FIB direct patterning of graphene islands for localizing GaN nanowires epitaxial growth

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Nanowires (NW) are promising candidates for the development of flexible optoelectronic devices, such as LEDs. With this objective, we have investigated the epitaxial growth of GaN nanowires (NWs) on graphene substrates patterned with finely and swift focused ion beams.

Nowadays Focused Ion Beams (FIBs) machines have become very important tools capable of fulfilling many challenges ranging from micro- to nanofabrication. These tools are irreplaceable both in industrial applications[1] and nanosciences prototyping applications[2]. Traditionally FIB instruments were based on Liquid Metal Ions Source and to fulfill user's requirement, both for larger milling speeds or higher resolution, news tools were developed respectively plasma FIB and GFIS ion microscopes amongst other. While these new technologies outperform classical LMIS-FIB in their respective application fields, LMIS based FIB are still relevant to many nanoscience emerging challenges.

For instance, gallium beams emitted from a very high brightness, long lifespan source exhibiting the highest stability (in position and versus extended time periods) known to date and the capability to routinely deliver ion probes focused down to a few tens of nanometers still own promising potential in advanced material science and processing.

In this work we will detail our investigations in patterning graphene flakes deposited onto silicon substrates. In opposition to FIB-based approaches where the local gallium implanted species, favors the coalescence of precursor seeds[3] for subsequent nanowire (NWs) epitaxial growth, we have explored an opposite approach with the fabrication of anti-dots type patterns.

This approach relies on a direct and fast/low dose irradiation of the graphene surface, which locally inhibits the NWS epitaxial process. Following this approach, we have patterned arrays of antidots structures with variable pitches thus preserving graphene islands.

First, we transferred CVD-grown graphene onto SiO_2/Si samples. Then, the graphene was patterned as described above into arrays of antidots structures. GaN NWs were finally grown on these structures using a Plasma Assisted Molecular Beam Epitaxy (PAMBE) technique. The MBE reactor used for the growth of III-N materials is a Riber Compact 12 frame equipped with a radio-frequency (RF) plasma source for generating the active nitrogen species. The flow of active material is controlled by the flow of injected N2, adjusted by a mass flow meter, and by the RF power applied to the cavity. The MBE machine is equipped with five other sources which are effusion cells: three for the metallic elements (Ga, Al, In) and two for the dopants (Mg and Si). For this type of source, the emitted material flow is controlled by the temperature of the cell.

We used a growth temperature of 815°C which enabled the required selectivity, *i.e.* GaN NWs growth on graphene but not on SiO_2. The fluxes used are, at equivalent growth speed, 10.5nm/min for nitrogen and 8.9nm/min for gallium, i.e. a V/III ratio of 1.1. It was observed that nucleation only occurred on the preserved domains (Figure 3&4). The number of GaN NWs was found to be depending on the size of the domains directly determined by the grid spacing and the ion dose applied to define the patterns. We were able to obtain in certain patterns, one single nanowire per domain, which is quite encouraging for the future optimization (grid width and ion dose) since these nanowires are aimed as precursor seeds to form GaN micro-domains by lateral re-growth using MOCVD and HVPE growth techniques. These micro-domains could be then used as substrates for flexible LEDs manufacturing.

[1] S. Reyntjens and R. Puers, Micromech. Microeng. 11 (2001) 287–300
[2] J. Gierak Nanofabrication 2014; Volume 1: pp. 35–52
[3] P. Mélinon, A. Hannour, L. Bardotti, B. Prével, J. Gierak, E. Bourhis, G. Faini and B. Canut, Nanotechnology 19 (2008) 235305 (9pp)

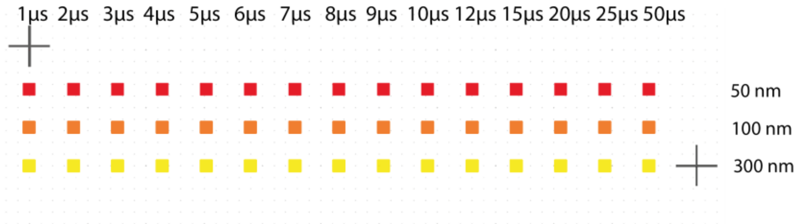


Figure1: Schematic of the patterning. Individual pattern are square grids (10µm x 10µm) with 3 different line spacing. The ion dose is varied for each column from 1µs up to 50µs/pixel. Alignment crosses are added to ease pattern localization and ion dose identification.

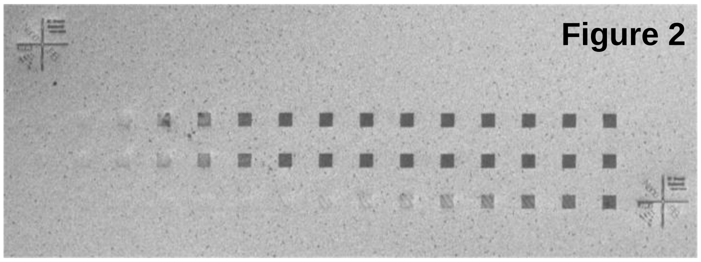
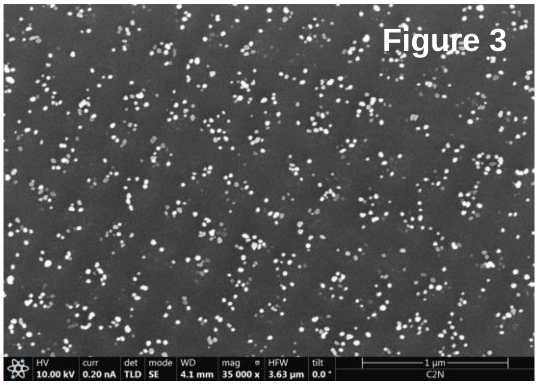


Figure2: Scanning Electron Microscopy (SEM) image (420 µm x 150 µm) revealing the variable dose / spacing grid patterns after PAMBE growth of GaN nanowires.



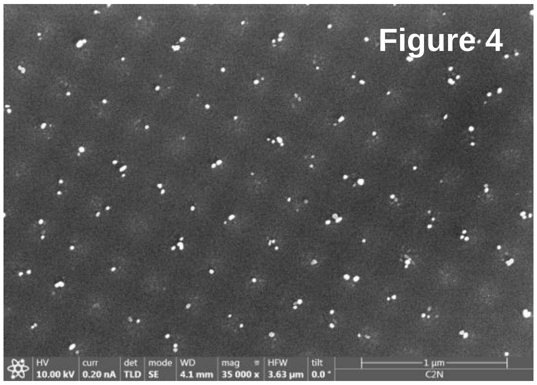


Figure 3: SEM image after NWs growth on a 300 nm spacing grid pattern. Ion dose is 3000 ions/pixel. (10µm long lines, 10nm pixel-to-pixel, writing speed 3333µm/s). In this case the preserved domains allowing multiple GaN NWs nucleation and growth.

Figure 4: SEM image after NWs growth on 300 nm spacing grid pattern. Ion dose is reduced is 12500 ions/pixel. (10µm long lines, 10nm pixel-to-pixel, writing speed 200µm/s).