6
Conclusions and future perspectives

6.1
Conclusions and achievements

We have synthesized boron doped single wall carbon nanotubes using Triethyl borate as a new precursor in a high vacuum chemical vapour deposition system. We used SEM images and XPS to determine that the optimum temperature regarding the amount of produced tubes is around 800^0C and that this precursor produces a higher amount of tubes in comparison to Triisopropyl borate and Ethanol.

Raman spectroscopy was used to discover the diameter distribution, that is around 1nm. We also discovered that those tubes have a lower I_D/I_G ration when compared to a reference sample produced at similar conditions. This technique also provide evidences that the tubes produced with the boron containing precursors have the Fermi level lowered, thus indicating that the tubes are doped.

Based on our results, professors Rodrigo B. Capaz and L.A. Terrazos showed a theoretical evidence for the XPS boron 1s peak upshift when this element is doping the SWNT. This evidence validates all the previous XPS analysis reported on the literature.

Using XPS analysis, we found a doping level around 1.2±0.3at% for tubes produced by Triethyl borate and discovered a good relation with the Raman evidence of doping using the equation used on GICs. We also used that equation to show that it gives a great correspondence for the doping level obtained by XPS even for boron doped single and double wall nanotubes found on the literature.

6.2
Discussions

As discussed in the beginning of the preceding chapter, there are some discrepancies among some results found on the literature.

As exposed on the Raman section of the preceding chapter, we found an upshift of the G band of the Raman spectra for tubes synthesized using

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Triisopropyl borate as precursor. However, as discussed on the fourth chapter, the same result was found by Suzuki, S et al., (39) only when H_2 or Argon was used within this precursor, and not by it's use alone. Our guess to this discrepancy, is that when this substance was used alone in their system, the boron atoms were probably being deposited on the walls of the HVCVD system and only a fraction of them were reaching the catalyst in comparison to our system. As proposed on the last chapter, this discrepancy could be explained by different geometries used on the HVCVD system, but can also be promoted by the lower pressure that they used, that increases the mean free path of the molecules, making easier to them to hit the hot walls of the system. On the other hand, the presence of one of those gaseous species act lowering the mean free path of the molecules, enabling a higher concentration of boron:carbon atoms to reach the catalyst, having a similar effect of enlarge the diameter of the quartz tube. In this way, the sample became with a higher doping concentration and a upshift of the G band could be reported on the Raman spectroscopy. However, despite the described above, other effects can not be ruled out.

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6.3
Remaining questions or future perspectives

1) Is it possible to easily produce a super growth sample of boron doped tubes?

2) Is the boron doping, or is the presence of boron atoms on the precursor that lowers the I_D/I_G ratio in comparison to the samples produced by Ethanol?

3) What is the chirality distribution of boron doped SWNTs produced by HVCVD?

4) Is it possible to grow a p-type doped tube connected to a n-type doped one?

5) Is it possible to grow boron doped tubes on a desired place on a nano device?

6) Like the arc discharge sample, are the tubes produced by any or some CVD method composed of nanodomains of boron, instead of substitutional doping?

7) Knowing the answer of the previous question, can Raman analysis of an individual low doped SWNT provides indirect information to guide us on the analysis of the density of states near the Fermi level of the tube? I mean, Raman can provide us with the information of which (n,m) SWNT we are dealing. The shift of the G band gives an estimative of the doping level and

theory says that the density of states of a low doped tube can be inferred by the application of the rigid band model.

8) Based on what was discussed on the previous chapters and section, what is the effect, and is it possible to control the doping level by changing the radius and the length of the quartz tube on the HVCVD system?

9) We studied the growth at different temperatures and constant pressure on the HVCVD system. Based on the previous section, what is the effect of pressure on the doping environment and concentration? As exposed on the preceding section, I believe that using the precursor alone, without the use of other gaseous species, the reduction of pressure would lead to a decrease on the boron:carbon concentration reaching the catalyst, since it would magnify the mean free path of the molecules, making easier to them to reach the walls of the system before reaching the catalyst.

10) Based on the discussion of the energy of the 1s orbital of the boron atom substitutionally doping the SWNT, is this energy diameter or chirality depended?

At the end, we must say that all of those questions, as well as the achievements obtained on this thesis will lead to a better comprehension of the boron doped SWNTs, and shows that a lot of work can still be done in this field.

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