Screening in insulating granular aluminium films

Insulating granular aluminium films are experimental realizations of disordered insulators. They have received a renewed interest recently because they display slow relaxation of the conductance after a rapid-cool down to low temperature. This relaxation could be the experimental signature of a new type of glass predicted theoretically 30 years ago and called the electron glass. Measuring electrical field effects in thin films, we have found that part of the conductance relaxation is insensitive to gate voltage changes. This shows the existence of a metallic-like screening in the films and allows us to estimate the typical screening length. Although the nature of the screening is related to the existence of an electron glass, it has so far rarely been considered experimentally and theoretically.

Glasses are systems with such a slow internal dynamics that they cannot reach their thermodynamic equilibrium within any experimentally accessible time. Famous examples in condensed matter are structural and spin glasses. It was theoretically suggested in the 1980's, that the electrons can "freeze" at low temperature in disordered insulators (Anderson insulators) due to the coexistence of disorder and ill-screened electron-electron interactions. In these materials, the electrons move at low temperature from one localized site to another by thermally activated tunnelling, giving a "hopping" conductivity. The presence of interactions puts additional constraints on the electrons' motion: it favours simultaneous hops of many electrons, which can be extremely slow compared to individual jumps.

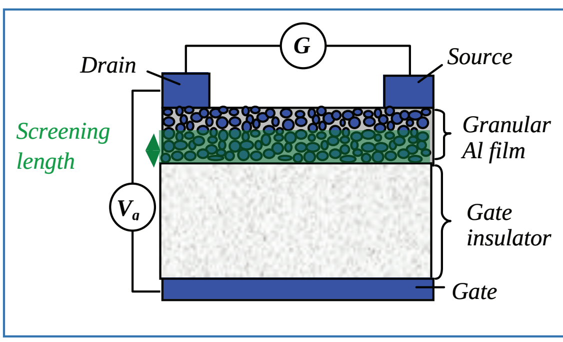

Figure 1: Schematic drawing of a MOSFET device. The part of the granular Al film in green is located at a distance less than the screening length from the gate insulator and is therefore sensitive to changes in the gate voltage Vg.

A fundamental question is whether electron glass features can indeed be observed experimentally in real systems. Interestingly enough, very slow conductance relaxations are found at low temperature in some disordered insulating systems, such as oxygen deficient indium oxide, granular aluminium or ultrathin films of metals. Following a rapid cool-down (quench), the conductance is seen to decrease as a logarithm of time, without any sign of saturation after weeks of measurement. Within the electron glass picture, this decrease reflects the approach of the electronic system towards its new, low temperature equilibrium (this will, in theory, require an infinite time).

Electrical field effect measurements have turned out to be a powerful technique for studying these slow relaxations. When disordered insulators are used as the (weakly) conducting channel of a MOSFET device (see Fig. 1), a gate voltage change can be used to inject or remove electrons, pushing the electronic system out of equilibrium.

We have recently shown how such MOSFET devices can also be used to determine the effective screening length of a disordered insulator like granular aluminium. Our insulating granular aluminium films are made of nanometric size aluminium grains embedded in an alumina matrix. We found that after a quench to 4K, only the part of the film closer than about 10 nm to the gate insulator (layer in green in Fig. 1) can be pushed out of equilibrium by a gate voltage pulse. The rest of the film continues its slow relaxation towards equilibrium, characterized by a logarithmic time decrease of the conductance, independently of the gate voltage values. This result, illustrated in Fig. 2 for a 20 nm thick film, clearly demonstrates the existence of a metallic-like screening length of about 10nm at 4K in our films.

Our observations address the important but little explored question of the screening in a disordered insulator. Electron glass models are generally developed in the limit of strongly localized electrons. But in real systems, there is a mobility of the charge carriers at finite temperature which gives rise to a metallic-like screening. It is believed that fast single electron processes establish a short-time screening length whereas multi-electron hops may lead to a slow decrease of this screening length as a function of time. Our results indicate how this screening length can be measured in real systems and they make it possible to determine its temperature and time dependence.

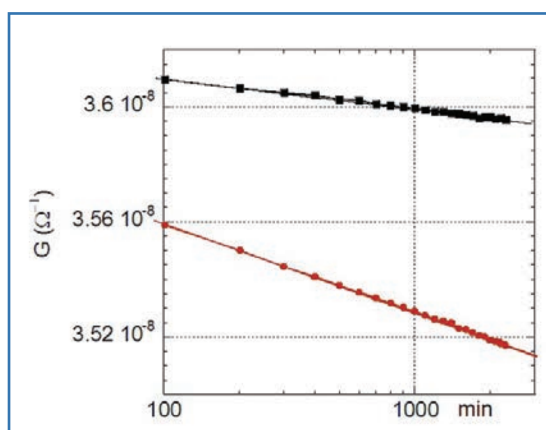

Figure 2: Conductance G of a 20nm thick granular aluminium film as a function of time (log scale) following a quench to 4.2K (Note the low values of G.). The red curve was measured with constant gate voltage Vg = 0V and represents the relaxation of the whole film. For the black curve, Vg was maintained most of the time at Vg=0, but the conductance was measured during short pulses to gate voltage Vg= -10V. Each pulse restores (re-excites) the part of the film sensitive to the gate field (green layer in Fig.1) to a constant state. Therefore, the black curve represents the sole relaxation of the part of the film beyond the screening length.

CONTACTS
Julien DELAHAYE
julien.delahaye@grenoble.cnrs.fr
Thierry GRENET
thierry.grenet@grenoble.cnrs.fr

FURTHER READING

SLOW CONDUCTANCE RELAXATION IN INSULATING GRANULAR ALUMINIUM: EVIDENCE FOR SCREENING EFFECTS
J. Delahaye, J. Honoré and T. Grenet
Phys. Rev. Lett. 106, 186602 (2011).