Shot noise in a Al-AlO$_x$-Al junction

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Objectives

- Measure Johnson-Nyquist noise through resistors
- Pattern a tunnel junction in the clean room.
- Characterize the morphology and electrical properties of junctions
- Measure the Johnson-Nyquist noise and the shot noise through the junction.
- Extract the value of the Boltzmann constant and the electric charge from the noise measurements.

Présentation

A tunnel junction is essentially formed by separating two conducting metallic plates by a thin (few nanometers) insulating layer as illustrated in Fig 1(a).

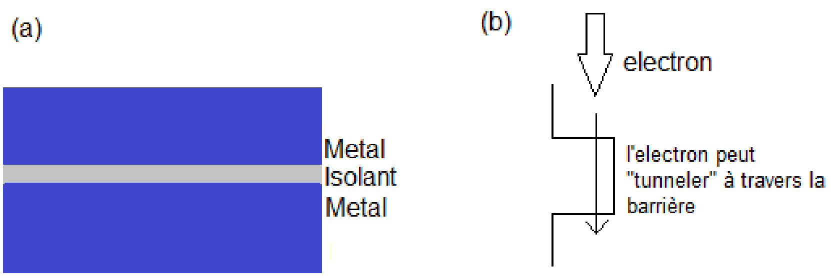


Fig. 1 (a) Schematic of a tunnel junction. (b) Electron tunneling through an energy barrier.

The fundamental basis behind the tunnel junction is the famous quantum mechanical problem of tunneling through a finite energy barrier (Fig. 1(b)). It is enough to solve the Schrodinger equation in the presence of such a potential to extract the electron tunneling probability.

$$\frac{p^2}{2m}\psi + U(x)\psi = E\psi$$

$$U(x) = \begin{cases} 0 & x < 0 \\ U_0 & 0 < x < a \\ 0 & x > a \end{cases}$$

Fabrication of a tunnel junction ?

For an experimentalist, however, the fabrication of tunnel junction is above all, a technical issue. One has to separate two metallic plates by a very thin insulating layer of no more than 3nm. The two metallic plates then have to be contacted independently to allow electrical transmission through the junction.

We will use oxidized silicon substrates to fabricate our junctions. The following procedure will have to be followed to pattern a junction with its contacts of the silicon substrates

1. « Draw » electrical contacts on silicon.
2. Deposit the first metallic layer of the junction
3. Produce a thin insulating layer of the first metal layer.
4. Deposit the second metallic layer without having it be in contact with the first one.

We will use **optical lithography** to perform these tasks. It is a standard technique for the semiconductor industry. Our junctions will typically have micrometric dimensions and a nanometric thickness, however, industry grade lithography allow companies such as Intel and Samsung to pattern transistors have dimensions as small as ~10nm. Our tunnel junctions will then be used to measure thermal and shot noise, and extract the NUMERICAL VALUE of the fundamental electric charge.

A separate document is given with a detailed derivation of different types of noise.

Optical lithography.

Lithography is a method of 'printing' geometrical forms on substrates. The method is summarized in Fig. 3.

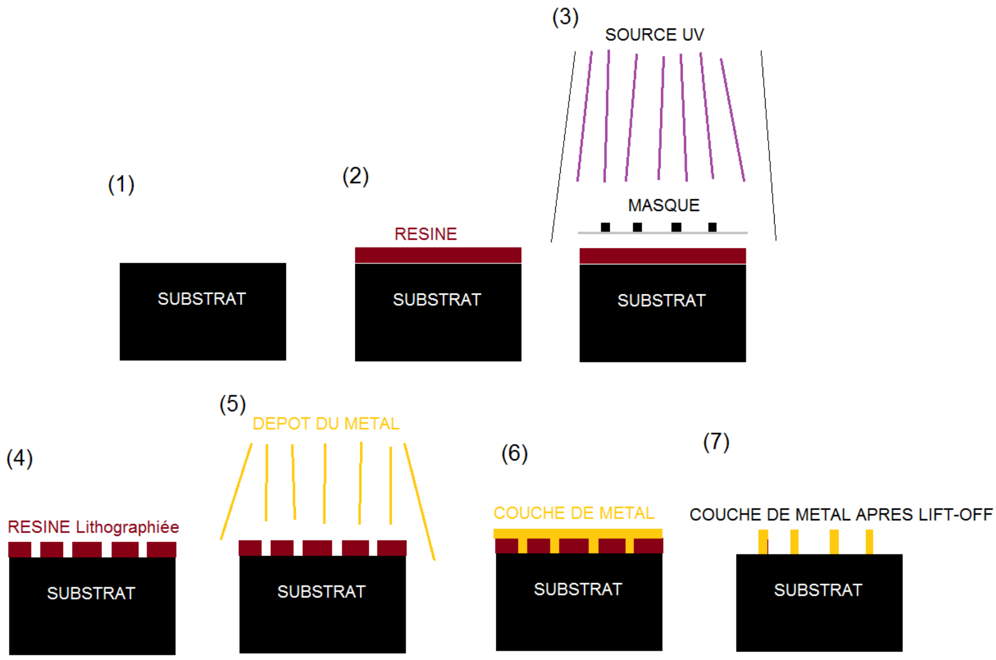


Figure 3. Different steps of a lithography process. (1) Pristine substrate. (2) Deposition of optically sensitive resist or resine (usually a polymer). (3) Exposure to UV through a mask to reproduce the geometrical forms of that mask. (4) The resist is then developed in a selective etching solution that removes the parts that were/were not exposed to UV. (5) Metal deposition through the holes left by the UV exposure. (6) Metallic layer after deposition. (7) Lift-off of the resist leaving behind the patterned metallic layer.

Metal evaporators

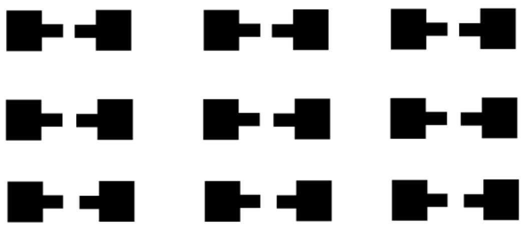
You will also use two metal evaporation setups. They are essentially vacuum chambers where metals can either be sublimated or evaporated by thermal heating. The metals available to use are Au, Cr and Al. One of the evaporators allows metal deposition on a tilted substrate. Aluminium metal can also be oxidized in-situ to procude aluminum oxide or alumina AlO_x. AlO_x is a good insulator that can be used as a barrier in a tunnel junction

L’aluminium s’oxyde facilement dans l’O_2 pour donner l’oxyde d’aluminium (ou l’alumine Al_2O_3). L’Al oxydé est un très bon isolant. Vous allez donc utiliser l’Al oxydé comme couche d’oxyde dans votre jonction tunnel.

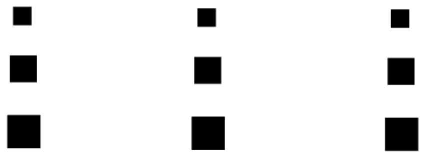
<u>Optical masks</u>

We will use the two masks shown below to pattern metal contacts and the junctions.

Masque Contacts:



Masque Jonction:



<u>Procedure</u>

The two first days of this work will be dedicated to the fabrication of the tunnel junction. After having understood the lithography procedure, devise a strategy to fabricate a Al/AlO_x/Al tunnel junction with Au contacts.

The work should be devided into two steps

1. How to fabricate Au contacts.
2. How to make a junction with an insulating layer intercalated between two metallic conductors. **The insulating layer should not be exposed to air before the second metal layer is deposited on top!**

We will discuss your strategy on the first day of the project.