Fabrication of nanoelectrodes combining standard microfabrication processes and focused ion beam (FIB)

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Recently, molecular electronic devices are increasingly attractive for the scientific community as possible candidates for the miniaturization of future electronic devices [1, 2]. The main challenge on these devices is the electrical characterization of individual molecules, which requires the fabrication of metallic electrodes separated by gaps in the nanometer range. The fabrication of these nanoelectrodes is difficult with the current microelectronic technology, as conventional electron beam lithography has a limit resolution of approximately 20 nm.

Some methods for the fabrication of nanoelectrodes can be found in the literature [3-5], but they normally involve complicated processes not easy to implement in the standard technology.

The focused ion beam (FIB) is a technique first developed in the late 1980s and which is already in use in the semiconductor industry, especially for circuit modification. However, FIB can be also used for a wide variety of applications, as ion beam lithography, micromachining and the preparation of samples for materials characterization [6-8]. The FIB uses a liquid metal ion source to emit gallium ions under high vacuum. These gallium ions are accelerated to form a small (approximately 10 nm in diameter) energetic beam, which is focused on the sample surface and can be scanned over a selected area. This ion beam can be used for the localized and controlled etching and milling of the sample and, combined with the insertion of a gas, it can also be used for the deposition of metals and other materials.

A dual beam Strata 235 FIB (FEI Company, The Netherlands) has been used for the experiments. This instrument has the advantage of combining the ion beam with a high-resolution scanning electron microscope with a field-emission electron source. Gallium ions are accelerated by a fixed energy of 30 kV and metals (platinum and tungsten) are deposited from organometallic gas precursors.

In this work we explore three alternatives for the fabrication of nanoelectrodes using the FIB, and some standard microfabrication processes. In every case we begin with a standard photolithographic process to define micropaths of platinum or silicon dioxide. The first possibility studied is the direct deposition, after the deposition of platinum micropaths, of metal lines (platinum or tungsten) on the surface of an oxidized silicon wafer and the milling of a narrow gap on these lines to get two separated electrodes (see figure). The optimum ion beam current conditions for the deposition and the milling are established, and several nanoelectrode configurations (single electrodes, interdigitated electrodes) are investigated. It is known that the ion-assisted metal deposition performed in the FIB can lead to poor metal quality, so we also explore the use of the e-beam source to produce a chemical vapour metal deposition.

The second alternative studied for the deposition of nanoelectrodes consists of milling by FIB of a previously deposited metal layer. First, a platinum layer is deposited and patterned by lift-off technique, defining micro-paths and microelectrodes. A thin gold layer is then deposited and patterned by lift-off to form conducting gold paths between microelectrodes. FIB milling of this gold layer defines the nanoelectrodes. This option has some advantages over the previous one, because we can produce nanoelectrodes from one metal and the micro-paths from a different metal (for example Platinum).

The last option we have explored is to machine a silicon master mould to be used in nano-imprint lithography (NIL) process. First of all, silicon dioxide micropaths are defined by photolithography and Reactive Ion Etching. Then, the nanoelectrode region is formed by silicon oxide deposition with the FIB. After a silicon etching process (made using RIE apparatus), the oxide is removed by means of HF etching. In this way, a silicon mould can be made and can be utilised in NIL apparatus. Consequently, the mould is transferred to a PMMA resist covered wafer, a metal layer is deposited on this wafer and, finally, a lift-off technique is used to define the nano and micro-electrodes at the same time.

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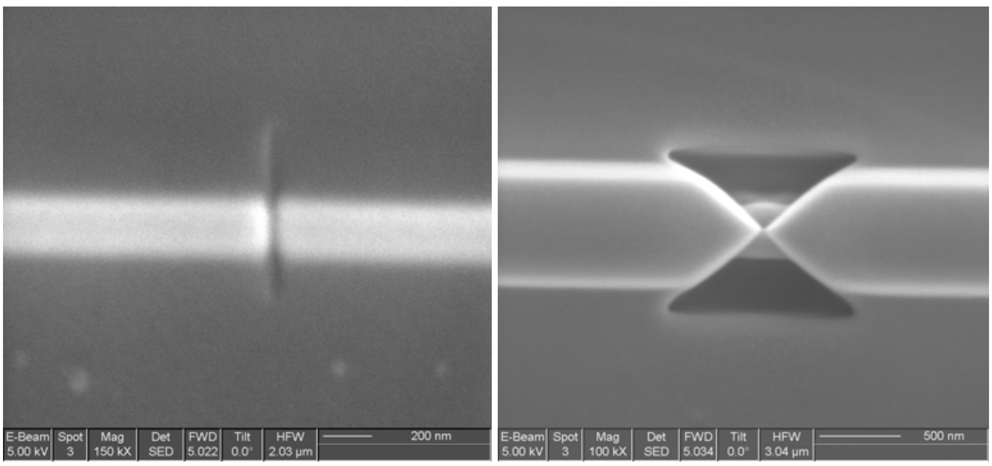

(a) (b)

Figure: Platinum electrodes deposited and etched by FIB with nanogaps of (a) 40 nm and (b) 20 nm.