Micro Chemical Vapor Deposition System: Design and Verification

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  – Previous study by the same lab group

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Introduction

• **Chemical vapor deposition (CVD):**
  
  – Widely used for fabricating thin films on substrates
  – Uses thermal decomposition of reaction gas for deposition
  – Common CVD systems includes HFCVD, LPCVD, PECVD, APCVD ...
  – Example of products: diamond, carbon nanotubes, ZnO, etc.
CVD is useful however...

Several challenges may be encountered when fabricating nanostructures...

- Long time in heating and cooling process
- Long time in gas switch due to large chamber volume
- Large flow rate may cause turbulent flow and results in bad quality.
Introduction

- Previous research by Professor Liwei Lin:

- In this study:
  A micro-CVD system is proposed and fabricated. The system size is decreased from the scale of meters to tens of micrometers

Temperature stabilization:

Large heat capacity of the conventional furnace system takes **long time** for the system to warm up and cool down and unwanted reactions can happen.

**Analysis**

Time constant can be estimated by $\tau_h = R_h C_h$

where $C_h \propto L^3$ and $R_h \propto L^{-1}$

because

$$Q = k \int dA \cdot \nabla T \sim k L^2 \left( \Delta T / L \right) \propto \Delta T \cdot L$$

$\Rightarrow R_h = \Delta T / Q \propto L^{-1}$ and $\tau_h = R_h C_h \propto L^2$

$\Rightarrow$ shrinking system from meter to micrometer scale results in $10^{-8}$ reduction of response time.

$\Rightarrow$ time will go down from tens of minutes to several microseconds and unwanted side reactions can be avoided.
Theoretical Modeling

Rapid gas species exchange:

• To control a CVD process, switching from one type of gas to another is often advantageous for the process flexibility. (e.g. in CNT synthesis switch of carrier gas, Ar, to reactant gas, CH₄, is critical.)

• Larger chamber volume results in longer exchange time and slow concentration change.

• The micro-CVD system provides fast gas exchange because of the reduced reaction chamber volume.

• The gas exchange time should be about 10⁻⁴ reduction. Therefore, the gas exchange process will be 10⁴ quicker which takes only several milliseconds.
Small Reynolds number for Laminar flow:

- Laminar flow is often preferred in CVD process. Reynolds number, $R_e$, is often used to characterize different flow regimes.
- For their conventional APCVD system using CH$_4$, the Reynolds number is estimated to be:

$$Re = \frac{\rho v_m D}{\mu} = \frac{\rho Q D}{\mu A} \approx \frac{1\text{Kg/m}^3 \times 3000\text{sccm} \times 0.05\text{m}}{1 \times 10^{-5}\text{Pa} \cdot \text{s} \times 0.002\text{m}^2} = 125$$

For the micro-CVD system

- Reynolds number is as small as 0.01
- With a small $R_e$ flow rate can be increased without worrying about turbulent flow.
Enhancement on reactant gas mass transfer:

- Efficient gas transfer is necessary to produce high quality products from the CVD process by carrying away the by-products.
- The mass transfer mechanism in an APCVD system is usually diffusion.
- There would be a $10^4$ increase in velocity gradient following out prototype example.
- This large velocity gradient can ensure efficient mass transfer.
Short gas warming up distance:

- One concern about the micro-CVD system is that whether the gas is fully heated up by flowing through such a short-distance in a microchannel.
built-in vertical microchannels (5μm in diameter and 50μm in length) as the chemical reaction chambers

microstructures are constructed on a SOI wafer

backside hole (100μm in diameter and 400μm in length)
Device Design and Fabrication

Images of the prototype

Figure 4: A SEM picture shows an overview of the device.

Figure 5: Electrical and gas interfaces.
Experimental Verification

Results show the successful growth of good quality SWCNTs with approximately 100 μm in length and 1~2 nm in diameter.

Figure 6: Process flow for single-walled CNT growth.

Figure 7: (a) CNTs grown by Micro-CVD. (b) Aligned growth. (c) AFM image. (d) CNTs by furnace growth.
Conclusion

- The concept of micro-CVD system is proposed and verified experimentally with distinctive advantages.

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<td>Micro-CVD</td>
<td>Fast</td>
<td>Fast</td>
<td>Small</td>
<td>Fast</td>
<td>Short</td>
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<tr>
<td>Conventional CVD</td>
<td>Slow</td>
<td>Slow</td>
<td>large</td>
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- The control test using conventional furnace CVD system with the same setup was not able to produce high quality CNTs.
References


Thanks for your attention!!