

ON THE MECHANISM OF CARBON NANOSTRUCTURES FORMATION

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Introduction

After discovering fullerenes and carbon nanotubes (CNT) methods of their synthesis are continually investigated and improved. At present plasma chemical deposition, pyrolysis of hydrocarbons and arc discharge in inert gas are employed especially widely for CNT production. Considering the results obtained during further 20 years [1-4] in 2000 we proposed the method for synthesis of carbon nanostructures and composites based on them using an arc discharge in liquid phase [5-7].

The present work is focused on the investigation of physical and chemical peculiarities in synthesis of carbon nanostructures and the effect of the cooling rate (i.e. the residence time of a carbon atom in the reaction zone) on peculiarities of the formation and morphology of the product. We have compared peculiarities of the formation of the nanostructures synthesized by pyrolysis, the arc method in the gas phase and the arc method in liquid in order to understand the effect of the earliest stages of nucleation on the further process of the nanostructure formation. All the methods are distinguished by the time of interaction between reagents.

Discussion

The nanostructural carbon product (different multi-wall and single-wall carbon nanotubes (SWNT) and other structures) produced by three methods applied in this work has similar properties and morphology at the nano-level. According to the literature data and experimental results, the duration of the technological process (the residence time of a reagent in the reaction zone) of the carbon nanoprodukt synthesis by pyrolysis averages $1 \cdot 10^{-4}$ s, by the arc synthesis in the gas phase it is $1 \cdot 10^{-3}$ s and by the arc synthesis in the liquid medium the duration is more than $1 \cdot 10^{-9}$ s. For each of the methods the rate of the reagent transformation into a nucleus of product should not be different much, although the time of the technological cycle differs considerably for each method.

The difference in the duration of the technological process between the first and the

last methods of synthesis is, on average, 13 orders. Experiments have shown that the transition from one method to another and the decrease in the interaction time do not have a significant effect on the nuclei morphology of the forming product, but affect considerably the product mass yield that mainly depends on the geometry of the objects formed in the end. At the first moment of interaction at the nano-level the nanostructural product, e.g. nuclei of a new molecular-sized structure, are formed. Hence the processes of the nanosecond duration, that determine the morphology and properties of the final product, should be given a special attention in the synthesis of nanostructural objects.

The technological chain of transformations, that are undergone by the initial carbon-containing reagents in the course of carbon nanostructure synthesis (by any of three methods), is shown in Fig.1.

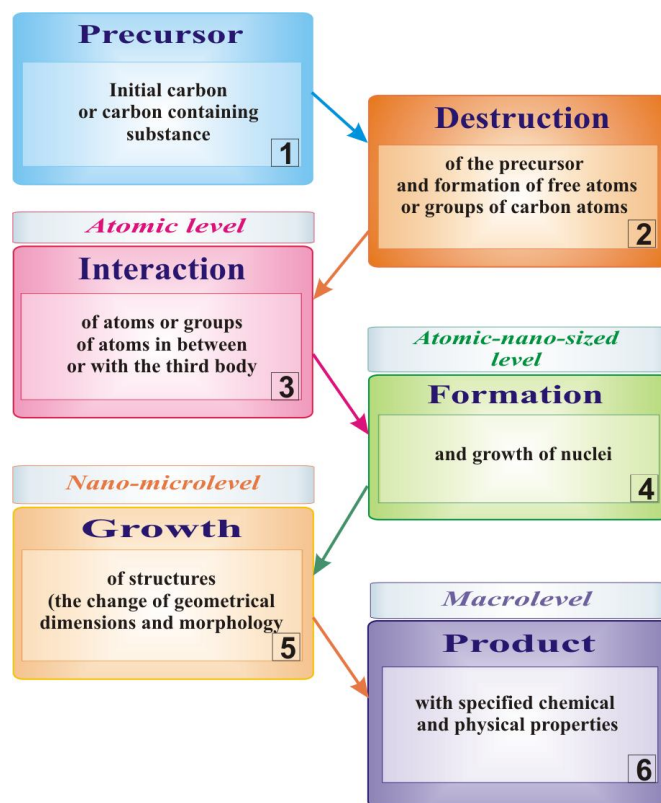
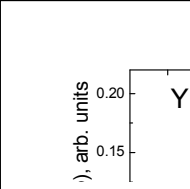


Fig. 1. Technological chain of carbon structure formation



For synthesis of a new structure the reagents are produced by the method of destruction of carbon and carbon-containing precursor. The nuclei of certain carbon structure are formed during the interaction. Depending on the conditions of synthesis, the carbon structure may be carbene, fullerite, diamond, nanotube or other nanoobjects.

On holding the formed nuclei during some time in the certain technological conditions can cause the reconstruction of one structure to the another, the change of the morphology or the growth of nuclei and the yield of product in macro-amounts.

Conclusions

Based on experimental data and theoretical calculations we have attempted to consider the conditions and the mechanism of the processes proceeding in synthesis of carbon nanostructures.

The distinctive feature of the discussed method for nanostructural carbon material synthesis is that there is a possibility to produce these materials without catalysts owing to a very quick synthesis (competing with velocity of light). An example of such type of process is synthesis of carbon nanotubes by evaporation of pure graphite in liquid media.

If we consider the fact that during arc synthesis in the liquid phase the SWNTs are formed within nanoseconds, we can suppose that in pyrolysis of hydrocarbons the nuclei of CNTs should also appear sufficiently quickly. Their geometric dimensions vary within the rest of the time. Hence, using the holding time as a limiting factor (at all another equivalent conditions), one can synthesize the carbon nanostructures with the predetermined geometric dimensions. The process of SWNTs synthesis will be the fastest as this is a primary process, i.e. the process of nuclei synthesis. Affecting this process, one can form morphology and properties of the final product.

All obtained results are of scientific and practical interest. The materials prepared require further investigations.

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