Synthesis of nanoparticles in RF thermal plasmas: state-of-the-art and emerging fields

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1. Introduction

Decrease of particle size into the nanometer range leads to significant changes in the macroscopic properties of powders. Nanoparticles can have very different shapes and chemical compositions, which means that their properties can be engineered in broad limits to make them suitable for different applications.

Structure and properties, especially surface properties of nanoparticles are key factors determining their behaviour in many respects. Both structure and properties of particles and hence, those of powders are actually determined by conditions in which they have been synthesized.

The RF thermal plasmas offer unique advantages over other methods for the synthesis of nanosized powders. The advantages include very high temperature, intensive heat and mass transfer conditions, and very rapid cooling of reaction products [1]. Neutral, oxidizing or reducing conditions can be maintained in RF thermal plasma reactors making possible to play with process chemistry.

2. Models and method of synthesis

Over the last 15 years extensive research has been done in IMEC CRC HAS on the synthesis of different nanosized powders from solid, liquid or gaseous precursors in RF thermal plasma conditions. The models included oxides (SiO₂, Si₃N₄O, TiO₂, CeO₂, Al₂O₃, ZnO, stabilized ZrO₂, and Zn-, Ni-Zn- and Li-ferrites), non-oxides (Si₃N₄, SiC, SiCₓNy, and LaB₆) and special materials (fullerenes, composite powders and catalysts), as well. The nanopowders were characterized in a complex way for morphology and size distribution, specific surface area and adsorption properties, bulk and surface chemical compositions, phase conditions, microstructure, and also for behaviour on further processing.

Nanoparticles produced and characterized as above, were tested for production of nanostructured ceramic materials for high temperature applications, heterogeneous catalysis, drug carriers for prolonged and targeted administration, formation of heat absorbing layers and materials for MW absorption, and preparation of polymer-ceramic and ceramic-ceramic composite materials.

3. Discussion

On the basis of accumulated knowledge on the thermal plasma synthesis and materials from there, it is possible to establish some general correlations among the composition, microstructure, properties and synthesis conditions of nanoparticles.

In order to make these findings applicable for a broader selection of materials, in this paper the above correlations will be studied for systems described more recently in other papers and publications, as well.

As an example, a result of our work on the synthesis of fullerenes from commercial graphite powders is shown here. It was found that the heat transfer between plasma flame and graphite is of decisive importance both in terms of fullerene yield and composition. In this respect, the heat conductivity of graphite connected to its structural orderliness has an important role. We characterized the orderliness of graphite by the D₅₀/L₀₀₂ ratio, where D₅₀ is the mean particle size and L₀₀₂ is the size of coherently scattering domains [2]. The lower is the D₅₀/L₀₀₂ ratio the better the heat conductivity. The fullerene yield is plotted against this ratio in Fig. 1, which clearly refers to more effective evaporation and hence, better transformation of graphite of ordered structure to fullerenes.

Fig. 1 Fullerene yield vs. D₅₀/L₀₀₂ ratio of graphite

The final goal of the study is to facilitate targeted synthesis of tailor-made nanoparticles for specified applications. In addition, it helps to outline the emerging fields in nanoparticle synthesis and application, which is the final section of this paper.

References