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

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http://lane.unl.edu
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

How to address?

New Energy Sources
- Biomass
- Solar
- Geothermal
- Wind
- Water

High Energy Efficiency
II - Background and Motivations

Electricity Generation Efficiency

<table>
<thead>
<tr>
<th>Method</th>
<th>Efficiency (%)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>33 – 36</td>
<td>Efficiency in Electricity Generation, EURELECTRIC</td>
</tr>
<tr>
<td>Coal</td>
<td>39 - 47</td>
<td>“Preservation of Resources” Working Group’s “Upstream” Sub-Group in collaboration with VGB, 2003</td>
</tr>
</tbody>
</table>
II - Background and Motivations

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

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conductivity ($\sigma$)</td>
<td>$\sigma &gt; 1 \text{ S/m}, \text{ flux } \approx 1 \text{ amp/cm}^2$</td>
</tr>
<tr>
<td>Thermal conductivity (k)</td>
<td>High heat flux from the combustion fluids at 2400 K</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>Melting point ($T_m$) above 2400 K</td>
</tr>
<tr>
<td>Oxidation resistance</td>
<td>Resistant to an oxygen partial pressure about $10^{-2}$ atm at 2400 K</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td>Potassium seeds and aluminosilicate slags</td>
</tr>
<tr>
<td>Erosion resistance</td>
<td>High velocity hot gases and particulates</td>
</tr>
<tr>
<td>Thermionic emission</td>
<td>The anode and cathode should be good acceptor and emitters, respectively.</td>
</tr>
</tbody>
</table>
### III - Proposed Solution and Activities

#### Project tasks, milestones, and planned completion dates

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

**Timelines and corresponding milestones of the project**

<table>
<thead>
<tr>
<th>Task</th>
<th>Period</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>1</td>
<td>09/01/14 - 06/30/17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Milestone:** Successful completion of the proposed project within the 3-year period.

<table>
<thead>
<tr>
<th>Task</th>
<th>Period</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>2</td>
<td>09/01/14 - 08/31/17</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Milestone:** Achieve the growth of VA-CNT carpets on Cu substrates with CNT lengths up to 1 cm

<table>
<thead>
<tr>
<th>Task</th>
<th>Period</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>3</td>
<td>12/01/14 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Milestone:** Achieve the growth of uniform CNT-BN composite structures.

<table>
<thead>
<tr>
<th>Task</th>
<th>Period</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>4</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.4</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
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</tr>
</tbody>
</table>

**Milestone:** Determine the stability and resistance of the CNT-BN composite structures, and obtain the electrical and thermal conductivities of the composite structures.

<table>
<thead>
<tr>
<th>Task</th>
<th>Period</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>5</td>
<td>09/01/15 - 08/31/17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Milestone:** Determining the thermionic emission performance of the CNT-BN composite structures.
## IV - Deliverables and Spending Plan

<table>
<thead>
<tr>
<th>Type</th>
<th>Deliverables</th>
</tr>
</thead>
</table>
| **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

<table>
<thead>
<tr>
<th>Name</th>
<th>Qiming Zou</th>
<th>Degree</th>
<th>Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dept.</td>
<td>Electrical Engineering</td>
<td>Univ.</td>
<td>University of Nebraska - Lincoln</td>
</tr>
</tbody>
</table>

### 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

<table>
<thead>
<tr>
<th>Name</th>
<th>Joseph Hartwig</th>
<th>Degree</th>
<th>B.Sc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dept.</td>
<td>Electrical Engineering</td>
<td>Univ.</td>
<td>University of Nebraska - Lincoln</td>
</tr>
<tr>
<td>Goal</td>
<td>Completing a B.Sc. program in the field of Electrical Engineering and obtaining essential knowledge, skills, and industrial experience for pursuing a related profession.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Objectives</td>
<td>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 internship; 4. Developing effective communication skills; and 5. Developing collaborative and teamwork skills.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

VI - Preliminary Results

1. Growing CNTs with alignment control

Vertically aligned CNT patterns
2. Optically controlled \textit{in situ} growth and parallel integration of CNTs

Ref.: Nanotechnology. 2010, 21, 315601
VI - Preliminary Results

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

Ref.: Nanotechnology. 2010, 21, 315601
2. Optically controlled \textit{in situ} growth and parallel integration of CNTs

Ref.: Nanotechnology. 2010, 21, 315601
3. Direct formation of graphene on dielectric surfaces via a solid-state process

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

VI - Preliminary Results

Sample A: Ni/quartz
Sample B: Ni/C/quartz

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

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

VI - Preliminary Results

4. Laser direct writing of graphene patterns

Glass

Ni & C co-sputtering

LDW of graphene

Ni/C film removing

Graphene ribbons

Electrode deposition

Ni/C thin film

Oil: For anti-oxidation

Glass

Fs-laser

X100 Lens

Graphene

Glass

Optical Image

Raman Image

2 µm

Ref.: Scientific Reports. 2014, 4, 4892
VI - Preliminary Results

4. Laser direct writing of graphene patterns

Ref.: Scientific Reports. 2014, 4, 4892
VI - Preliminary Results

4. Laser direct writing of graphene patterns

Convert to ".gwl" file

Laser direct writing of graphene

Physical layout of integrated circuit (GDSII format)

Corresponding IC pattern in GWL program format

Graphene IC layouts on a glass substrate

Ref.: Scientific Reports. 2014, 4, 4892
VI - Preliminary Results

5. Resonant vibrational excitation in diamond growth control

(a) 5 h with laser irradiation (10.532 μm)
(b) 15 h with laser irradiation (10.532 μm)
(c) 36 h with laser irradiation (10.532 μm)
(d) 15 h without laser irradiation

(e) ~ 0.6 mm
(f) ~ 2 mm
(g) ~ 0.8 mm
(h) ~ 5 mm

![Diagram showing vibrational states and absorption peaks.](image)
5. Resonant vibrational excitation in diamond growth control
5. Resonant vibrational excitation in diamond growth control

a) No laser

b) $\lambda = 10.494 \, \mu m$

c) $\lambda = 10.513 \, \mu m$

d) $\lambda = 10.532 \, \mu m$

e) $\lambda = 10.551 \, \mu m$

f) $\lambda = 10.571 \, \mu m$
VI - Preliminary Results

5. Resonant vibrational excitation in diamond growth control

- **Flame absorption rate**
  - Absorption percentage (%)
  - Wavelength (µm)

- **Flame temperature**
  - CH rotational temperature (K)
  - Laser Wavelength (µm)

- **Deposition rate**
  - Deposition rate (µm/hr)
  - Laser Wavelength (µm)

- **Diamond quality**
  - Qi (%)
  - Wavelength (µm)
VI - Preliminary Results

6. Low-temperature synthesis of GaN thin films
Thank you!