Thermal Plasma for the Synthesis of Advanced Functional Nanomaterials

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Thermal plasma represents a powerful and flexible tool for a variety of applications, including waste decomposition, upcycling, secondary raw material production, modification and synthesis. Thanks to its extreme nature, thermal plasma generates highly reactive thermochemical enviromnent that can facilitate conditions for transformations and reactions that can otherwise be difficult or impossible to achieve via conventional methods.

A wide range of materials can be processed and converted into high-value products, including (a) organic feedstocks (biomass, wood, textiles, polymers) and wastes (food waste, refuse-derived fuel, medical waste) or (b) inorganic compounds like metals and metal oxides (Fe_2O_3, TiO_2, SiO_2, ZnO, etc.). Depending on the configuration, the material can be directly injected into the plasma zone inside the reactor or treated by the plasma jet as pre-deposited layers or films on a substrate to enable localized surface treatment.

In addition to synthesis gas (mostly formed by H_2 + CO), resulting products can include carbon-based nanostructures (functional soot or carbon black), metal and metal oxide nanoparticles, or hybrid nanomaterials with specific surface chemistry, morphology and properties (either optical, thermal or electronic). These materials show promise in a wide array of technological applications like catalysis (including photocatalysis), energy storage, semiconductors, supercapacitors, sensors, medical and environmental remediation. Moreover, flexibility of the plasma process allows for scalable production from surface treatment of components to tens or even hundreds of kilogram-scale syntheses of particulate nanomaterials. To assesss the structural, chemical and functional properties of the output products, a variety of advanced characterization techniques is employed. These include AFM, SEM, TEM, XRD, XPS, QMS, FTIR, PL or Raman spectroscopy.

This contribution presents an overview of the possibilities offered by thermal plasma technology for the design and synthesis of novel functional nanomaterials from diverse input sources, including waste streams. Several experimental configurations and application-specific case studies will be introduced, with an emphasis on process control, materials engineering, and the interdisciplinary potential of plasma-based synthesis.

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