Ecole Doctorale des Sciences Fondamentales

Title of the thesis: HVPE growth of III-Arsenide nanowire arrays for infrared devices

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Summary :

Since 2010, Institut Pascal (IP) is a unique laboratory in the world that can synthesize ultra-long III-V NWs of pure crystalline quality by hydride vapor phase epitaxy (HVPE). HVPE is now argued to be a very promising method to resolve current technological challenges at micro and nano scales, especially for III-Arsenide (III-As) synthesis [1,2]. In particular, in SAG (Selective Area Growth), where the growth occurs on specific sites on a patterned substrate, the selectivity is completely ensured in HVPE thanks to the use of III-Chloride precursors (GaClg, InClg). These features are crucial for the fabrication of devices based on organized nanowires arrays.

This PhD will be split into two periods between IP and McMaster. During the first period at IP, the student will perform the growth experiments of III-As nanowires based on InAs and $Ga_{1-x}In_xAs$ materials with an emphasis on the material composition to cover infrared emission wavelengths. The control of the crystalline quality in those binary and ternary nanowires is still a challenge task whatever the growth technique. Thermodynamic and kinetic modelling studies will be conducted through a collaboration with ITMO University (Saint-Petersburg). P and N doping experiments will constitute an important task. Optical Spectroscopy group of IP is the partner for the characterization in the wavelength range [0.87 µm-2.9 µm] and is developing at present a new experimental set-up. For the [2.9 µm-4µm] range, IES (Montpellier) is the expert who is involved in this project.

Moreover, the student will benefit from McMaster expertise in the field of substrate patterning as this partner will provide the patterned substrates required for the growth of the nanowire arrays. Regarding the growth process, HVPE-MBE hybrid process will be developed. The MBE growth at McMaster of a III-V shell will be performed to remove the oxides from the HVPE core. A second alternative for this passivation will performed by Surface and Interface group if IP through a nitrogen plasma process which has been already used on non-patterned substrates.

The PhD will follow the second period at McMaster to fabricate the devices based on InAs nanowire arrays. The infrared wavelength windows of interest are 1-2.5 µm (short-wave infrared (SWIR)), 3-5 µm (mid-wave infrared (MWIR)), based on the atmospheric transparency. Infrared sensors based on mercury cadmium telluride (MCT) currently dominate the marketplace because they can reach all these wavelengths by tuning the composition of the MCT material. However, image sensors based on MCT are expensive. There are also issues with stability, uniformity, toxicity and recycling of MCT. As an alternative technology, McMaster has demonstrated that multi-spectral infrared detectors based on InAs nanowire arrays can be fabricated on a single substrate by playing with the nanowire diameter to select infrared wavelengths. This technology is developed to create the next generation of multispectral infrared technology that is expected to improve resolution, recognition, accuracy, speed of data capture and cost of infrared detectors and cameras for military search, surveillance and tracking applications. [3]
The main target applications for $Ga_{1-x}In_xAs$ is nuclear / electrical power converters [4]

To conclude, the full PhD period will allow the student to develop high skills in device and process technology in addition to epitaxy and growth modeling ones.

[1] **Nano Letters 2014**, 14, 3938–3944 DOI: 10.1021/nl501239h
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[2] **CrystEngComm**, Advanced paper, https://doi.org/10.1039/D0CE01385D
"Long catalyst-free InAs nanowires grown on silicon substrate by HVPE"
G. Grégoire, E. Gil, M. Zeghouane, C. Bougerol, H. Hijazi, D. Castellucci, V. Dubrovskii, A. Trassoudaine, N. Isik Goktas, Ray R. LaPierre, Y. André
[3] **Journal of Applied Physics 2017**, 50 (12) 123001 DOI: 10.1088/1361-6463/aa5ab3
"A review of III–V nanowire infrared photodetectors and sensors"
R.R. LaPierre, M. Robson, K.M. Azizur-Rahman, P. Kuyanov
[4] **Journal of Applied Physics** 127 (24), 244303, https://doi.org/10.1063/1.5138119
"Design and optimization of nanowire betavoltaic generators"
DL Wagner, DR Novog, RR LaPierre

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