Effect of a Magnetic Field on the Synthesis of Single-Walled Carbon Nanotubes

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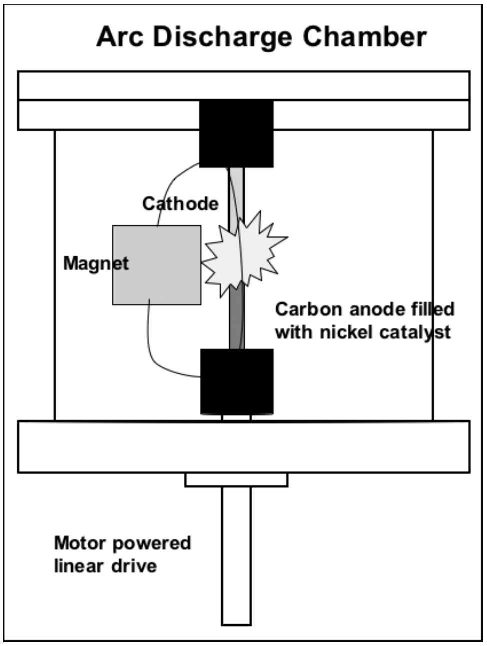
Abstract

The full potential of carbon nanotubes for applications in engineering cannot be achieved until synthesis techniques are refined and methods to control nanotube characteristics are discovered. In this research project, the arc discharge method for producing single-walled carbon nanotubes (SWNTs) was used to test whether the addition of a magnetic field to the arc chamber will create longer SWNTs. Through analysis using scanning electron microscopy (SEM), samples taken from the arc chamber showed that, statistically, the average length of SWNTs produced with the magnetic field were longer than those produced without the addition of the magnetic field.

This suggests that with the addition of a magnetic field, the arc discharge method is an efficient and inexpensive method for producing longer SWNTs. From these results, it is predicted that increasing the magnitude will further increase the length of the SWNTs and produce more consistent results.



Introduction

SWNTs have extremely high tensile strength, elasticity, flexibility and high thermal conductivity. They can also be electrically conducting like metals or semiconducting depending on their structure; making them suitable for a wide range of applications from reinforcement material to microscale machinery. Several techniques have been developed for carbon nanotube synthesis. The most common methods are chemical vapor deposition (CVD) and arc discharge. These techniques are potentially viable as large-scale processes of producing SWNTs; however, they struggle with producing high quality, uniform and homogenous SWNTs that will hopefully make it easier to take advantage of the nanotubes' many potential applications.

CVD, at relatively low temperatures, uses a metal catalyst coated substrate in a heated chamber. Then two gases are introduced to the chamber; a process gas and a hydrocarbon gas. Its perk is that it does not require high temperatures, but the nanotubes it produces usually have defects in their structure. The arc discharge method involves the evaporation of a graphite anode filled with metal catalyst mixture by discharging an electric current between the electrodes. It offers poor flexibility and produces excessive amounts of unnecessary carbonaceous material.

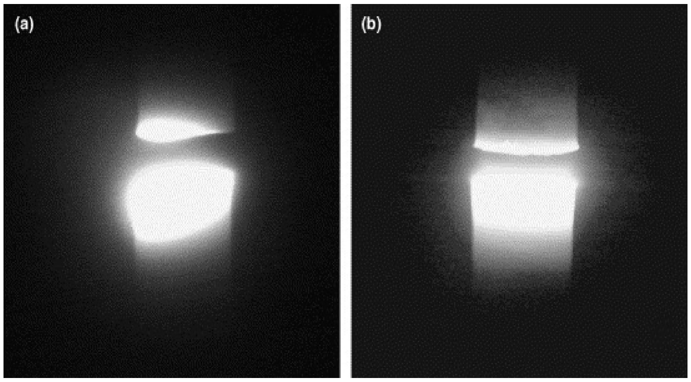


Figure 1: Photo of arc discharge; (a) without magnetic field, (b) with magnetic field.

In this research project, the arc discharge method for producing SWNTs is used to test whether the addition of a magnetic field to the arc chamber will affect the length of SWNTs. The theory behind adding the magnet predicts that if we can increase the density of the plasma between the electrodes, then we can increase the growth rate and consequently produce longer SWNTs. Adding the magnet has been shown to collimate the plasma in the chamber, specifically confining the plasma to the space between the electrodes and spreading it across the electrodes evenly as shown in Figure 1.

Experimental Procedure

We tested whether a magnetic field would make longer SWNTs by executing the arc discharge method of production with and without the magnet. The graphite anode was prepared by filling the 3″ graphite rods with metal catalyst (Ni: Yt: C = 4:1: 95 %) and placing it in the chamber. Attached to the lid of the chamber was the stainless steel cathode. After the anode had been prepared, the lid was placed on the chamber. The chamber was vacuumed down and then pumped with helium at 650 Torr. The current that was sent between the electrodes was usually between 70 and 80 amps. While the current ran through the chamber, particles from the anode evaporated and condensed on the cathode and other regions of the chamber. As the anode shrank, the gap between the anode and the cathode was maintained by the chamber's motor-powered linear drive, thus maintaining the target current. The magnet was propped so that the magnetic field ran axially through both electrodes.

Samples from different regions of the chamber were collected. Samples from the deposit were found on a rod-like hard carbonaceous material that formed between the electrodes, and those taken from the collaret were found on material that formed above the cathode and around the deposit. Collected samples were analyzed under the SEM, which allowed us to take measurements of the SWNTs that were found.

Results and Discussion

Our SEM data indicated that the presence of a magnetic field made a significant difference in the average length of the SWNTs produced by the arc discharge method. Of the entire measurements taken without the magnetic field, 50% were under 600 nm and 90% were under 1300 nm; while 50% of the measurements taken from samples with the magnet were under 1100 nm and 90% were under 2600 nm.

Thus, the presence of the magnetic field seemingly doubled the length of the SWNTs produced. Additionally, samples from the deposit with magnetic field produced some of our longest SWNTs of over 6 μm in length. Hystograms are shown in Figure 2.

Conclusion

Our results indicate that, with the assistance of a magnetic field, the arc discharge method can consistently produce SWNTs of up to or over 6 μm in length. However, our main sources of error arise from limitations with the SEM. It only allows us to analyze a small area at a time and it severely lacks vertical resolution. Thus, there needs to be a more efficient and precise method of taking length measurements. Improving our understanding of SWNT formation and developing efficient techniques to disperse and purify the nanotubes will hopefully make our results more conclusive.

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References

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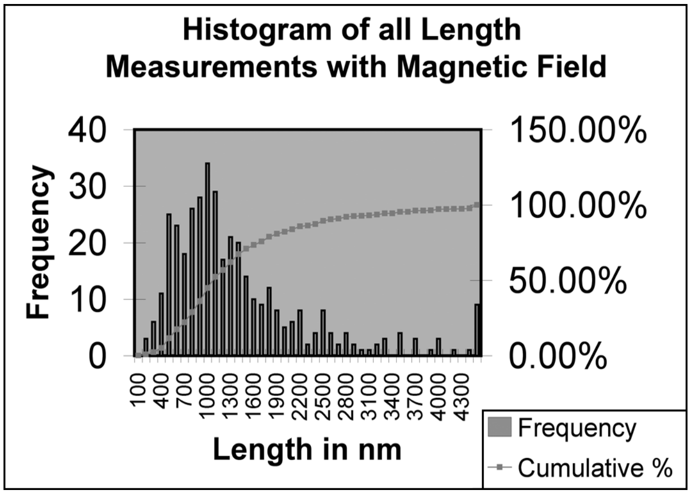

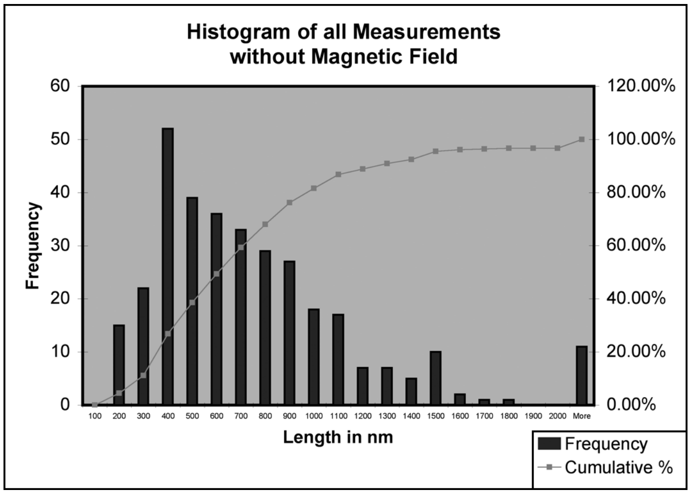

Figure 2