White Paper

Deposition of Conducting Features with ORION NanoFab

We make it visible.

Deposition of Conducting Features with ORION NanoFab

Authors: Dr. Diederik Maas, Dr. Paul Alkemade,
Dr. Larry Scipioni
Carl Zeiss Microscopy, LLC, USA

Date: July 2010

Application

Creation of electrically conducting nano-structures by helium beam induced chemistry. Deposition of features with high pattern density.

ORION NanoFab Capabilities

Deposition of material from platinum or tungsten precursors, deposits substantially free from halos, use of a non-contaminating ion species; lithographic pattern tool interfacing.

Background

Gas injection systems (GIS) are commonly employed on SEM and FIB tools. The use of the beam to induce local chemical reactions on a substrate allows direct writing of nanostructures without the added pattern transfer steps that lithography requires. One can carry out both additive (deposition) and subtractive (etch) writing processes. Deposited features from metal-bearing precursor gasses, in particular, can be used to create devices with tailored electromagnetic responses, they can provide conductive pathways and electrical contacts to other small features of interest, they can be used to introduce topology such as for anchoring biomolecules to a surface in a predetermined pattern, or give protection (coating) for objects already on the substrate. Since deposited material will grow upon itself as well, three dimensional objects can also be grown, which is quite difficult to do with conventional lithography. This technology is thus applied in fundamental research. Semiconductor manufacturing also makes use of such processes for photomask repair and circuit editing.

Challenge

As nanotechnology research advances it drives the investigation of features sizes to ever smaller dimensions. Beam deposition processes, then, must also provide structures at these length scales so that arbitrary features can be created in accordance with the dynamics being investigated. As an example, graphene based devices typically need to be below 20 nm in size to obtain quantum confinement, so that it would be beneficial to pattern ohmic contacts at this length scale to test the device[1]. Another challenge is the creation of structures with high patterning density. The proximity effects and deposition halos which accompany traditional FIB induced beam chemistry limit the patterning density. An example of this is seen in Figure 1, where pillars created by conventional gallium LMIS (Ga) FIB show large minimum diameter (160 nm) and extremely rough profiles.

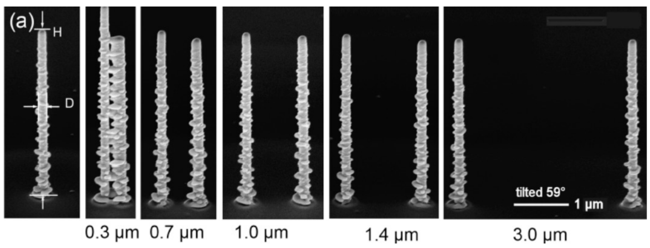

Figure 1
Deposition of Pt pillars in a gallium LMIS equipped FIB. See reference [2].

There is also a considerable proximity effect, in that two adjacent pillars must be more than 2500 nm apart during growth, or else the size of one will be affected by the presence of the other[2]. Electron beam induced chemistry can help to overcome some of these problems, but the deposition rate is typically much smaller[3].

Thus the most challenging applications could be served by a technology which can extend the structuring fidelity of deposited conducting features.

ORION NanoFab Solution

In this note we describe the formation of two basic structures, vertical pillars and horizontal lines, and we also show their characterization. Small feature size and tight patterning pitch can be achieved, as will be detailed. The ORION NanoFab helium ion microscope (HIM) can be equipped with a chemistry delivery system, the OmniGIS™ product (from Omniprobe, Incorporated). Deposition of platinum-bearing deposits is achieved from the gas delivery of (Methylcyclopentadientyl)-trimethyl platinum $C_9H_{16}Pt$. An additional advantage for HIM is that the structures can also be observed and measured using the same beam, since it provides sub-nanometer resolution without sample modification (for many materials).

The recipe to obtain a given structure consists of two parts: the setting of the gas flow from the delivery system, and the control of the beam scanning routine. For both pillars and lines the first part of the recipe is the same. Table 1 lists the parameter settings for the gas flow. The dialog boxes for setting these up in the user interface is described in a previous application note, "Beam Induced Chemistry in the ORION NanoFab". The second part of the recipe, beam scan control, can be provided in two ways. The first is the interface provided with the microscope user interface, described also in the aforementioned application note.
The second method is to utilize the facility in the microscope to allow an external pattern generator to control the beam. Inputs for the beam steering and blanking are provided at the front of the system's electronics rack, and a command in the user interface will surrender control of the deflection system to whatever third-party system is to be used to steer the beam.

Pillars are formed by exposing one spot on the sample to the beam during gas flow. The way the beam is applied will define the shape of the pillar. Pillar height and diameter are the two features of interest to control[4]. These are determined by the ion current and dose. To grow a higher pillar, more exposure time is used; to obtain a wider pillar, more beam current is applied. As can be seen in Figure 2, the narrowest pillar obtained by this recipe is 36 nm in diameter, grown at 0.8 pA or less beam current. Note that this is 4.5 x smaller than what can be obtained with Ga FIB processing.

Parameter	Setting
Precursor	$C_9H_{16}Pt$
Precursor temperature	30° C
On time	10 sec
Period on	10 sec
Carrier gas	N_2
Carrier gas temperature	40° C
Pulses per period	1
Chamber pressure	3 - 5 x 10^{-6} torr
Needle position from beam axis	50 - 100 µm
Needle position above surface	300 µm

Table 1
Gas flow settings for platinum deposition.

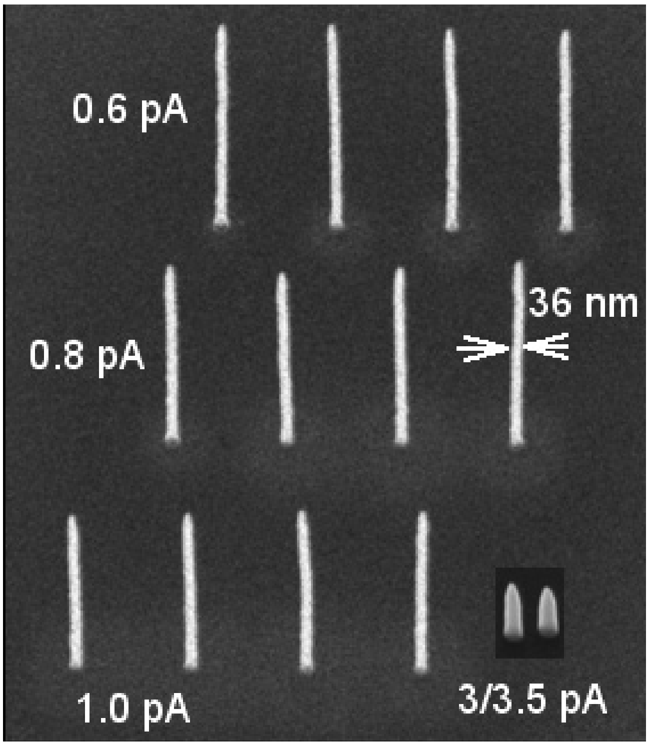

Figure 2
Dependence of pillar aspect ratio on applied beam current.

Under the conditions given in Table 2 the volume growth rate is fairly constant, at about 0.04 nm^3/ion. This is equivalent to the rate for Ga FIB processes. The pillars grow with a conical pointed top, as can be seen in Figure 2. This pointed top also demonstrates that negligible sputtering is occurring in HIM. We provide an example of the relationship between pillar height and diameter as a function of beam current – for a fixed total dose of 6 pC – in Figure 3. The pillars also can be grown closer to one another, as compared to Ga FIB processed structures, due to the reduced proximity effec when using the helium ion beam. It can be seen in Figure 4 that programmed spacing between adjacent pillars can be as low as 200 nm[5]. It is possible to achieve about 20 x higher areal packing density than for Ga FIB pillars.

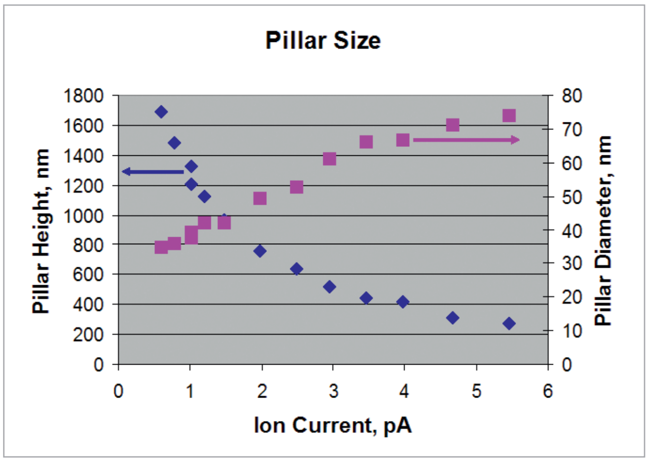

Figure 3
Deposited platinum pillar height and diameter as a function of ion current, for a fixed applied dose of 6.0 pC.

Parameter	Pillars	Lines
Beam Energy, keV	25	25
Beam Current, pA	0.2 - 6.0	0.5
Column aperture, µm	10	10
Dwell time, µsec	n/a	10
Refresh time, µsec	n/a	20
Pixel spacing, nm	n/a	2
Working distance, mm	9.3	9.3
Substrate	Silicon	Silicon

Table 2
Helium ion dose settings for platinum deposition. See text for further description.

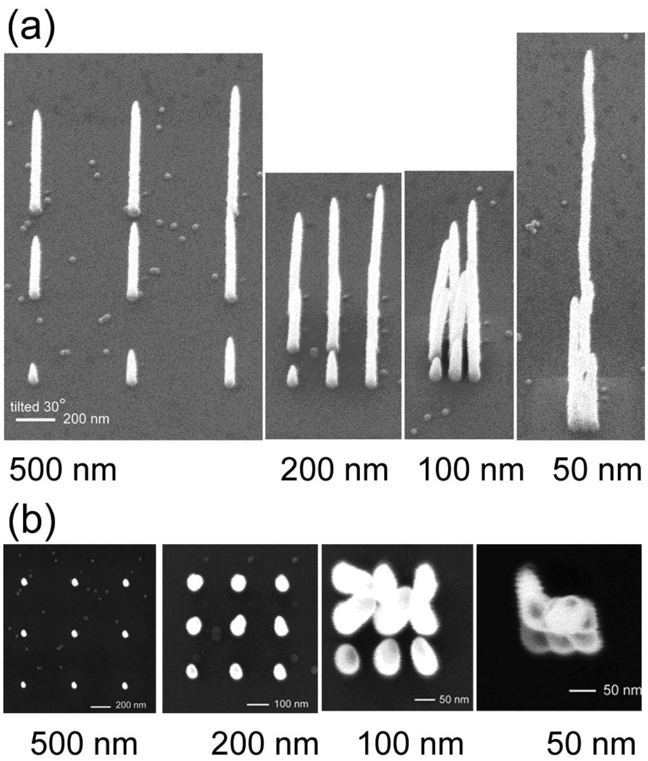

Figure 4
Pillar packing density, illustrated by a set of nine pillars. The pillars remain narrow and straight for spacing of 200 nm or greater.

Lines are grown along the substrate surface by scanning the beam along a desired path. Using a small pixel spacing along this path ensures that the deposits from neighboring pixels overlap, yielding a continuous line. Using the parameters given in Table 2, 15 nm wide lines can be obtained. Pixel spacing should not exceed 20 nm. The recipe yields lines with a pointed ridge along their tops.

Figure 5 shows a set of 5 lines grown with a 15 nm width and 100 nm pitch. The minimum pitch that may be obtained by this recipe is 30 nm – that is a 1:1 line:space ratio. If one considers that the deposition occurring at each pixel is simply the conical top to a pillar, then increasing the number of repeats used will grow the base, influencing both line width and height. Experimentally determined values for line width are provided in Table 3. Looking at Figure 6 we can appreciate that the proximity effect is quite low, since the lines on the ends have the same shape as those in the middle of the array. There is of course more flexibility in depositing patterns laterally on a surface, for a two-dimensional array of pixels can be addressed in any arbitrary way.

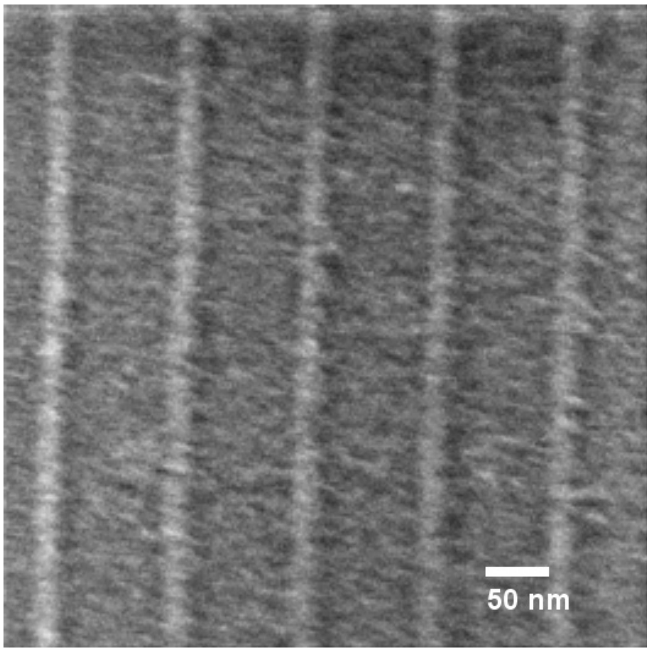

Figure 5
Platinum lines 15 nm wide, with a 100 nm pitch.

Number of Repeats	Line Width, nm
50	15
100	17
200	20
500	24
1000	28
2000	31

Table 3
Line width (Full Width Half Maximum) as a function of writing repeats.

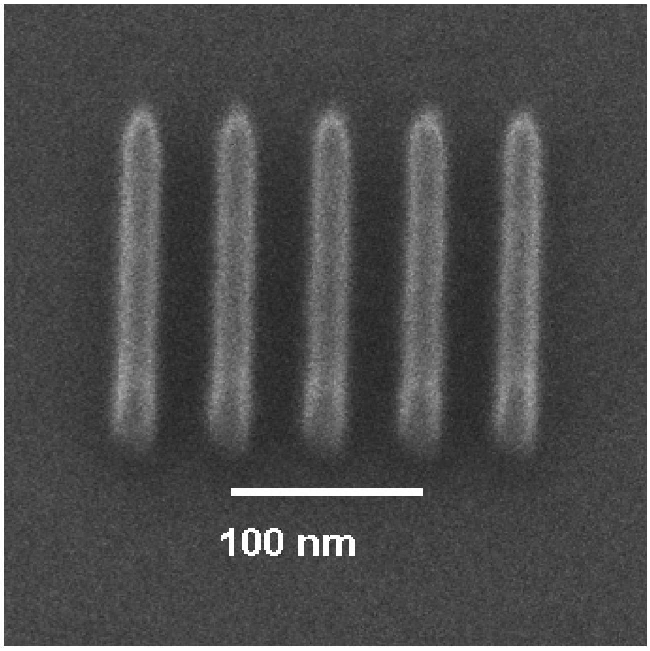

Figure 6
20 nm lines grown with a 50 nm pitch. Viewing angle is 30° from normal.

We have seen descriptions and recipes to create high aspect ratio pillars and low aspect ratio lines. Future applications notes will describe creation of features with optimized chemical composition and characterized electrical conductivity.

References

[1] M. Han et al., Phys. Rev. Lett. 98, 206805 (2007)
[2] P. Chen et al., J. Vac. Sci. Technol. B 27, 1838 (2009)
[3] I. Utke et al., J. Vac. Sci. Technol. B 26 (4), 1198 (2008)
[4] P. Alkemade et al., J. Vac, Sci. Tachnol. B (to be published 2010)
[5] Ping Chen (PhD thesis, TU Delft, 2010)

facebook.com/zeissmicroscopy

twitter.com/zeiss_micro

youtube.com/zeissmicroscopy

flickr.com/zeissmicro

Carl Zeiss Microscopy GmbH
07745 Jena, Germany
microscopy@zeiss.com
www.zeiss.com/microscopy

We make it visible.