NEW FRONTIERS IN MATERIAL PROCESSING USING THERMAL PLASMA TECHNOLOGY

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Abstract

A review is made of the fundamental aspects involved in material processing using thermal plasma technology. The description of plasma generating devices covers d.c. plasma torches, d.c. transferred arcs, radio frequency (r.f.) inductively coupled plasma torches and hybrid combinations of them. Emphasis is given to the identification of the basic energy coupling mechanism involved in each case and the principal characteristics of the flow and temperature fields in the plasma. Materials processing techniques using thermal plasmas are grouped in two broad categories depending on the role played by the plasma in the process. The simplest and most widely used processes such as spheroidization, melting, deposition and spray-coating makes use of the plasma only as a high temperature energy source. Thermal plasma technology is also used in applications involving chemical synthesis in which the plasma is used as a source of chemically active species. Examples of such applications are, the synthesis of titanium dioxide pigment, high purity synthetic silica and a large number of high purity ultrafine ceramic powders such as Al₂O₃, SiC, Si₃N₄, TiN, TiB₂.

Introduction

Plasmas are ionized gases composed of a mixture of molecules, atoms, ions and electrons in local electrical neutrality. Different types of plasma are commonly used in material processing. These can be classified in two broad groups, the equilibrium or thermal plasmas, and the non-equilibrium or cold plasmas. As shown in Fig. 1, thermal plasmas are characterized by their relatively high electron or particle densities, of the order of 10²⁰–10²⁸ m⁻³, and low particle energies, around 1 eV which corresponds to a particle temperature of the order of 8000 K. They are generated at atmospheric pressure or soft vacuum conditions and generally exist in local thermodynamic equilibrium in which the electron temperature is close to the heavy particle temperature (Tₑ ≈ Tₕ). In contrast, non-equilibrium plasmas are characterized by their relatively low electron or particle densities, less than 10²⁰ m⁻³, and their high electron temperature, of the order of a few eV. They are mostly generated under low pressure conditions, less than 1 torr, and exhibit strong deviations from kinetic equilibrium with the electron temperature considerably higher than that of the heavy particles (Tₑ >> Tₕ).

In material processing, low-pressure cold plasmas are mostly used in plasma etching and deposition processes and in plasma surface modifications in general. Their effectiveness is through the reactivity of the chemically active species present rather than the total energy available in the plasma. Thermal plasmas, on the other hand, are often used in material processing for their high energy densities and for their ability to heat, melt and, in some cases, vaporize the materials to be treated. Thermal plasmas are also increasingly used as a source of reactive species at high temperature in plasma chemical synthesis of high purity materials.

The objective of the present paper is to give a general overview of thermal plasma applications in material processing. Rather than attempting to cover the subject in an exhaustive way, the review is selective and limits its coverage to some of the most recently developed applications such as plasma melting and deposition, plasma spray-coating and the plasma synthesis of ultrafine powders of high purity materials. The presentation of the paper is divided into two principal sections, the first dealing with plasma generating devices, their principal characteristics, common features and basic differences between them. This is followed by a review of specific plasma applications with emphasis given to a discussion of the fundamental aspects involved in each of these processes and to identification of potential industrial developments and pressing research needs.