Limitations in nanoelectronics: current and temperature effects

Electrical cables are commonly used in our daily life. Typically they have metallic core covered with isolation. For example, one uses this wire to connect a lamp to a battery. When connected, electrons (negative elementary electric charges) flow through the circuit resulting in heating of the spiral in the lamp with the emission of light. In normal use, wires are not destroyed: in the example case the spiral in the lamp breaks while cables can still be used. But this situation changes when we decrease the size of the wires down to the nano or microscale. Now if the same amount of electrons needs to be transferred through this very narrow wire, the current density will be much higher, and as a result, the wire can degrade and will be destroyed. This phenomena is called electromigration – a migration or transfer of the metal atoms by the electric field or by the flowing electrons.

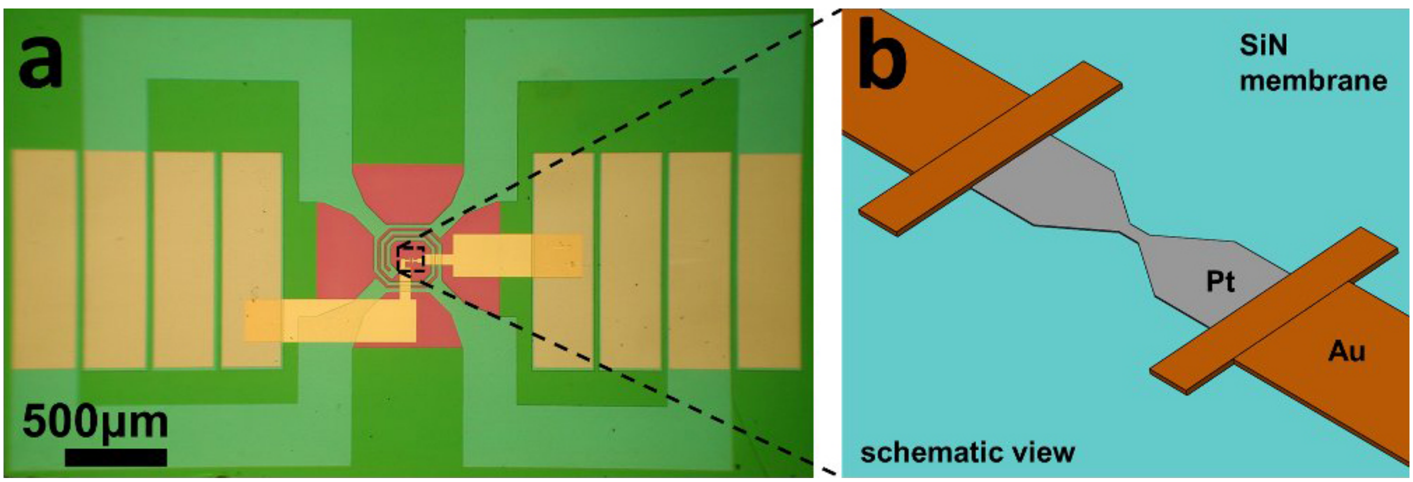

Fig. 1. (a) Optical image of a MEMS chip (4×3 mm2); four contacts for the heater spiral and two for electrical measurements of the bridge, purple area in the middle is a freestanding membrane. (b) Schematic view of a Pt nanobridge with gold contacts on a SiN membrane.

To visualise material transfer at atomic level, we used transmission electron microscope (TEM). In TEM electrons interact with the sample, producing an image. We investigated platinum metallic bridges (500 nm wide, 15 nm high and 1000 nm long) on electron-transparent support. The support contained a heating spiral in order to perform experiments at high substrate temperatures (Fig. 1.). The metallic bridges were connected through the sample holder with electrical setup to pass the electrical signal and measure the response.

Figure 2 shows typical electromigration experiments at high substrate temperature. As-prepared polycrystalline chip shown with dark grey colour in Figure 2a. During current passage (on Fig. 2b.)

electrons move in the direction of black arrow) voids forming at the negative side (indicated with yellow arrow). Material from those voids is transferred in the direction of electrons. When the current polarity is changed (Fig. 2c.), existing voids are not refilled but new ones are formed closer to the negative side (indicated with yellow arrow). Voids growth leads to the bridge breakage. The higher the substrate temperature, the bigger the size of voids formed near the contact pad at the negative side. As expected, at higher temperatures a lower power is needed to break the nanobridge.

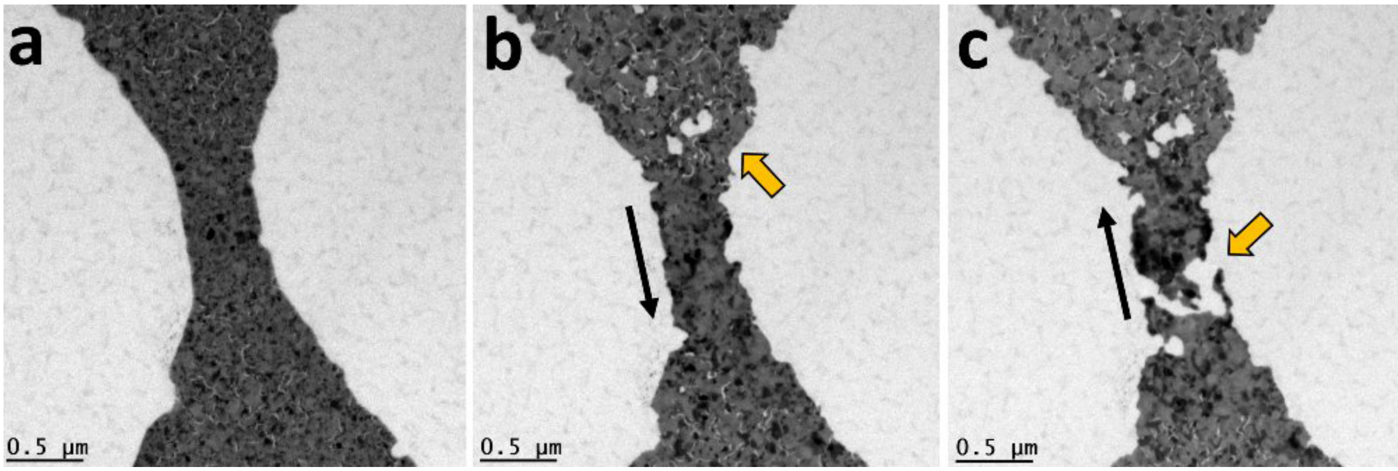

Fig. 2. Snapshots from the TEM movie showing the bridge break during electromigration at 660 K. (a) Initial TEM view of the Pt bridge at 660 K. (b) During current passage voids forming at the negative side (indicated with yellow arrow). (c) Upon polarity change, voids are not refilled and additional ones form at the new negative side which results in the nanobridge breakage. Black arrows indicate the direction of electrons.

As is shown above, in situ TEM electromigration studies allow to visualise transformations in the metallic structures during current passage. Such studies become more important because of the trend to downscale metallic contact lines to nanometer sizes in devices. Like in many cases, the disadvantage of the nanobridge breaking can also be used to ones advantage. Broken bridges on the heater can be used as a measuring contacts for the trapped particles or molecules, allowing their shape transformations to be visualised and their electrical properties to be measured during heating/cooling cycles.

Dr. ***Tatiana Kozlova***
Kavli Institute of Nanoscience, Delft University of Technology
The Netherlands

Publication

In situ visualisation of electromigration in Pt nanobridges at elevated temperatures.
Kozlova T, Zandbergen HW.
Ultramicroscopy. 2015 Nov