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A4_10 Electron beams cracking hydrocarbons

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Abstract

This article looks at using a scanning electron microscope, or SEM, to break apart (or 'crack') hydrocarbon chains for the purposes of creating carbon structures which are tens of micrometres in diameter. It was found that the energetics of the electron beam alone were not sufficient to characterise this cracking process.

Introduction

There has been considerable interest in the last few decades in the creation of micrometre scale carbon structures for a variety of purposes from constructing small semi-conductors [1] to higher resolution tips for use in an atomic force microscope (AFM) [2], [3]. One way this can be done is by using a scanning electron microscope (SEM) to crack large hydrocarbons and then use the electron beam to deposit the resulting carbon on a conducting substrate.

Diffusion pumps for an SEM

In order to perform this cracking and subsequenct deposition, an SEM is used with a diffusion pump. The diffusion pump is used to create a vacuum in the microscope, but as a by-product it also inevitably leaves traces of hydrocarbons in the vacuum chamber. It is for this reason that diffusion pumps have fallen out of favour and been replaced by newer machines that do not leave such traces in the vacuum chamber. It is also this however that makes this sort of microscope unusually placed to be used for the formation of carbon micro-structures.

The electron beam from the SEM strikes a hydrocarbon chain and breaks it up, causing the carbon to collect together at the point on a surface that the electron beam is aimed at. The question then becomes, is the energy of the electrons impacting on the hydrocarbon chain sufficient to characterise the cracking of the chain, or are other factors at work?

Analysis

Experiments have been conducted using an electron beam with a potential of 3 kV [3], however it was found that there was no noticeable carbonaceous deposition in the microscope. Is this consistent with the idea that the cracking only depends on the energy of the electrons?

An SEM operates in a vacuum, so apart from the hydrocarbon chains that are present in the chamber, it shall be assumed that there are no other particles present. It shall be assumed that the hydrocarbon in question is of a structure comparable to an alkane, meaning that there are only C-C and C-H single bonds present. The bond enthalpy of the C-H bond is 413 kJ/mol [3], and as the aim is to separate the hydrogen out of the hydrocarbon to leave just the carbon, the C-C bond and the electron beam interactions with it shall be ignored. If the electron beam has a potential of 3 kV, then by definition this means that the beam has an energy density of 3 kJ/C. The bond enthalpy of the C-H bond is 413 kJ/mol.

The required quantity of energy needed to break this bond can then be found by writing the relevant definitions in a mathematical manner. That is to say that the energy required to break each bond present (E) is simply the amount of energy required to break the bonds in a mol of the substance (or bond enthalpy per mol, H) divided by the number of molecules present (Avagadro's number). Doing this generates Eq. (1)

$$E = \frac{H}{N_A}. \tag{1}$$

Putting in the values here, one obtains that the energy required to break each bond is 6.86×10^{-19} J, or 4.28 eV. This means that 4.28 J of energy would be needed per coulomb of charge, which is about three orders of magnitude less than the beam energy. Thus, it would seem that the breaking of the hydrocarbon chain is a function of more than just the energy of the electron beam, as this alone is insufficient to break the chain.

This is perhaps not contrary to what should be expected as the rate of reaction (which would be closely related to the amount of deposited carbon) should also depend on the concentrations of reactants and the next question to ask would be how the amount of deposited carbon varied with the rate of collision of reactants (perhaps by changing the concentration of hydrocarbons in the vacuum chamber).

Conclusion

It was found that electron energetics alone are insufficient to explain the behaviour of hydrocarbons being impacted on by an electron beam, with the energy of the beam being an order to magnitude higher than that required to break the chain, but with so such measurable break. It was suggested that collision frequency would play a large part of the process.

REFERENCES

[1] N. Miura, H. Ishii, J. Shirakashi, A. Yamada, M. Konagi, Applied Surface Science 113 - 114, pp. 269 - 273 (1997)
[2] B. W. Halstead, Ph.D. thesis, La Trobe University, 2010
[3] T. M. Conlon, (unpublished)