Hot-wire Chemical Vapour Deposition of Carbon Nanotubes

FR Cummings[1,2] , CJ Arendse[1], GF Malgas[1], M Scriba[1], D Knoesen[2] and CC Theron[3]

[1] CSIR Materials Science and Manufacturing, PO Box 395, Pretoria 0001, South Africa, www.csir.co.za
[2] Department of Physics, University of the Western Cape, Private Bag X17, Bellville 7530, South Africa
[3] Materials Research Group, iThemba LABS, PO Box 722, Somerset West 7129, South Africa

INTRODUCTION

Owing entirely to their structure, carbon nanotubes (CNTs) possess some of the most remarkable chemical and physical properties. More specifically, they exhibit exceptional strength and toughness, chemical inertness, magnetism, and electrical and thermal conductivity, which have led to them being identified as possible components in a variety of applications such as reinforced composites, nano-scale electronic, electrochemical and power devices.

Techniques used to synthesize CNTs include laser ablation of graphite, carbon-arc discharge and chemical vapour deposition (CVD). However, some of these techniques have been shown to be expensive due to high deposition temperatures and are not easily controllable. Recently hot-wire chemical vapour deposition (HWCVD) has been employed for the growth of CNTs at low temperatures [1] as compared to the laser-ablation and arc-discharge techniques with deposition temperatures in excess of 900 ºC. Furthermore, compared to other CVD techniques, the HWCVD system allows for greater control of the growth conditions, is more versatile, offer greater CNT yield and can easily be up-scaled to large substrates [1-3]. This paper presents the design of a compact, versatile HWCVD system, constructed at the CSIR, for the growth of CNTs and the study of the deposition parameters influencing the tube structures.

HWCVD DESIGN

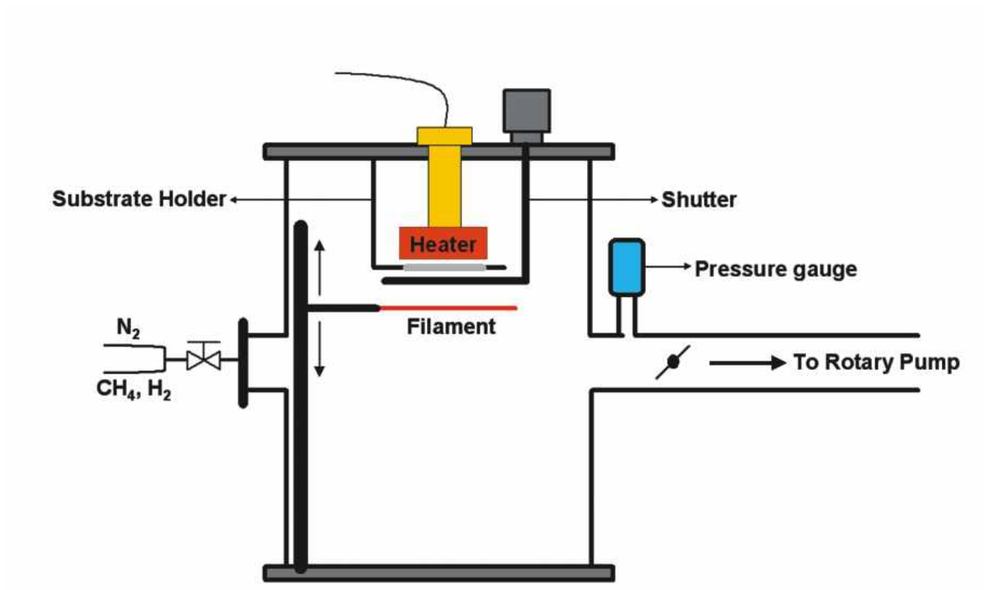

Figure 1: Conventional HWCVD chamber

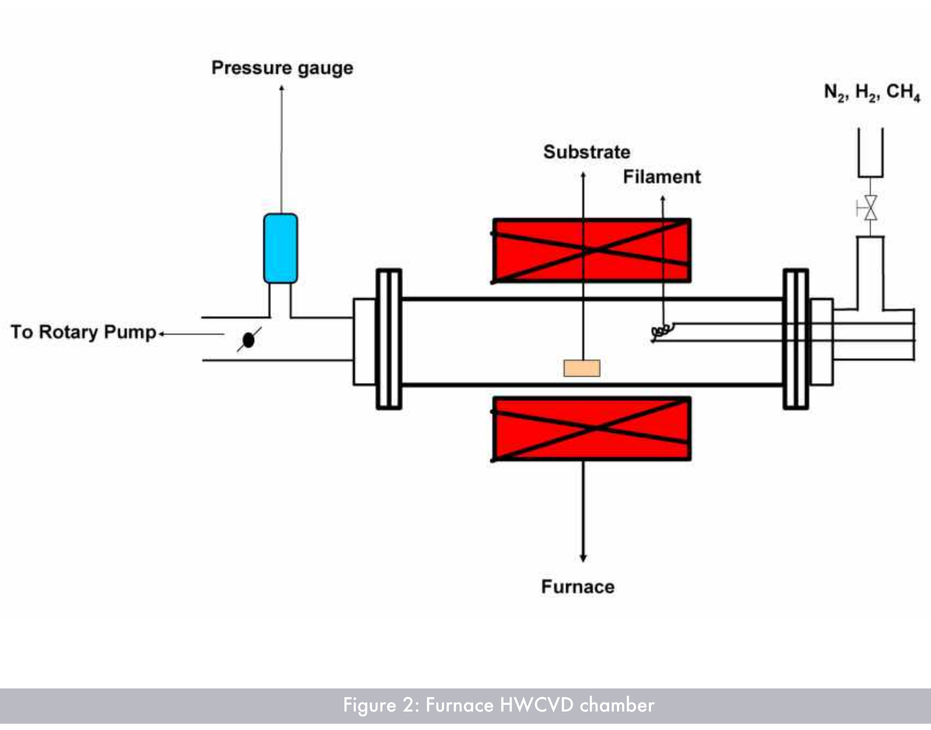

Figure 2: Furnace HWCVD chamber

REPORTED RESULTS

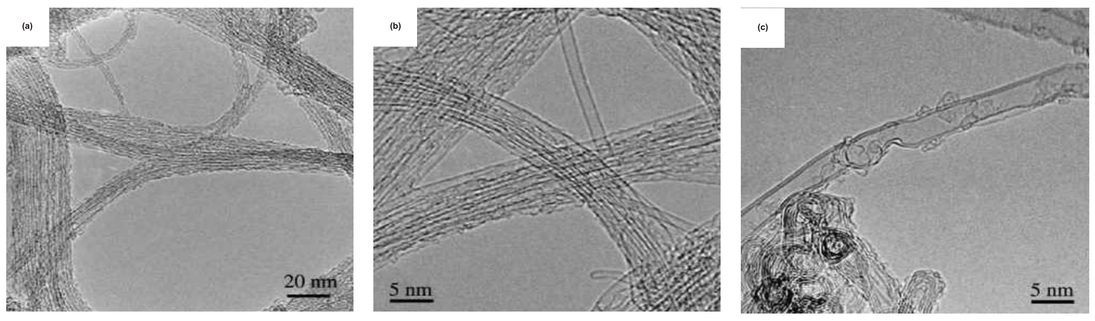

Figure 3: (a) and (b) TEM images of SWCNTs produced by Okazaki et al. [2] via conventional HWCVD, similar to that of **Figure 1: (c)** TEM image of multi-walled CNTs (MWCNTs)

- SWCNTs and MWCNTs present in deposit → low percentage of SWCNTs
- CNTs are isolated and scarcely populated → low yield
- Substantial amount of non-CNT soot in sample → low purity and quality of CNTs

Reason(s):

- Non-uniformity of the temperature within the system → certain parts of the system did not have adequate energy supply for the formation of SWCNTs

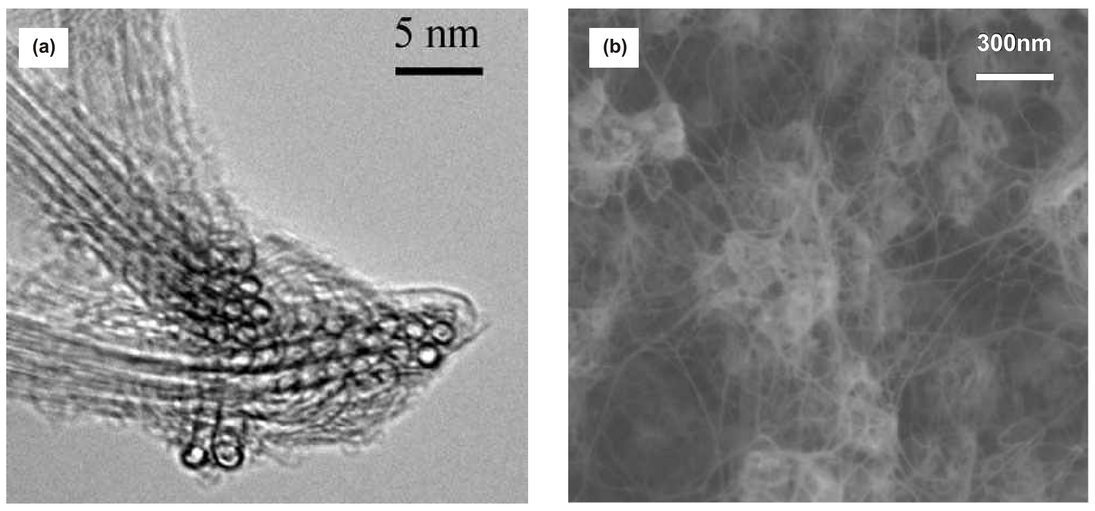

Figure. 4: (a) TEM image of SWCNT 'ropes' produced by Sugai et al. [3] with a furnace HWCVD system similar to that of **Figure 2.**
Figure 4: (b) SEM image illustrating how these web-like SWCNTs grow on metal catalyst particles

- TEM image shows that SWCNTs are produced in ropes (~ 10 SWCNTs/rope) → increased percentage (> 90% of the observed CNTs)
- TEM image clearly shows the advancing metal catalyst particle → tip growth
- SEM image shows that the sample mostly comprise of these ropes
- Minimal/no MWCNTs and non-CNT products formed during synthesis process
- CNT synthesis time ~ 3 min

Reason(s):

The furnace allows for a homogeneous spread of energy throughout the system, which ensures that all CNT constituent parts get supplied with the same amount of energy per unit time, thus allowing for increased SWCNT formation.

CONCLUSION

Two HWCVD designs were presented for the production of SWCNTs. It was shown that HWCVD can produce SWCNTs of high purity and yield. It was also shown that by supplying the HWCVD system with an even distribution of heat energy by means of an electric furnace, the SWCNT yield can be increased by a considerable amount. Furthermore, the modified HWCVD system also demonstrated lower CNT synthesis time (about 3 min), which makes it very cost-effective and can be easily up-scaled into the commercial market for mass production of SWCNTs. A research plan was designed for the deposition of SWCNTs with both HWCVD systems and initial depositions are underway.

BIBLIOGRAPHY

[1] A. C. Dillon, A. H. Mahan, R. Deshpande, J. L. Alleman, J. L. Blackburn, P. A. Parillia, M. J. Heben, C. Engtrakul, K. E. H. Gilbert, K. M. Jones, R. To, S-H. Lee and J. H. Lehman, Thin Solid Films, 521, 216, 2006
[2] T. Okazaki and H. Shinohara, Chem. Phys. Lett., 376, 606, 2003
[3] T. Sugai, T. Okazaki, H. Yoshida and H. Shinohara, New Journ. Phys., 6, 21, 2004

CSIR
our future through science