Vertically Aligned Carbon Nanotubes Embedded in Ceramic Matrices for Hot Electrode Applications

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Outline

I. **Goal and Objectives**

II. **Background and Motivations**

III. **Proposed Activities**
   1. Super growth of vertically aligned carbon nanotube (VA-CNT) carpets
   2. Fabrication of CNT-boron nitride (CNT-BN) composite structures
   3. Stability and resistance studies of the CNT-BN composite structures
   4. Thermionic emissions of the CNT-BN composite structures

IV. **Deliverables and Spending Plan**

V. **Student Training**

VI. **Preliminary Results**

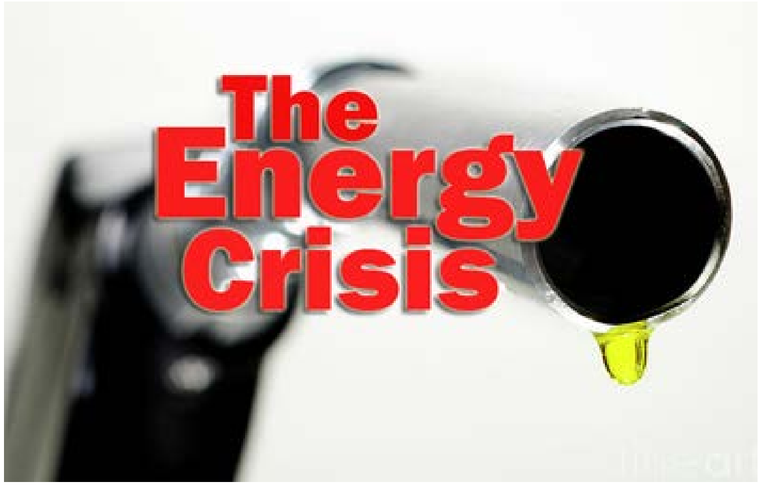
I - Goal and Objectives

Primary goal: Develop CNT-BN composite structures in which VA-CNTs are embedded in BN matrices for hot electrode applications in magnetohydrodynamics (MHD) power systems.

Objectives:

1. Super growth of VA-CNT carpets
2. Fabrication of CNT-BN composite structures
3. Stability and resistance studies of the CNT-BN composite structures
4. Thermionic emissions from the CNT-BN composite structures

II - Background and Motivations



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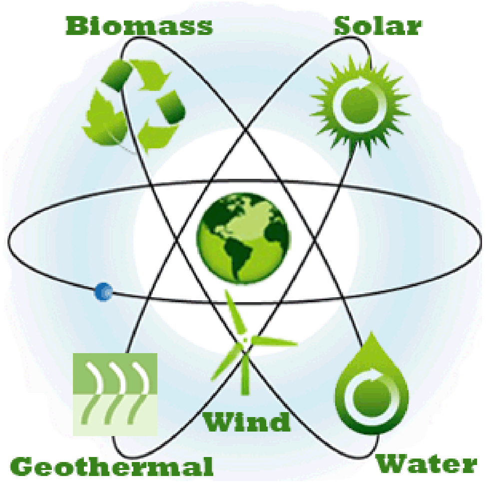
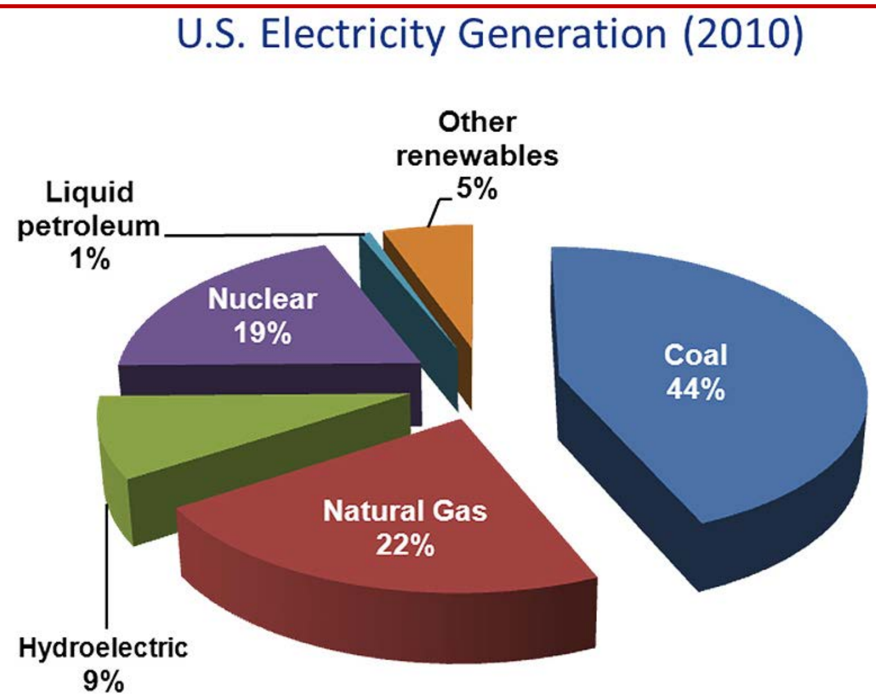


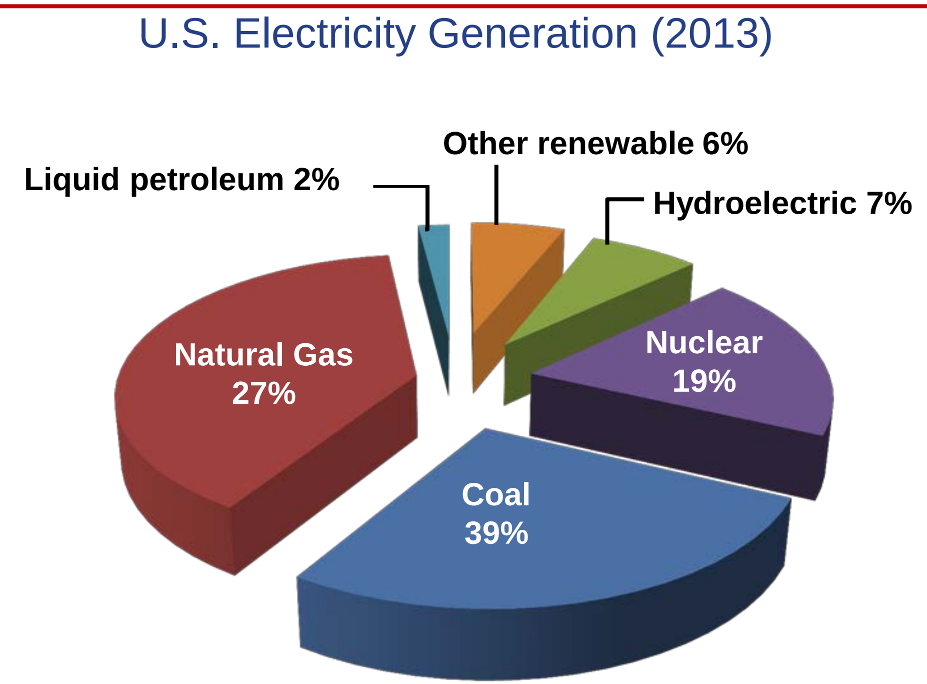
New Energy Sources

High Energy Efficiency

II - Background and Motivations



http://crf.sandia.gov/index.php/coal-use-and-carbon-capture-technologies/#.VBaDbvldV8E

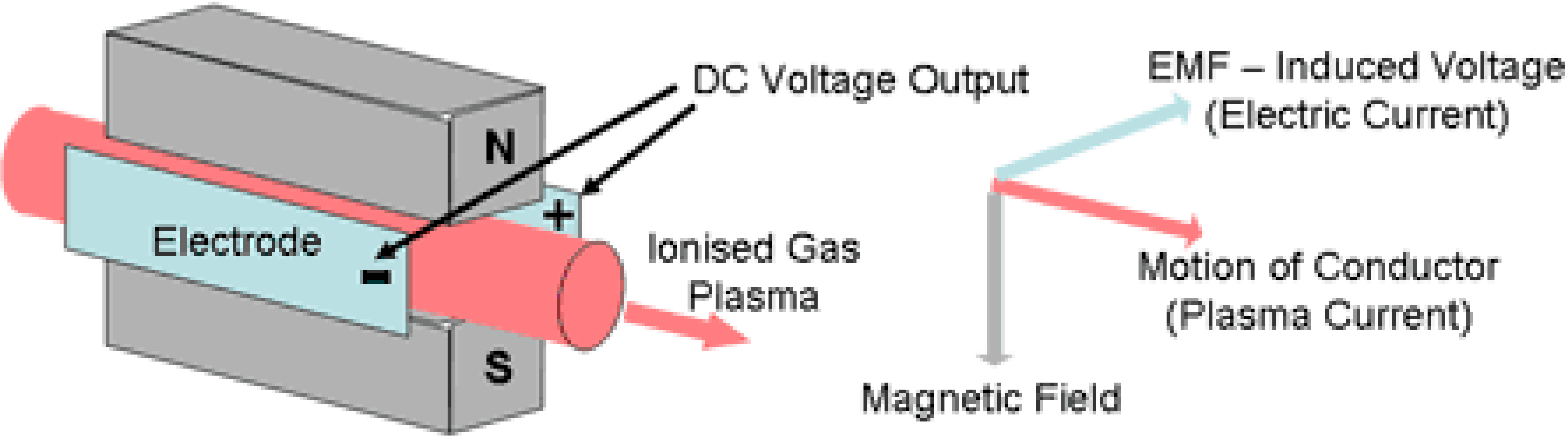


http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3

Electricity Generation Efficiency

Method	Efficiency (%)	Ref.
Nuclear	33 – 36	Efficiency in Electricity Generation, EURELECTRIC "Preservation of Resources" Working Group's "Upstream" Sub-Group in collaboration with VGB, 2003
Coal	39 - 47	
Natural gas	< 39	

II - Background and Motivations



Magnetohydrodynamic Power Generation (Principle)

1) Only working fluid is circulated without moving mechanical parts;

2) The ability to reach full power level almost directly.

3) Lower infrastructure cost than conventional generators.

4) A very high efficiency (60% for a closed cycle MHD).

http://en.wikipedia.org/wiki/Magnetohydrodynamic_generator#Generator_efficiency

II - Background and Motivations

Material Challenges for a MHD Generator

Requirement	Remarks
Electrical conductivity (σ)	$\sigma > 1$ S/m, flux ≈ 1 amp/cm^2
Thermal conductivity (k)	High heat flux from the combustion fluids at 2400 K
Thermal stability	Melting point (T_m) above 2400 K
Oxidation resistance	Resistant to an oxygen partial pressure about 10^{-2} atm at 2400 K
Corrosion resistance	Potassium seeds and aluminosilicate slags
Erosion resistance	High velocity hot gases and particulates
Thermionic emission	The anode and cathode should be good acceptor and emitters, respectively.

III - Proposed Solution and Activities

Project tasks, milestones, and planned completion dates

Tasks	Milestone	Completion Date
1.Project Management and Planning	Complete of the proposed project within the 3-year period.	08/31/2017
2.Super Growth of Vertically Aligned CNT Carpets	Achieve the growth of VA-CNT carpets on Cu substrates with CNT lengths up to 1 cm.	08/31/2015
3.Fabrication of CNT-BN Composite Structures	Achieve uniform and dense growth of BN matrices wrapping VA-CNTs.	02/29/2016
4.Stability and Resistance studies of the CNT-BN Composite Structures	Determine the stability and resistance of the CNT-BN composite structures	08/31/2016
	Determine the electrical and thermal conductivities of the CNT-BN composite structures.	02/28/2017
5.Thermionic emissions from the CNT-BN composite structures	Determine the thermionic emission performance of the CNT-BN composite structures.	08/31/2017

III - Proposed Solution and Activities

Timelines and corresponding milestones of the project

<table>
<tr><th colspan="2" rowspan="2">Task</th><th rowspan="2">Period</th><th colspan="4">Year 1</th><th colspan="4">Year 2</th><th colspan="4">Year 3</th></tr>
<tr><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th></tr>
<tr><td colspan="2">1</td><td>09/01/14 - 06/30/17</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="15">Milestone: Successful completion of the proposed project within the 3-year period.</td></tr>
<tr><td colspan="2">2</td><td>09/01/14 - 08/31/17</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="15">Milestone: Achieve the growth of VA-CNT carpets on Cu substrates with CNT lengths up to 1 cm</td></tr>
<tr><td colspan="2">3</td><td>12/01/14 - 08/31/17</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="15">Milestone: Achieve the growth of uniform CNT-BN composite structures.</td></tr>
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<tr><td colspan="15">Milestone: Determine the stability and resistance of the CNT-BN composite structures, and obtain the electrical and thermal conductivities of the composite structures.</td></tr>
<tr><td colspan="2">5</td><td>09/01/15 - 08/31/17</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="15">Milestone: Determining the thermionic emission performance of the CNT-BN composite structures.</td></tr>
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IV - Deliverables and Spending Plan

Type	Deliverables
Method	1. Super-growth of ultralong VA-CNT carpets 2. Fabrication of CNT-BN composite 3. Modulated photothermal radiometric method for measuring the thermal conductivity of the CNT-BN composite 4. Thermionic emission current method for measuring the thermionic emission of the CNT-BN composite
Equipment setup	1. Water-vapor-assisted CVD system 2. Plasma-enhanced CVD system 3. Modulated photothermal radiometric system 4. Thermionic emission current measurement system
Reports	Quarterly reports, annual reports, final report and other reports required by DOE
Presentations	Conference and review meeting presentations
Journal papers	Journal and conference proceeding articles

V - Student Training

Name	Qiming Zou	**Degree**	Ph.D.
Dept.	Electrical Engineering	**Univ.**	University of Nebraska - Lincoln
Goal	Pursuing a Ph.D. degree in the field of Electrical Engineering and developing necessary knowledge, expertise, leadership, teaching skills, and mentorship towards an academic profession.		
Objectives	1. Grasping necessary knowledge in the field of electrical engineering; 2. Grasping necessary experimental and simulation techniques required in this project; 3. Establishing teaching skills by taking two semester teaching assistants and participating in outreach programs; 4. Developing leadership and mentorship by working with undergraduate assistant, Joseph Hartwig; 5. Publishing at least 3 articles in peer-reviewed journals within related fields; 6. Developing essential communication skills; 7. Attending academic conferences within related fields and establishing networking capability; and 8. Independent and critical thinking by developing a complete research plan in his comprehensive exam.		

V - Student Training

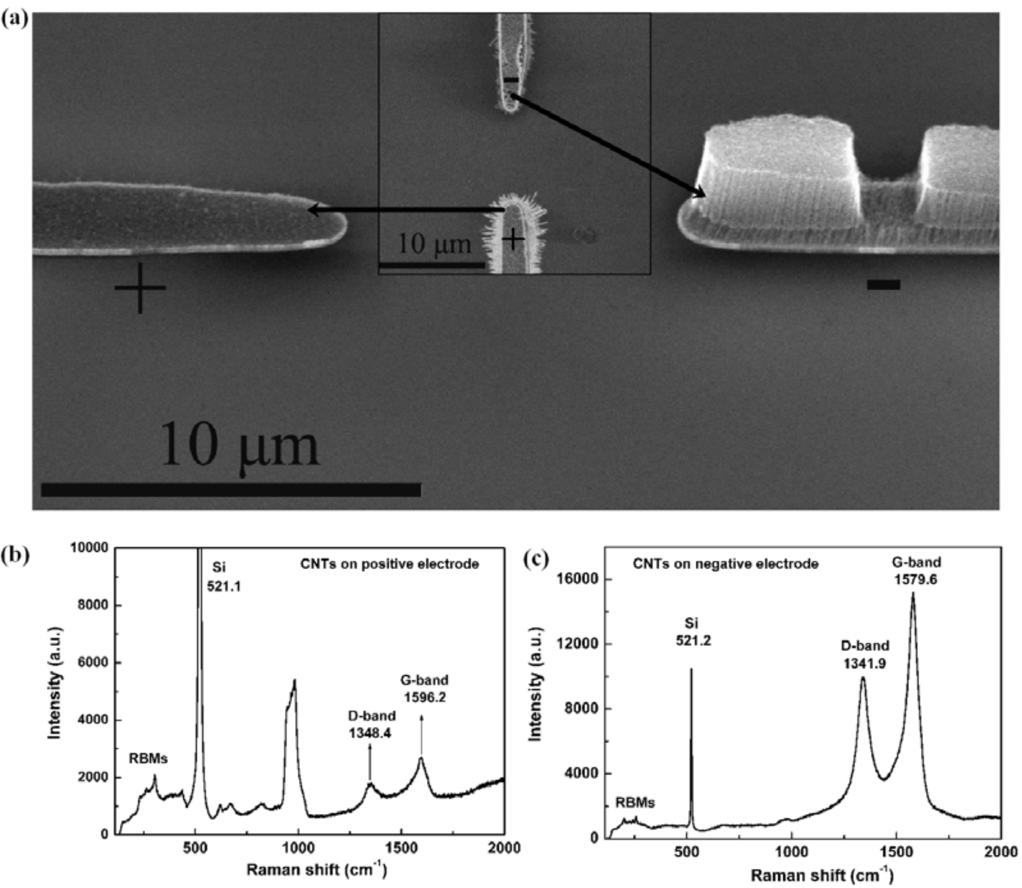
Name	Joseph Hartwig	**Degree**	B.Sc.
Dept.	Electrical Engineering	**Univ.**	University of Nebraska - Lincoln
Goal	Completing a B.Sc. program in the field of Electrical Engineering and obtaining essential knowledge, skills, and industrial experience for pursuing a related profession.		
Objectives	1. Grasping necessary knowledge in the field of electrical engineering; 2. Grasping necessary experimental and simulation techniques required in this project; 3. Establishing essential industrial experience by conducting industrial intership; 4. Developing effective communication skills; and 5. Developing collaborative and teamwork skills.		

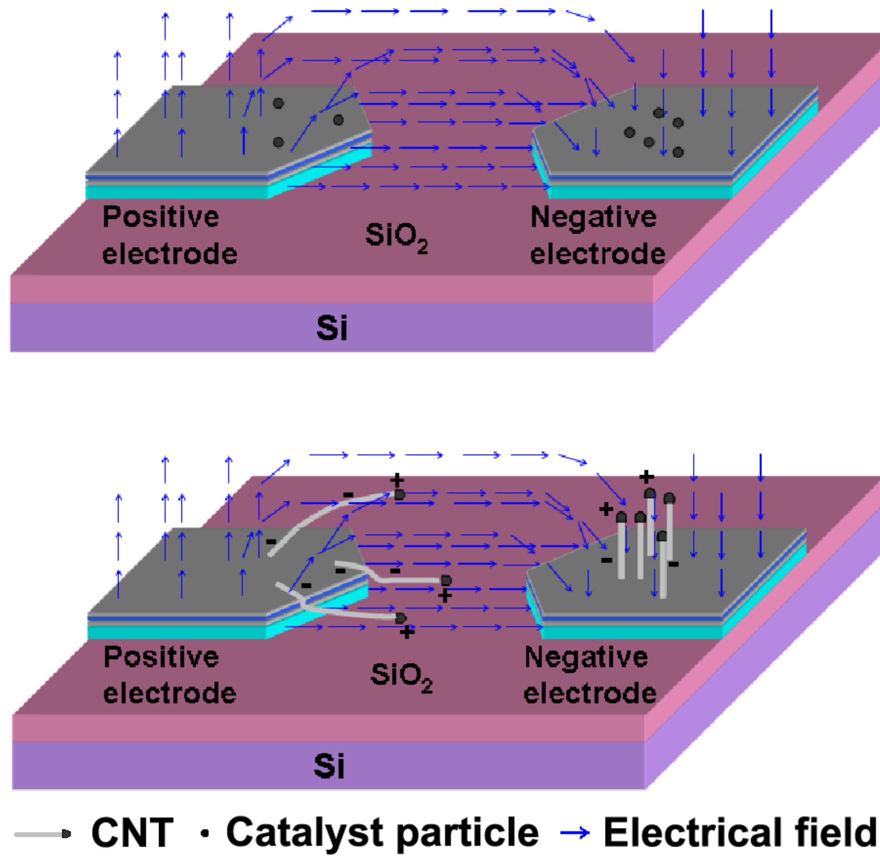
VI - Preliminary Results

1. **Growing CNTs with alignment control**
2. **Optically controlled *in situ* growth and parallel integration of CNTs**
3. **Direct formation of graphene on dielectric surfaces via a solid-state process**
4. **Laser direct writing of graphene patterns**
5. **Resonant vibrational excitation in diamond growth control**
6. **Low-temperature synthesis of GaN thin films**

VI - Preliminary Results

1. Growing CNTs with alignment control



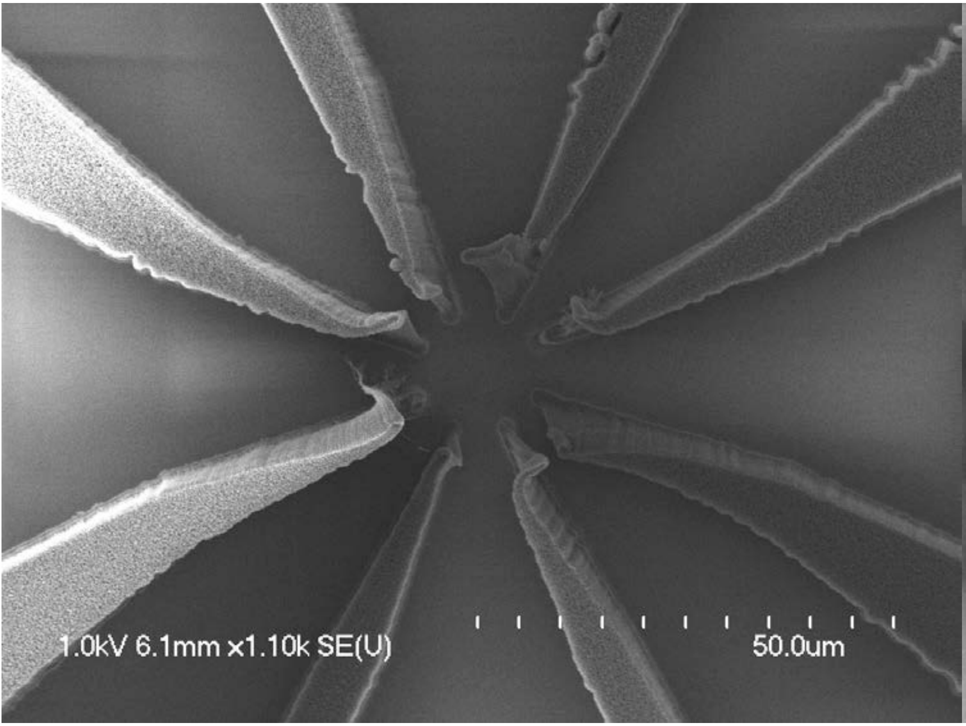


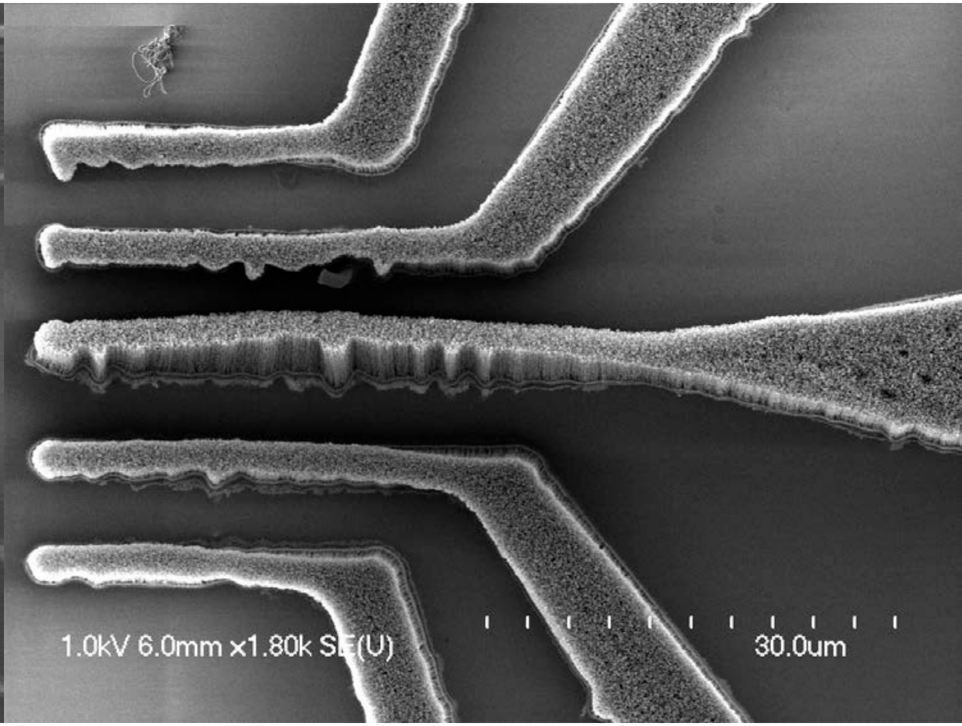
Ref.: Applied Physics Letters, 2009, 95(14), 143117.

VI - Preliminary Results

1. Growing CNTs with alignment control

Vertically aligned CNT patterns

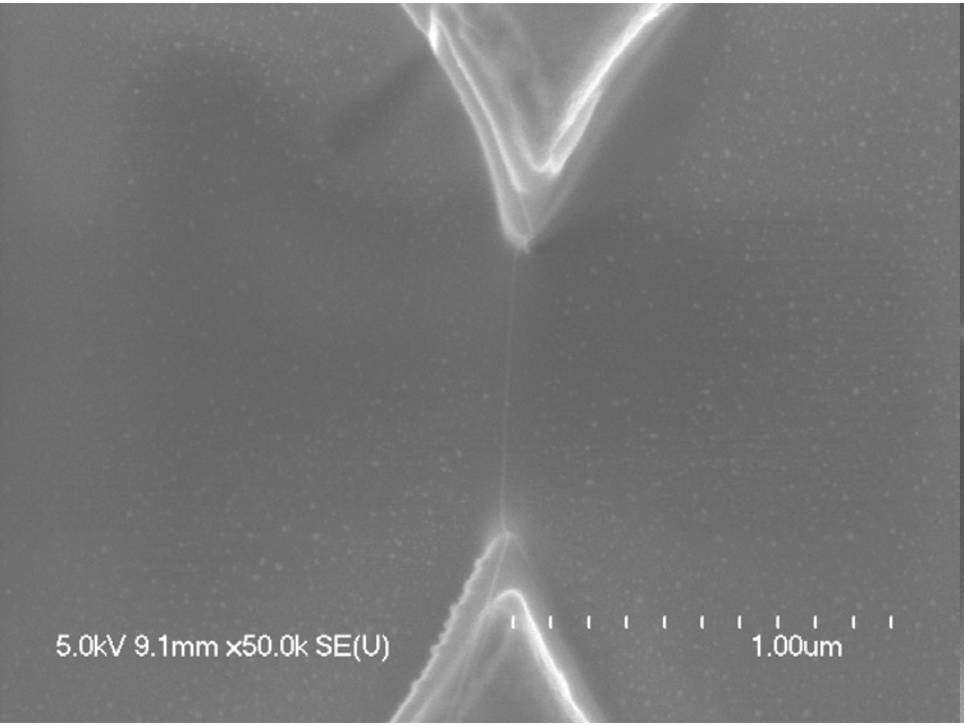




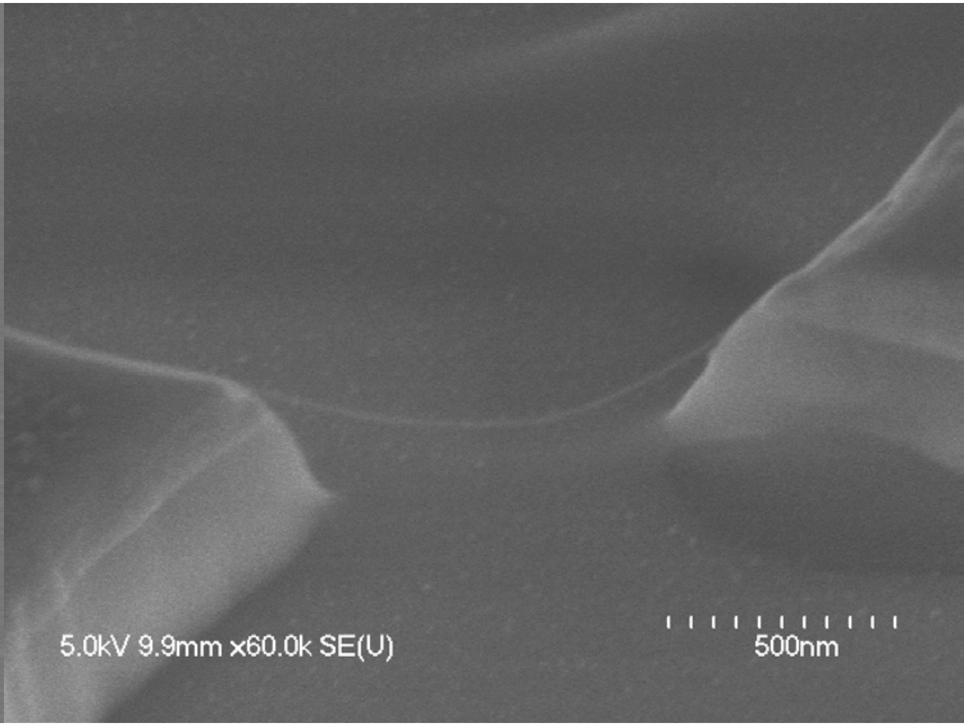
VI - Preliminary Results

2. Optically controlled *in situ* growth and parallel integration of CNTs

Top view



Side view



Ref.: Nanotechnology. 2010, 21, 315601

VI - Preliminary Results

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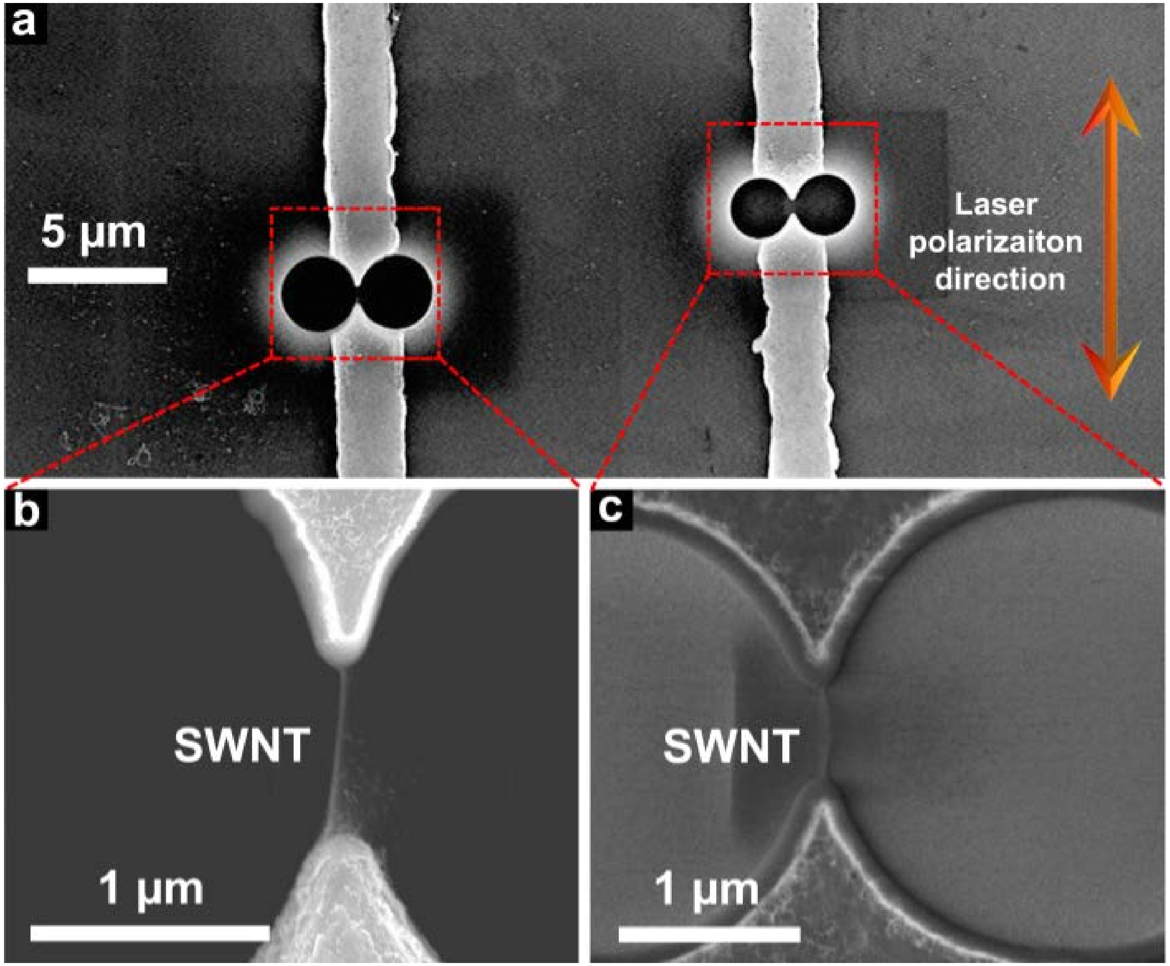

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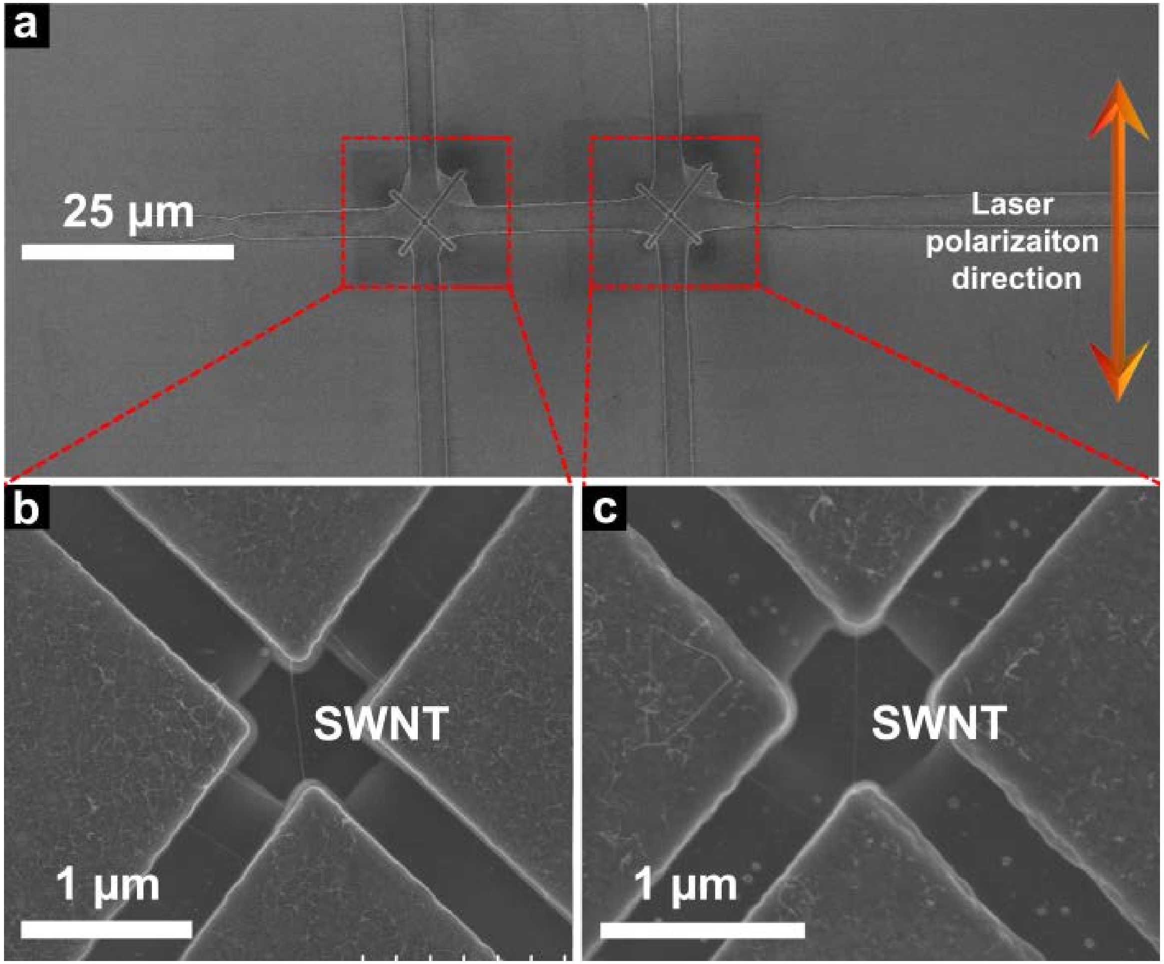

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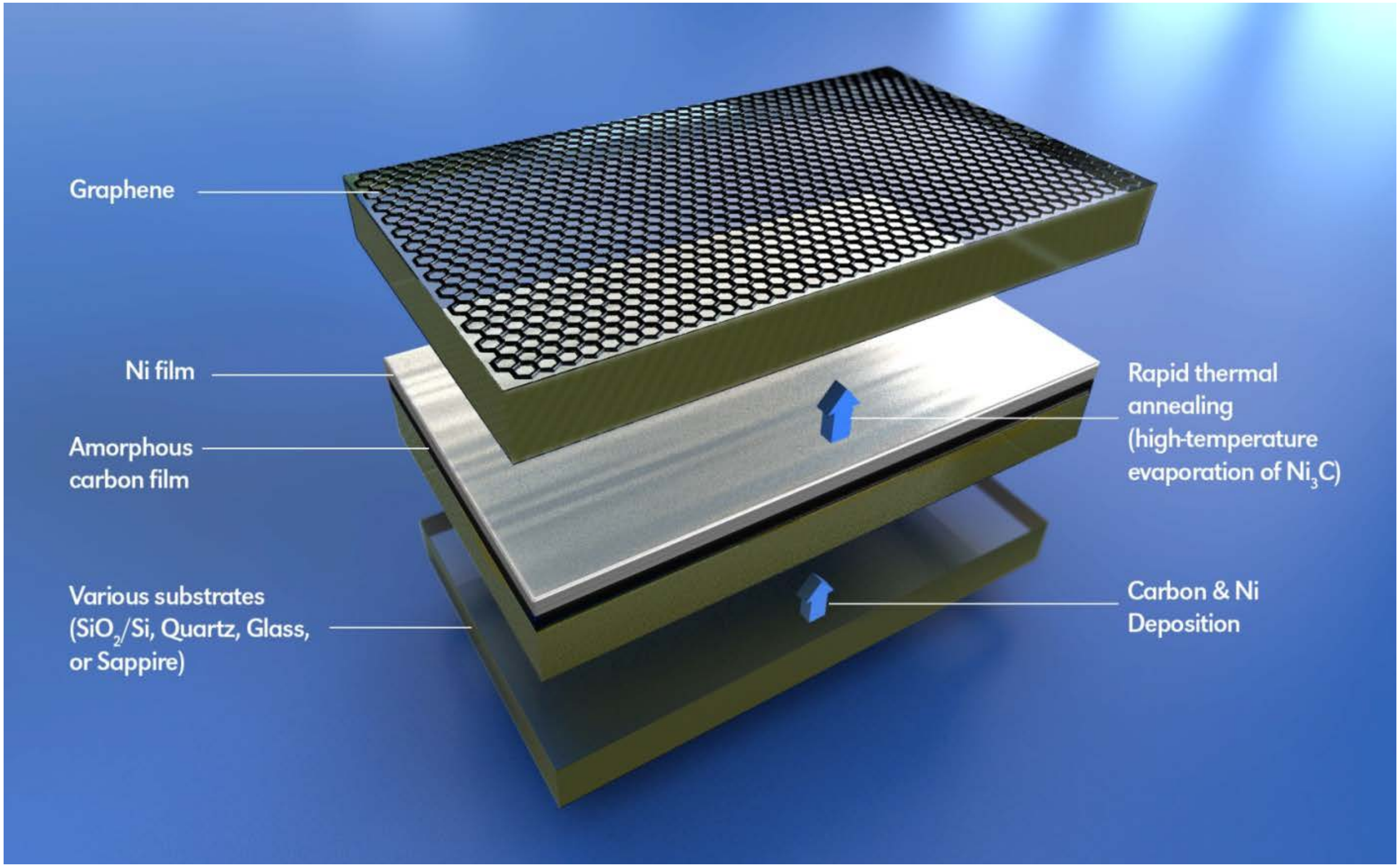
VI - Preliminary Results

3. Direct formation of graphene on dielectric surfaces via a solid-state process



Ref.: Advanced Materials. 2013, 25, 630-634.

VI - Preliminary Results

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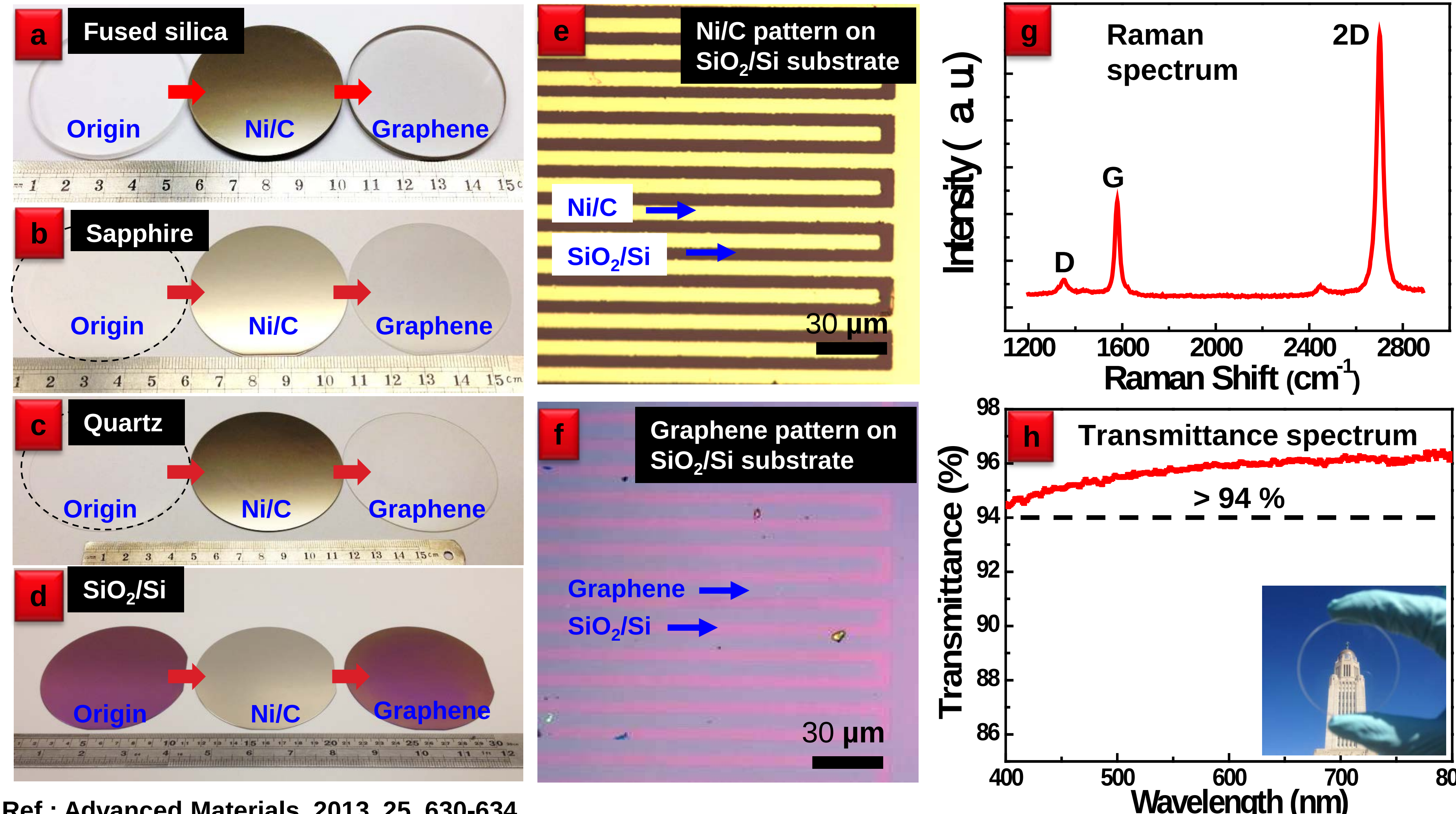

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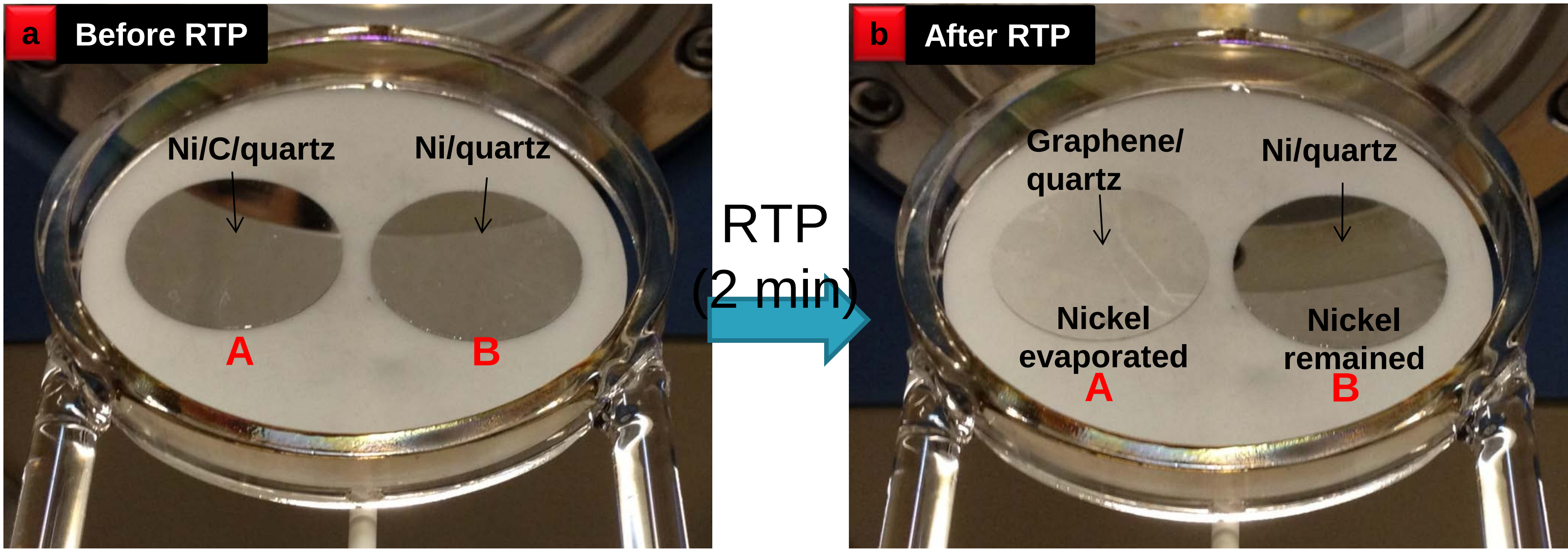

Sample A: Ni/quartz

Sample B: Ni/C/quartz

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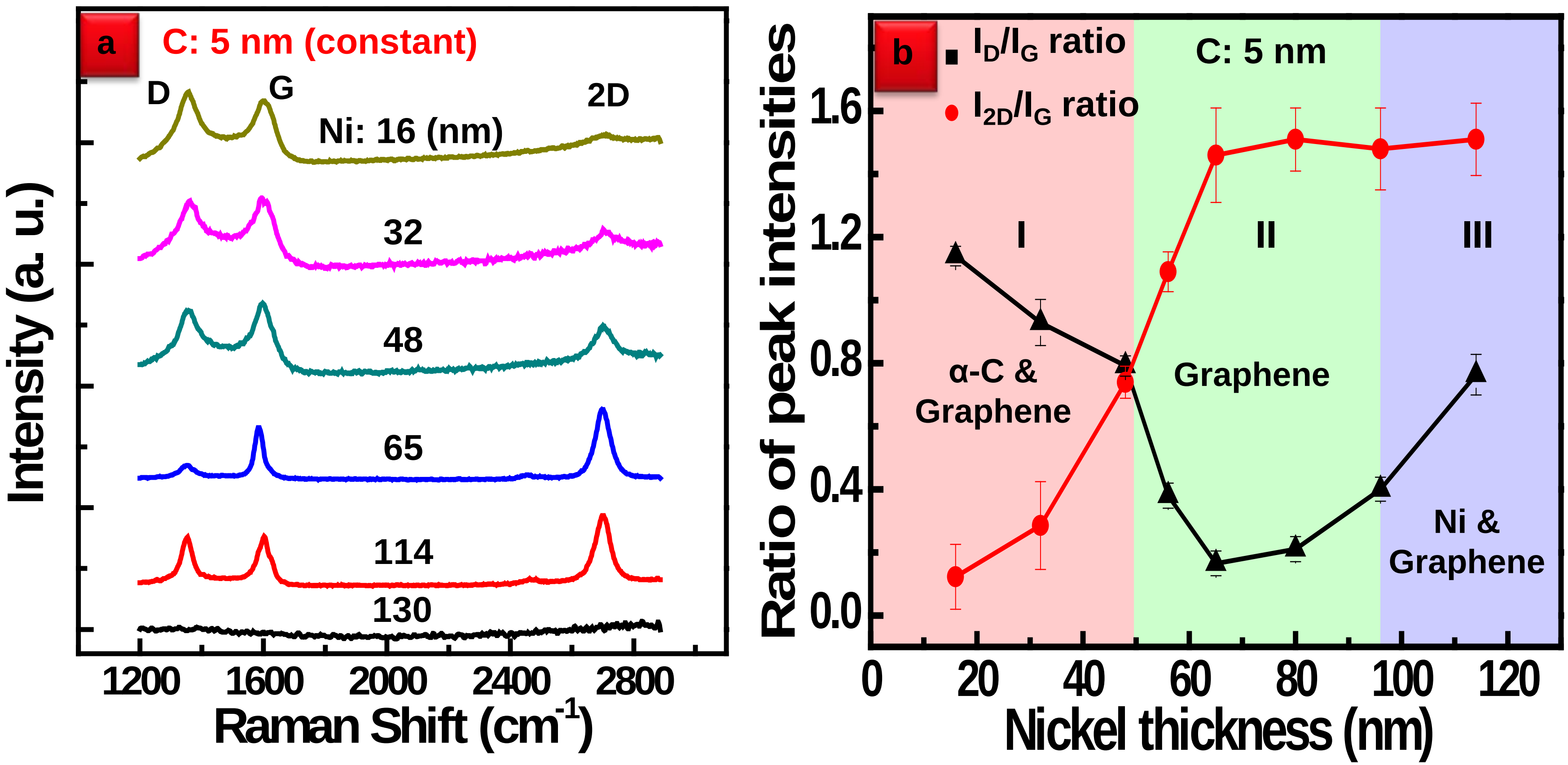

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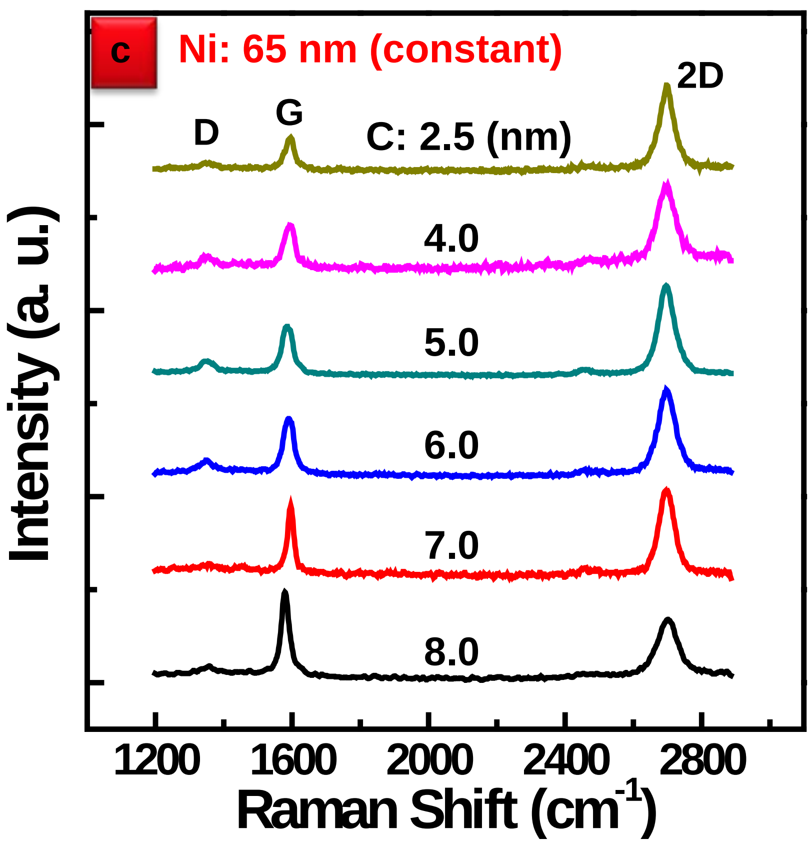

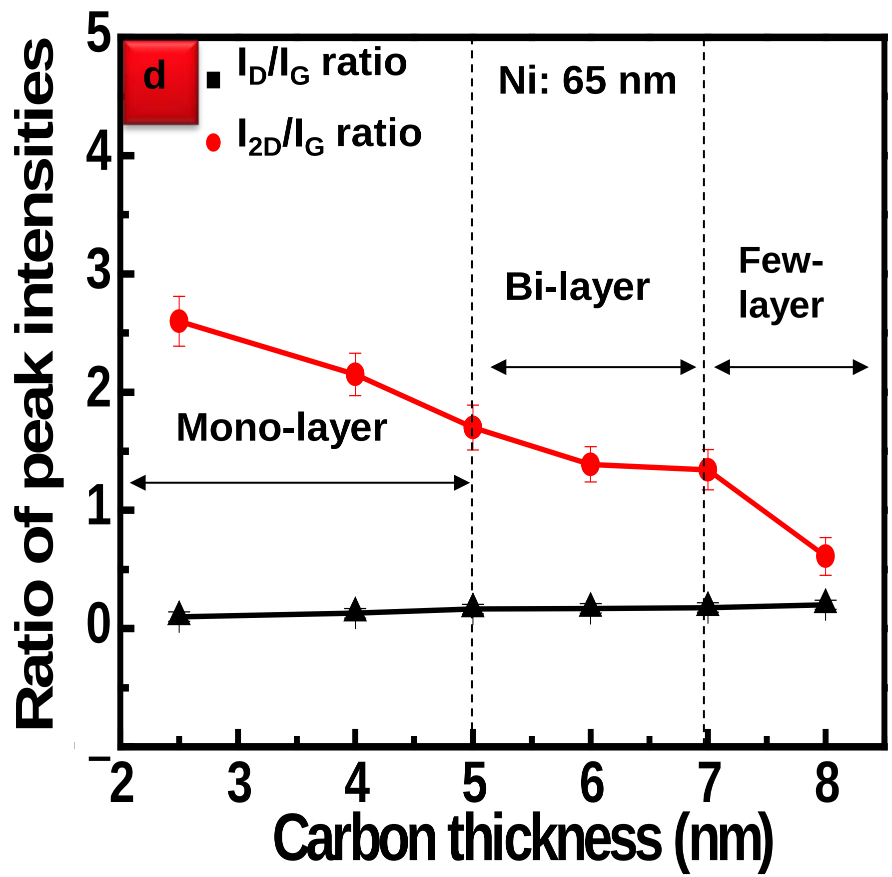

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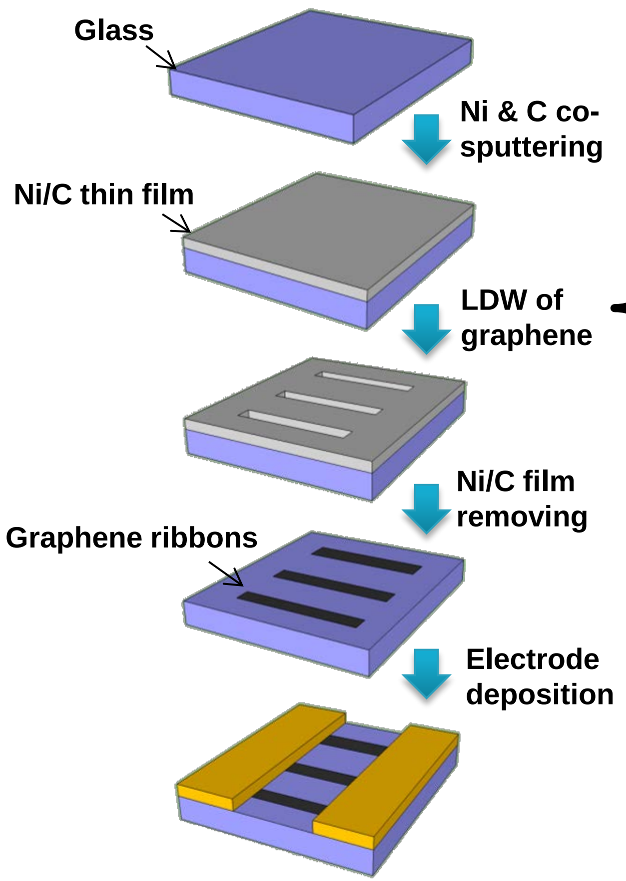
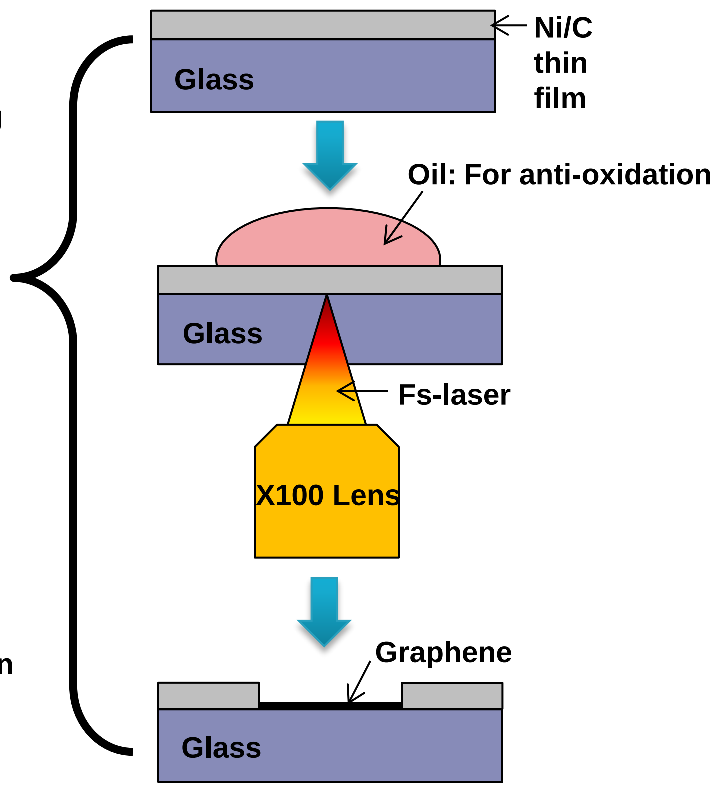
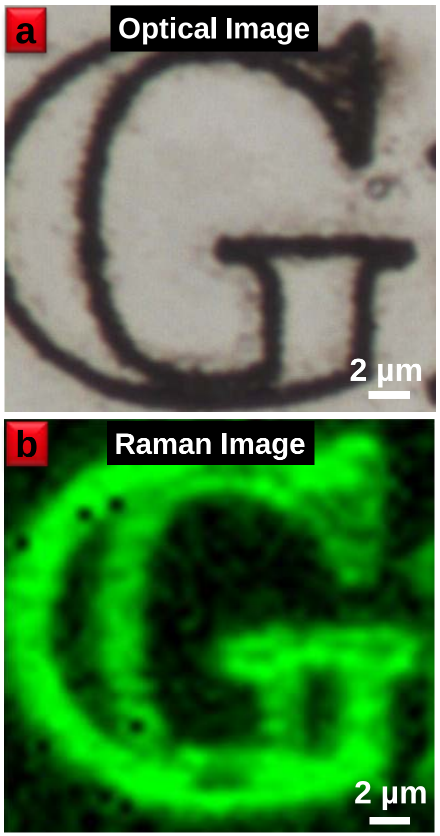
VI - Preliminary Results

4. Laser direct writing of graphene patterns







Ref.: Scientific Reports. 2014, 4, 4892

VI - Preliminary Results

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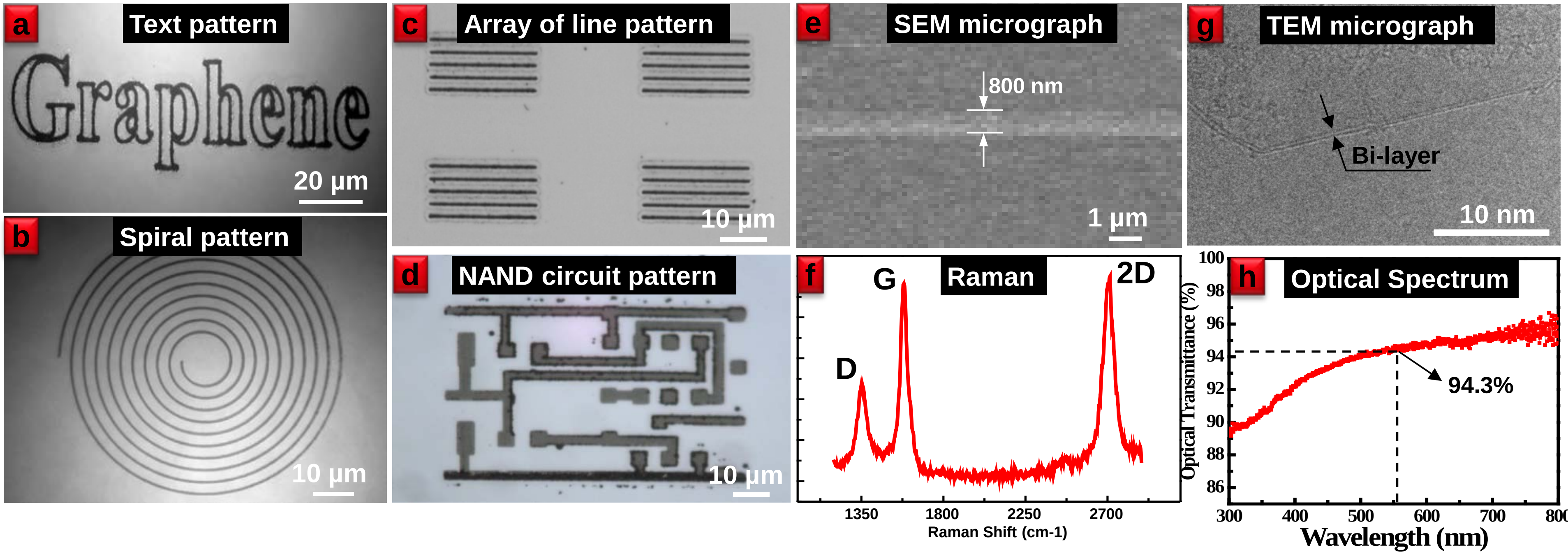

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VI - Preliminary Results

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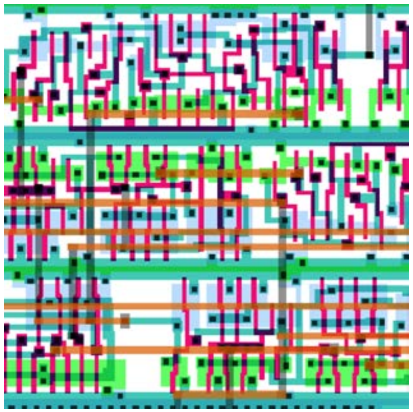
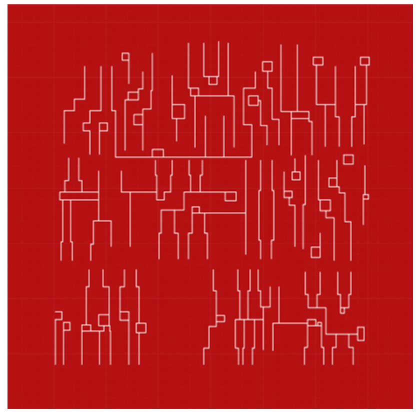


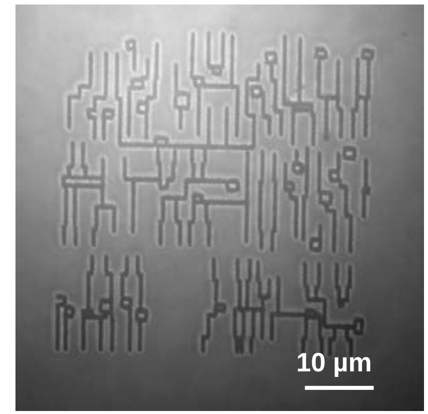
Physical layout of integrated circuit (GDSII format)

Convert to “.gwl” file

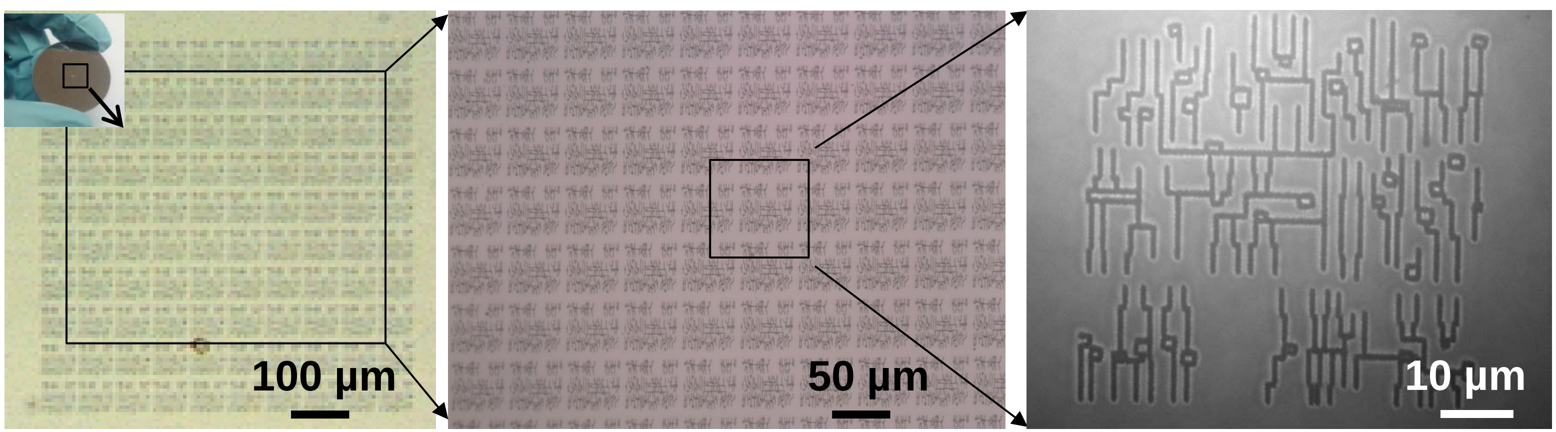


Corresponding IC pattern in GWL program format

Laser direct writing of graphene



Graphene IC layouts on a glass substrate



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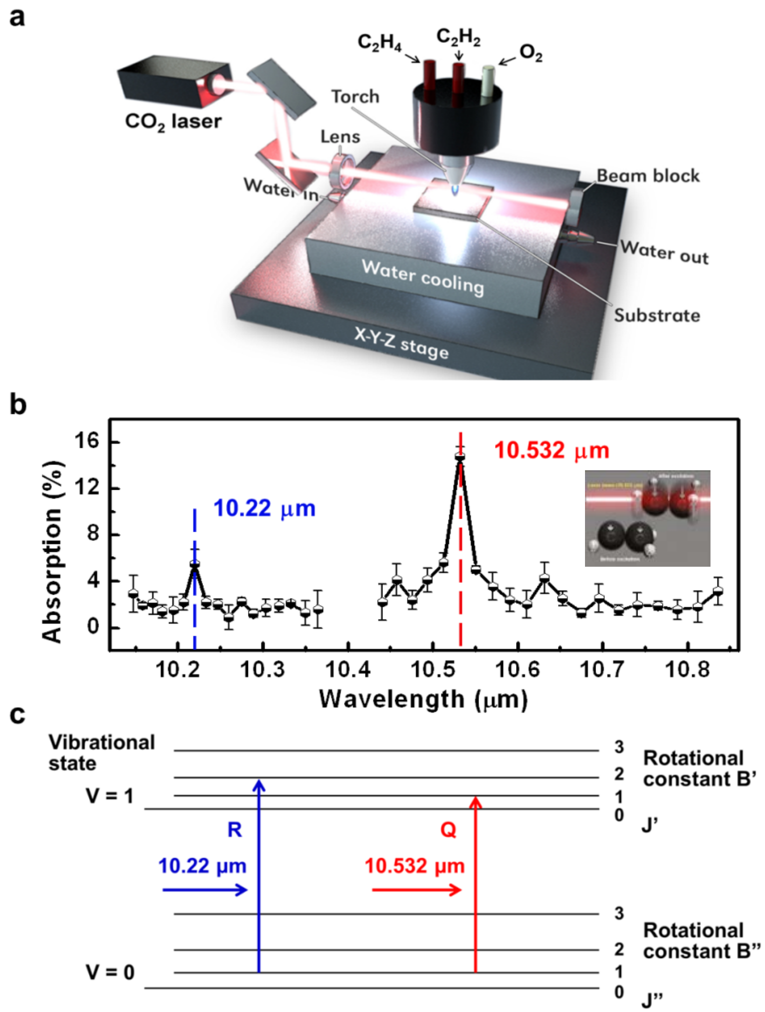
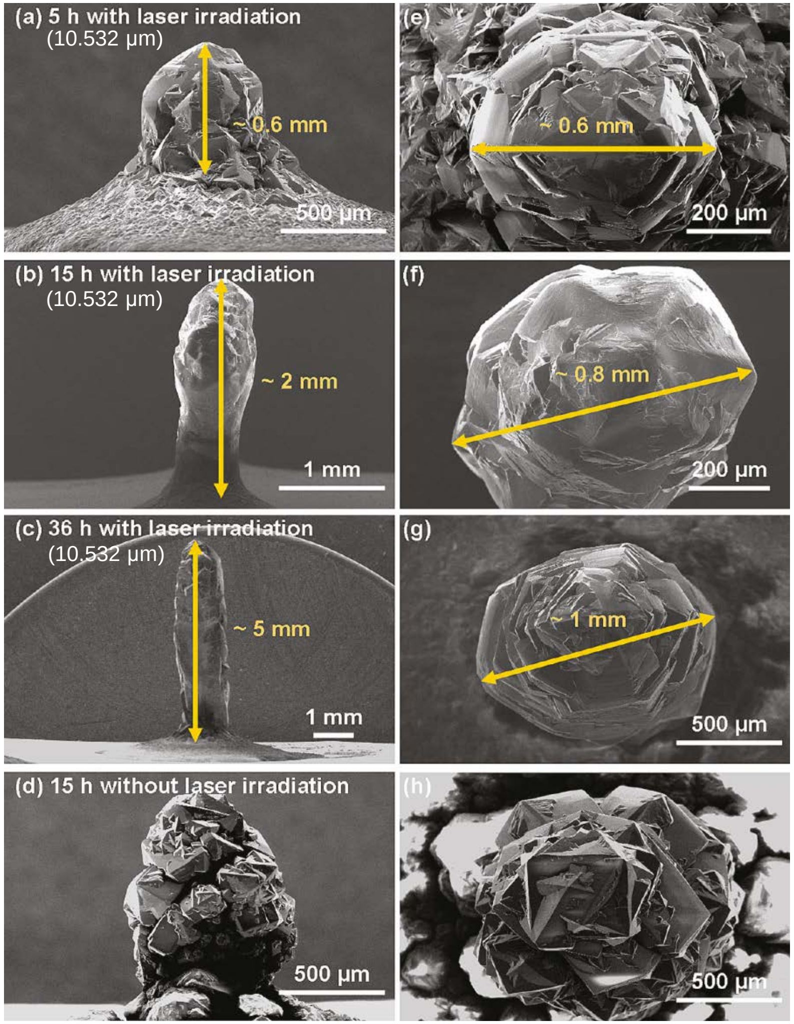
VI - Preliminary Results

5. Resonant vibrational excitation in diamond growth control





VI - Preliminary Results

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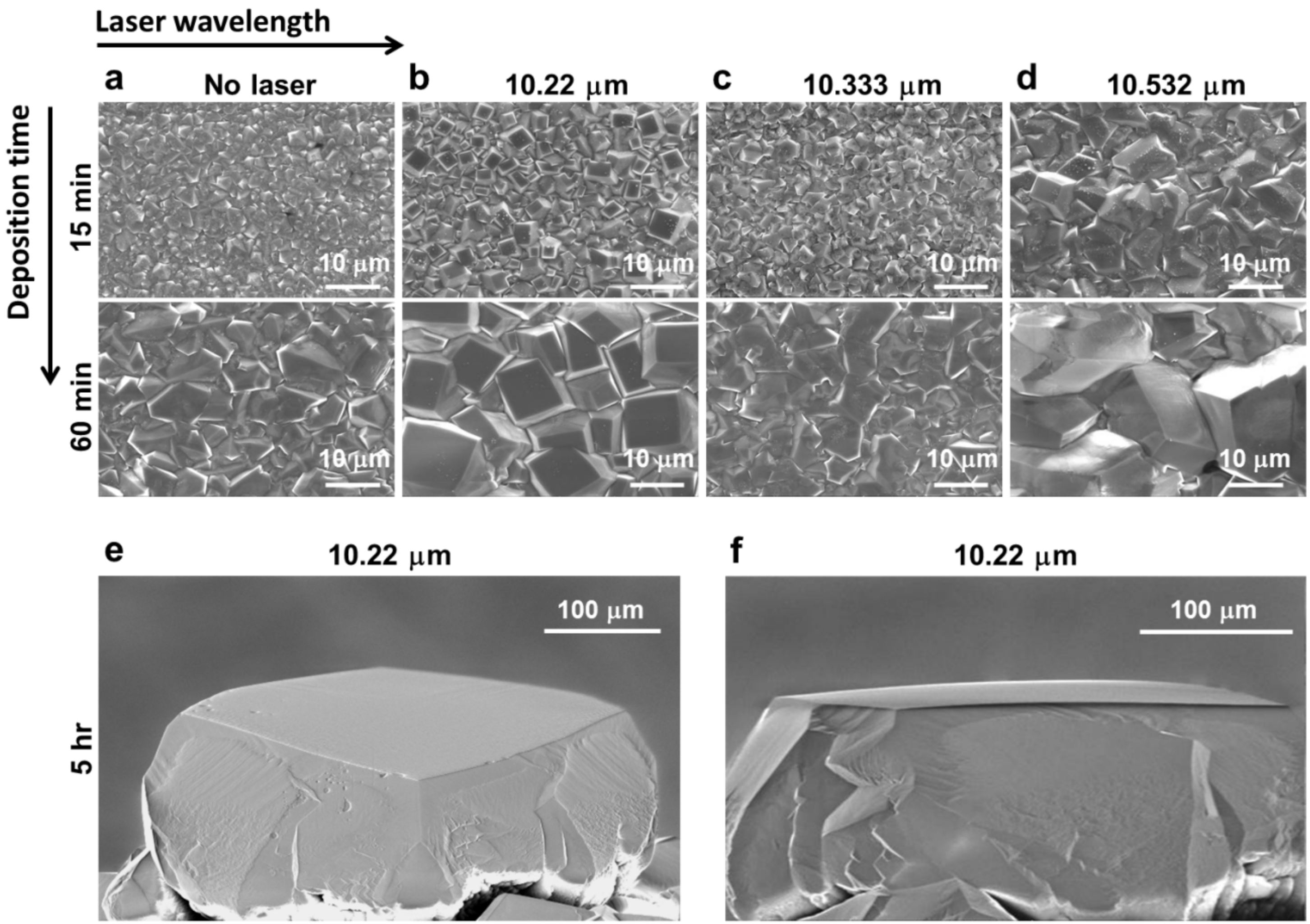
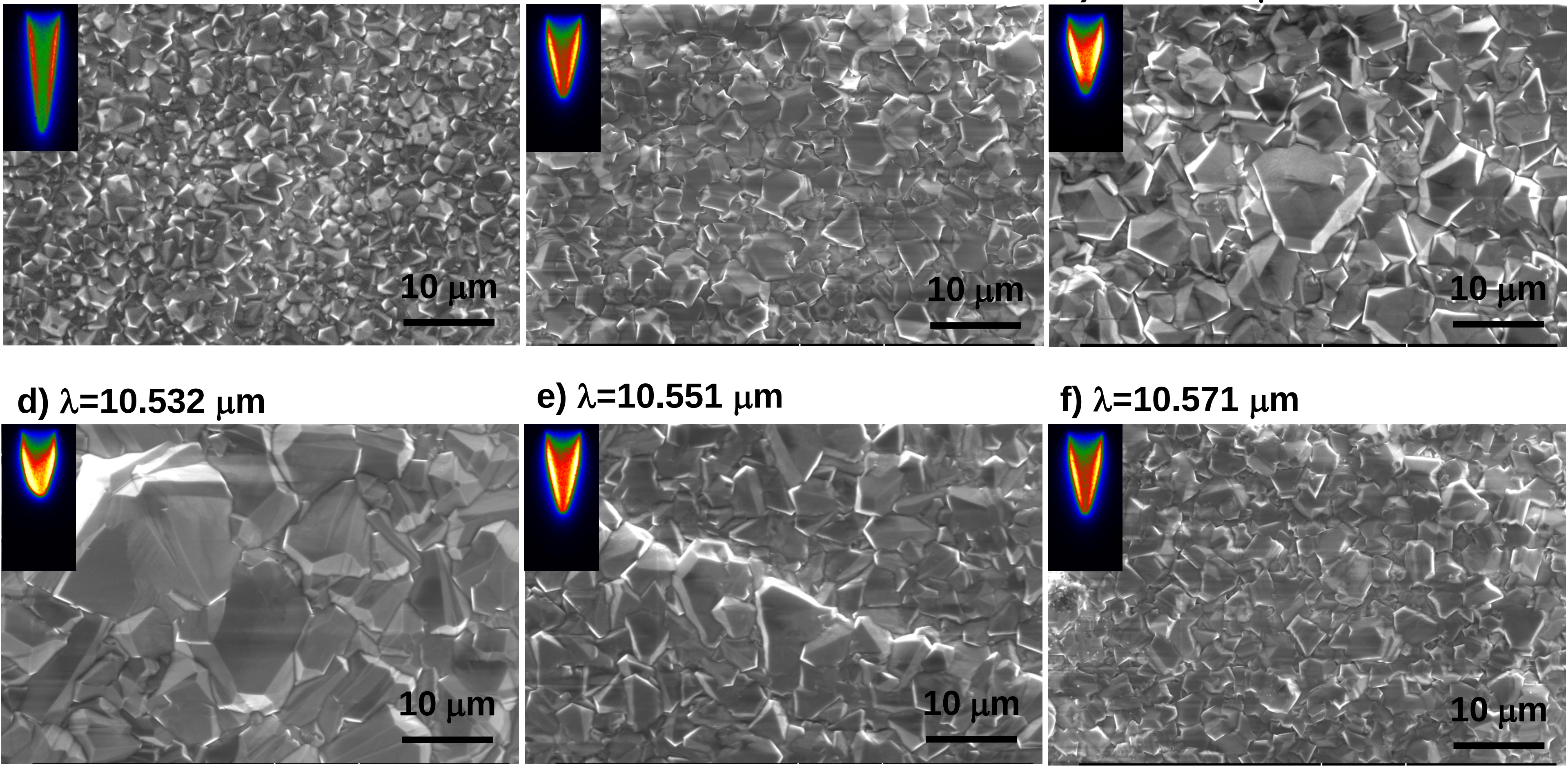


VI - Preliminary Results

5. Resonant vibrational excitation in diamond growth control

a) No laser
b) λ=10.494 μm
c) λ=10.513 μm

d) λ=10.532 μm
e) λ=10.551 μm
f) λ=10.571 μm



VI - Preliminary Results

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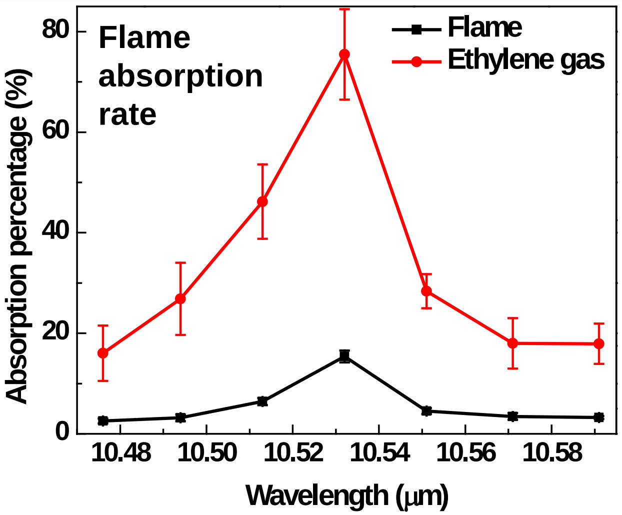
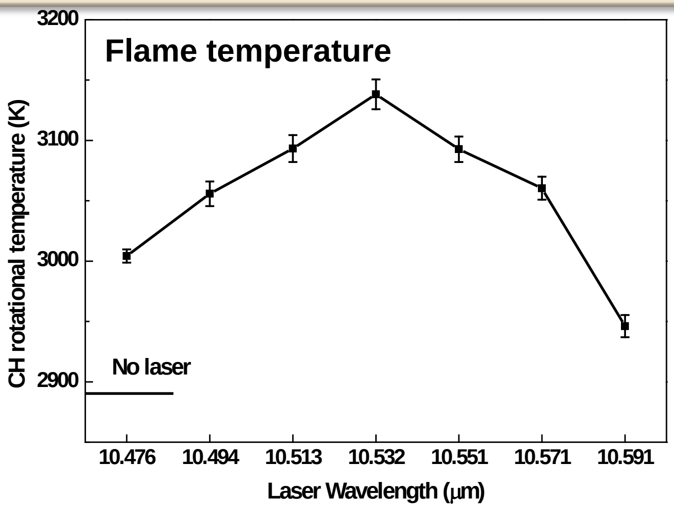
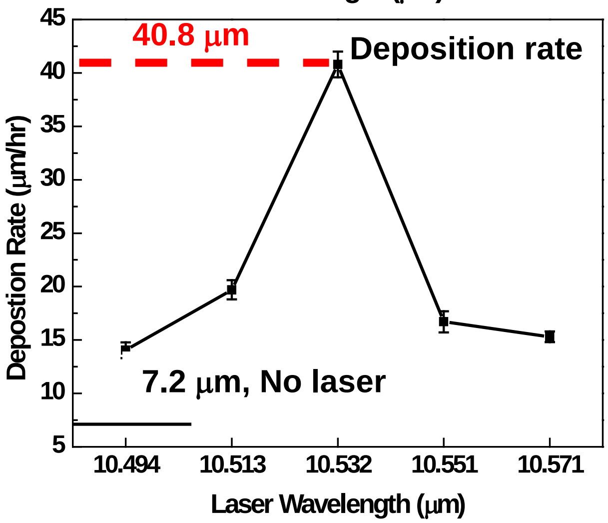
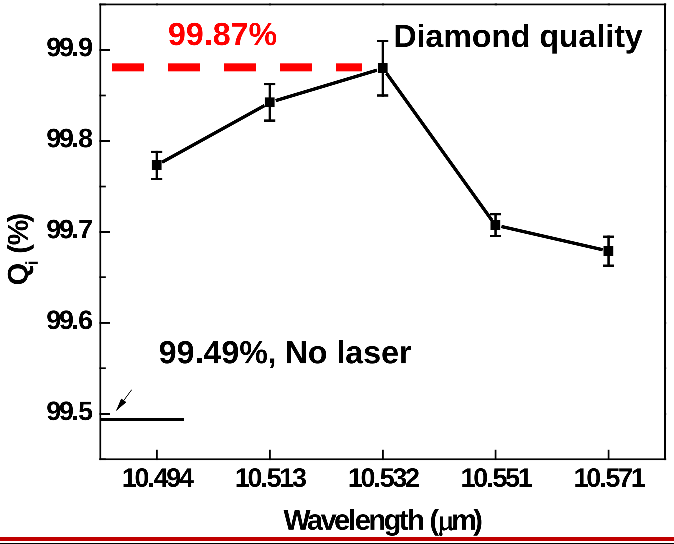


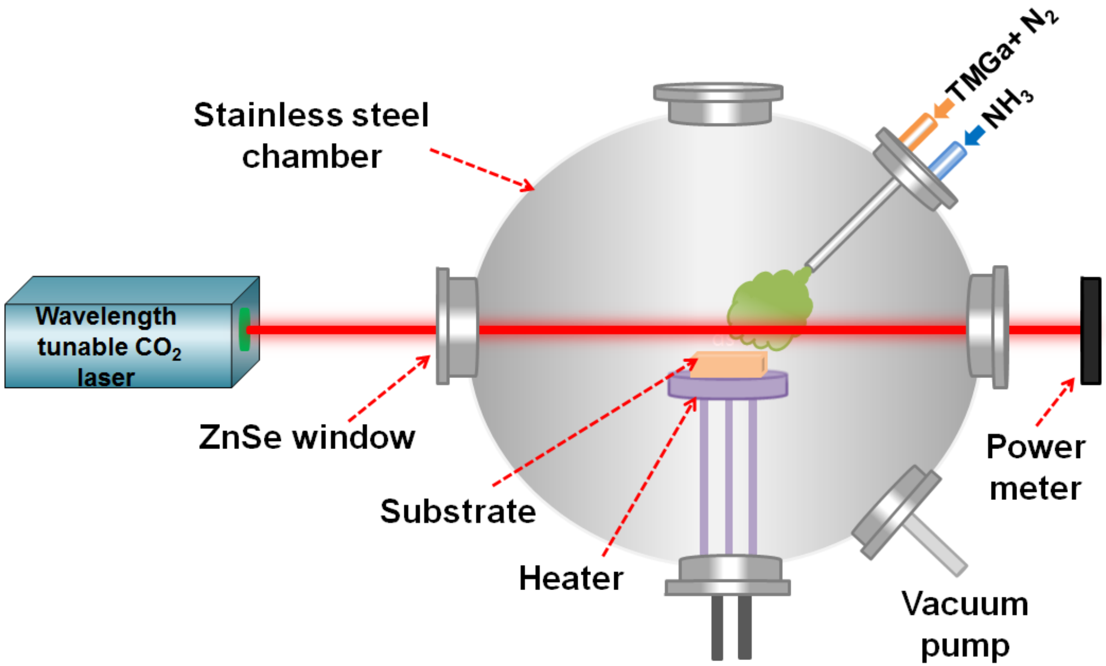


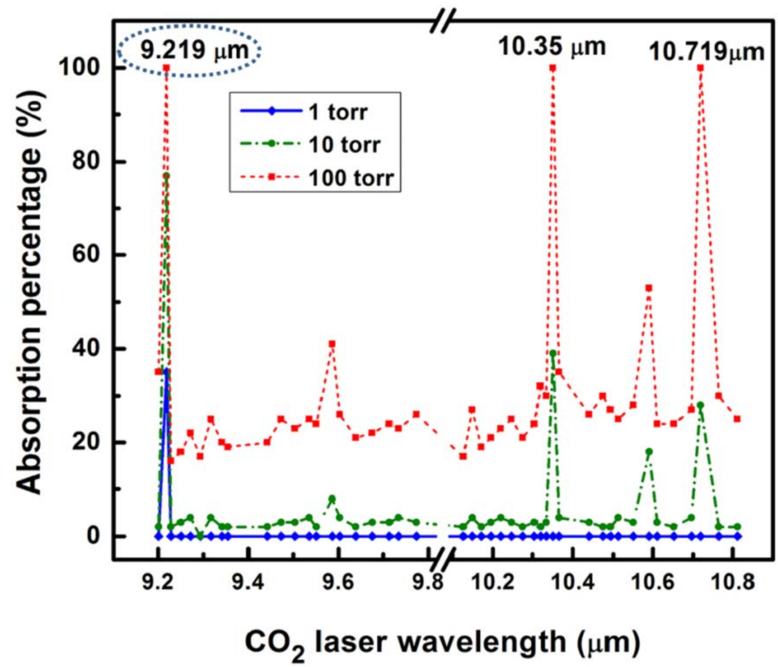




VI - Preliminary Results

6. Low-temperature synthesis of GaN thin films





Thank you!