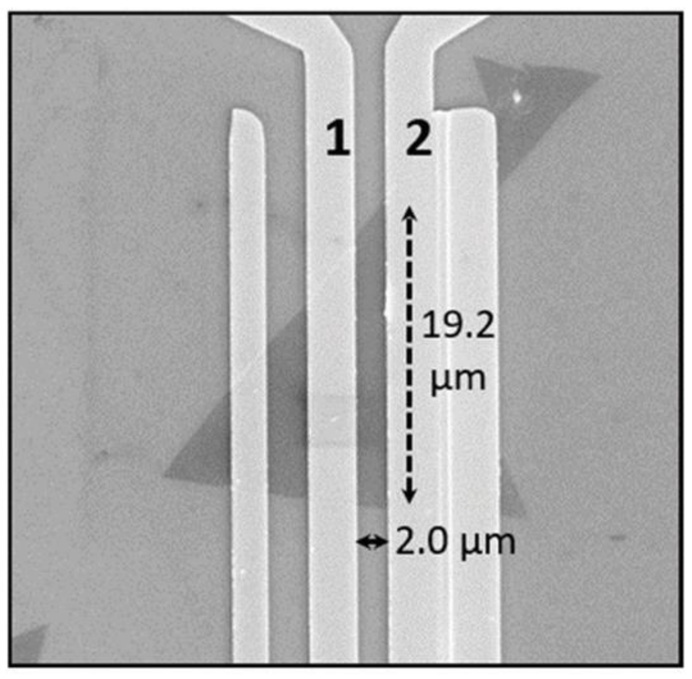
Abstract

Monolayers of molybdenum disulfide (MoS_2) and tungsten diselenide (WSe_2) have been synthetized by chemical-vapour deposition on a SiO_2/Si substrate. They were initially contacted to realize back-gated field-effect transistors, both showing n-type conduction under high-vacuum conditions. The n-type conduction enables field emission (FE), i.e. the extraction of electrons by quantum tunneling under the application of a high electric field. Local field emission measurements from the edges of the monolayers have been performed inside a scanning electron microscope (SEM) by using a nanomanipulated tip-shaped anode [1,2]. We demonstrate a turn-on field of the order of 100 V μm−1 and a good time stability of the emitted current for both materials. Finally, we show that the field emission current can be modulated by the back-gate voltage, opening the way for the development of a field-emission vertical transistor.

WSe_2

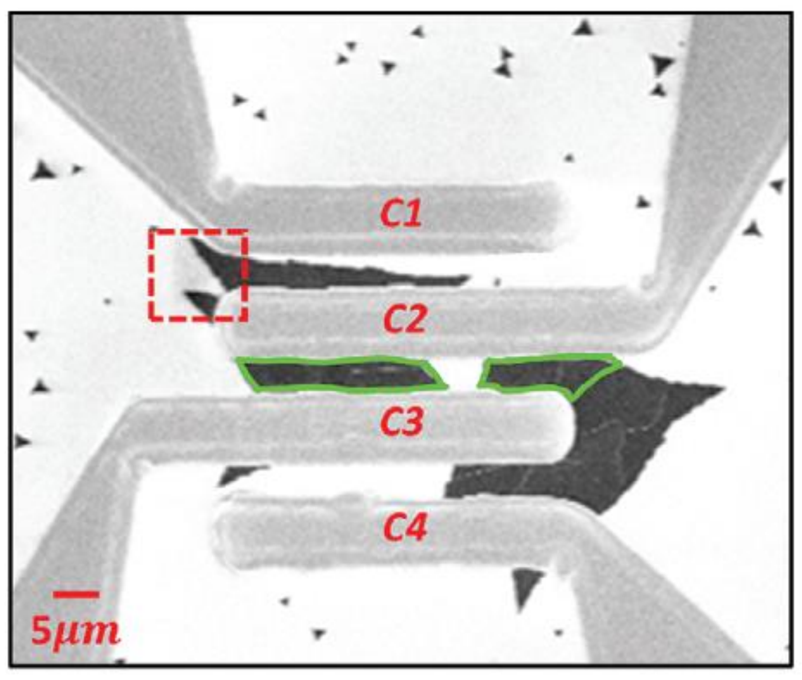


Layout of a typical device, where the Si substrate, functioning as the back-gate, is connected to a voltage generator and the metal leads, constituting the source and the drain of the transistor, are connected to a source-measurement unit (SMU).

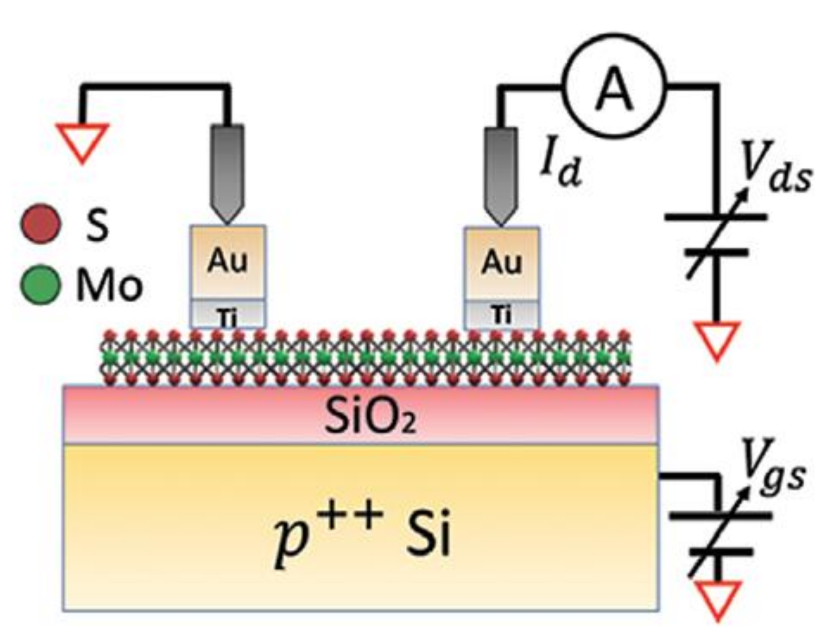


Scanning electron microscopy (SEM) top view of a contacted WSe_2 flake. The transistor formed between the leads 1 and 2 corresponds to a WSe_2 channel with length L ≈ 2 μm and average width W ≈ 19 μm.

MoS_2



The MoS_2 flakes (CVD grown) are monolayer according to the PL and Raman characterization performed before metal deposition

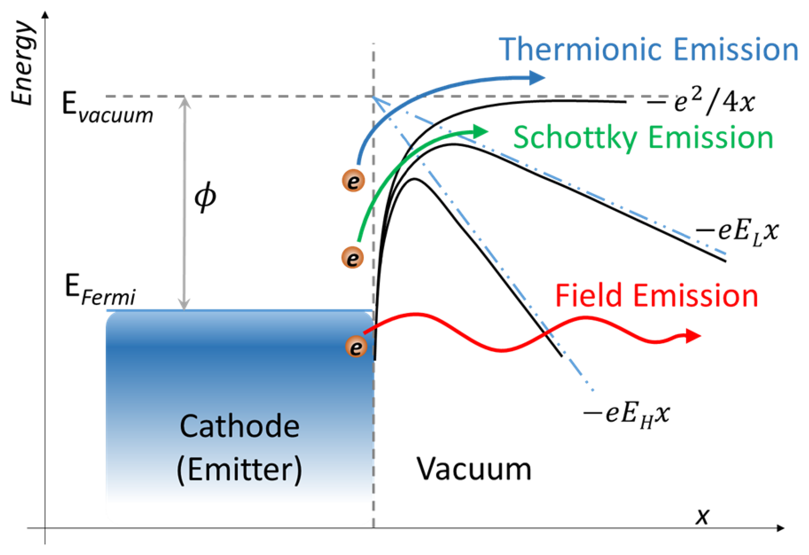


MoS_2 FET layout and schematic of the common source configuration used for the electrical characterization

Ti/Au (10/40 nm) electrodes

Field Emission

When the applied field becomes > 10^7 V/cm, electrons can leave the metal and escape into vacuum



Fowler-Nordheim theory

Effective emitting area

$$I_{FE} = S \cdot A \frac{F^2}{\varphi} exp\left(-B\frac{\varphi^{3/2}}{F}\right)$$

Work function

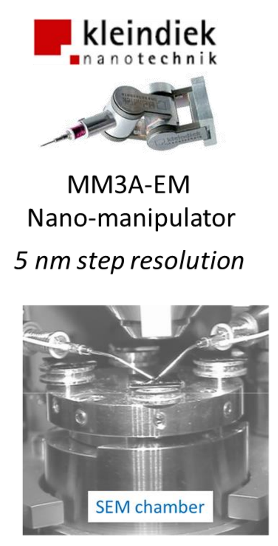
Costants
$A = 1.56 \times 10^{-10}[AV^{-2}eV]$
$B = 6.83 \times 10^{9}[VeV^{-3/2}m^{-1}]$

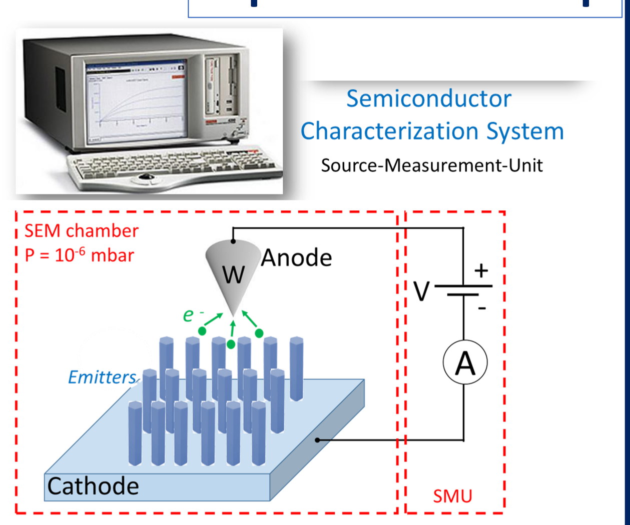
Current Density
$J_{FN} = I_{FE}/S \quad [A/m^2]$

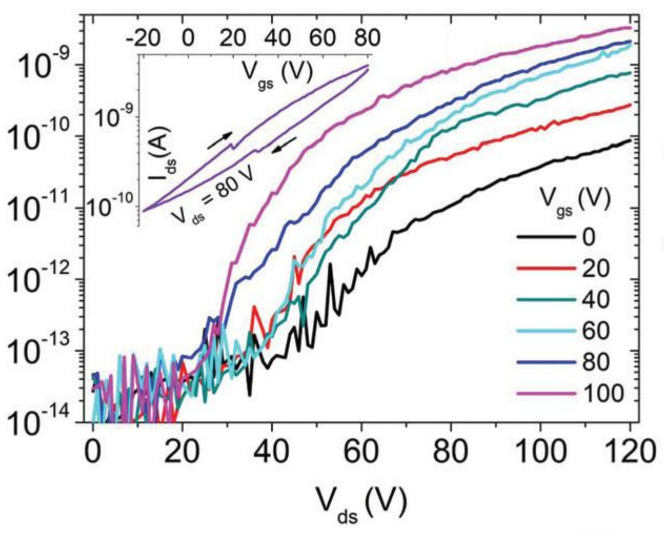
Local Electric Field
$F = \beta \cdot V \cdot d^{-1} \quad [V/m]$

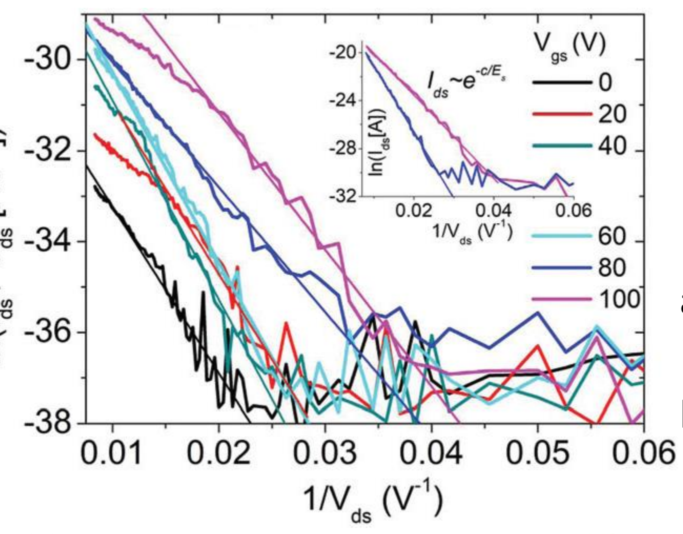
Field enhancement factor — Cathode-anode separation distance

Experimental setup

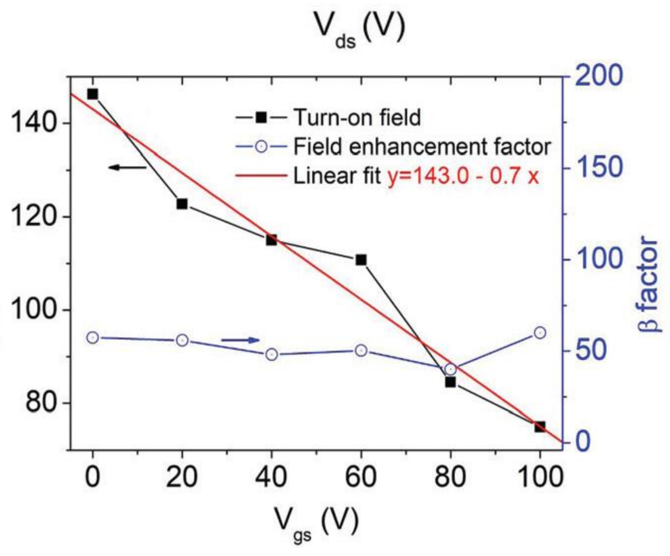


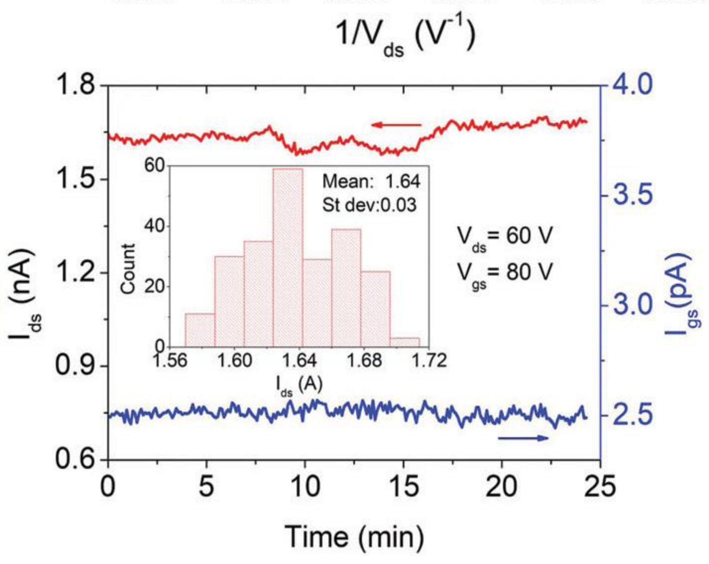






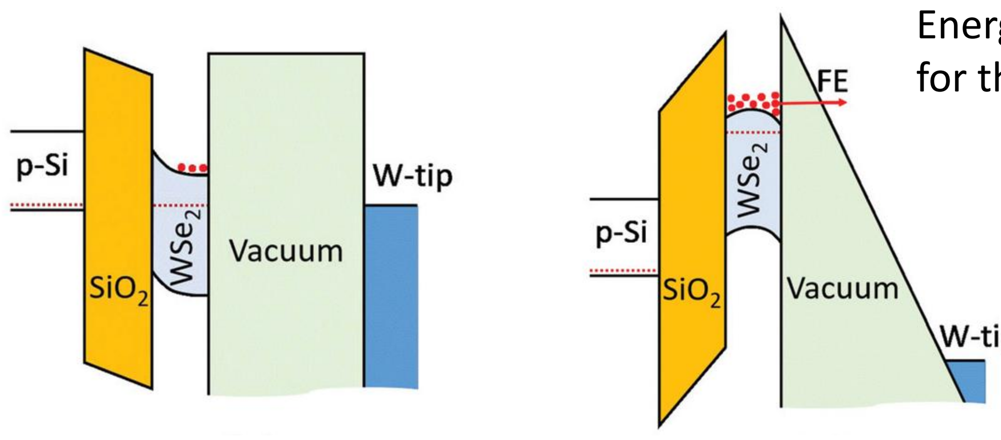
FE measurements with the W-tip at a distance d ~ 400 nm and corresponding Fowler–Nordheim plots





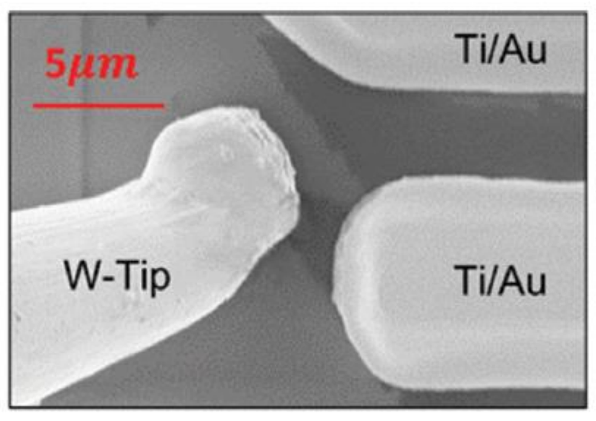
Turn-on field and field nhancement factor versus V_{gs}

FE current stability at V_{ds} = 60 V and V_{gs} = 80 V

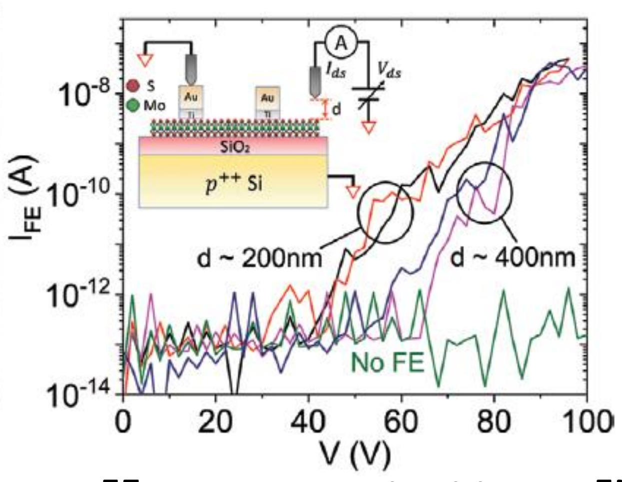


Energy band diagram along the vertical direction for the unbiased and biased ($V_{ds} > V_{gs} > 0$ V) cases

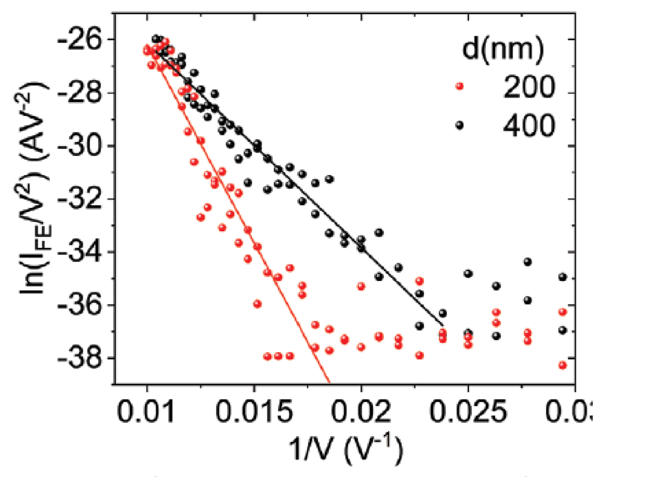
The application of a positive gate voltage induces n-doping in the WSe_2 channel. The availability of electrons impinging on the field-narrowed vacuum barrier, resulting from the Vds voltage, favors the FE current, which is thereby gate-controlled.



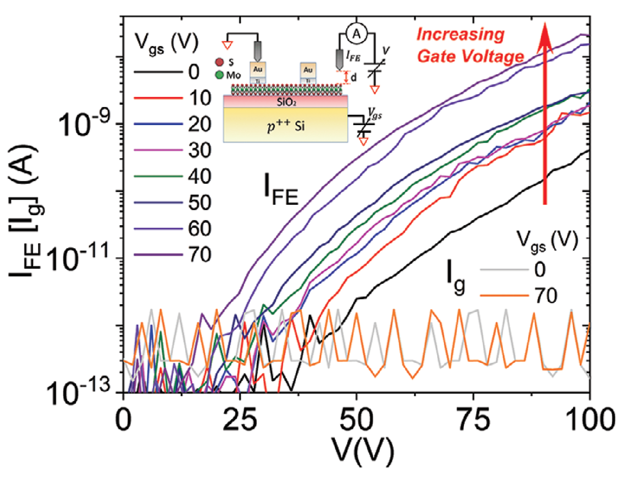
The W-tip works as the anode while the Ti/Au lead is the cathode

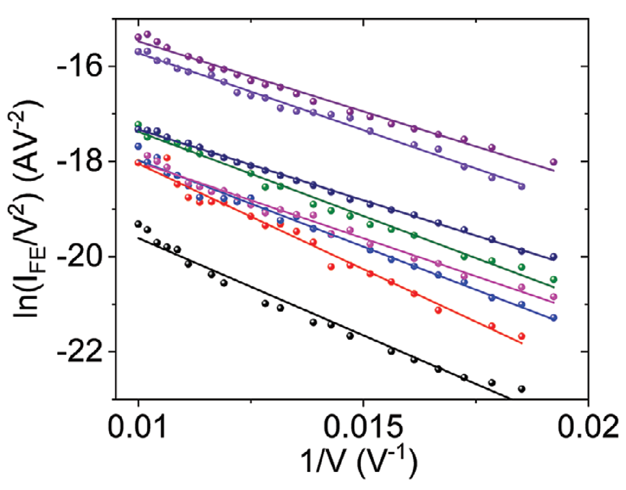


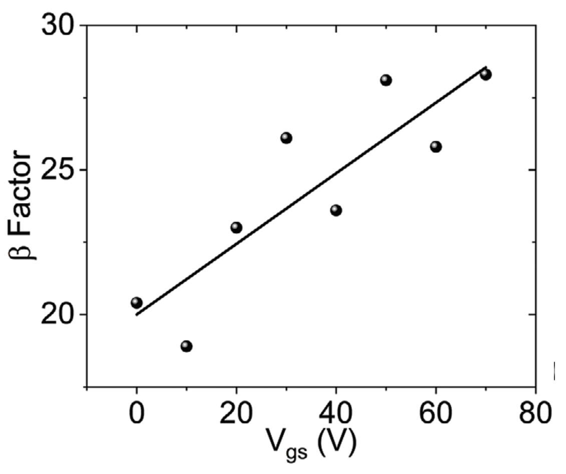
FE measurements at two different distances



FN plots: field enhancement of about 16.5 (at 200nm) and 17.0 (at 400 nm)







The back gate can be used to electrically control the doping level of the MoS_2 channel. Greater availability of conduction electrons increases the tunneling probability. Therefore, a positive voltage on the gate is expected to enhance the FE current. Indeed, experimental data confirm an increasing FE current for increasing gate voltages.
The growing field enhancement factor with V_{gs} is an artifact related to the enhanced MoS_2 doping level rather than to a real field enhancement.

CONTACT PERSON

Filippo Giubileo, Researcher
Institute for SuPerconductors, Innovative materials and devices (SPIN),
National Research Council (CNR) , Salerno, Italy
E-mail: filippo.giubileo@spin.cnr.it

REFERENCES

1. A. Pelella, A. Grillo, F. Urban, F. Giubileo, M. Passacantando, E. Pollmann, S. Sleziona, M. Schleberger, and A. Di Bartolomeo, Adv. Electron. Mater, (2020) 2000838.
2. A. Di Bartolomeo, F. Urban, M. Passacantando, N. McEvoy, L. Peters, L. Iemmo, G. Luongo, F. Romeo and F. Giubileo, Nanoscale, 11 (2019) 1538

GRAPHENE FOR US ONLINE
International Conference
★ Feb. 23-24, 2021 ★