Advanced Diagnostic Techniques for Thermal Plasmas

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The dynamics of a flowing plasma, its chemical state, and the interactions between the plasma and injected material is controlled by the major energy pools and the rates of energy transfer between them. The major energy pools for a typical 1 ev atmospheric pressure thermal plasma are the kinetic energy of the electrons and heavy particles (neutrals and ions), and the energy which is required for the formation of ionized states and/or dissociation if molecular species are present. The electronically excited states account for only a small percentage of the total internal energy. The ions (and/or dissociated molecular species) are particularly important, since they constitute a significant fraction of the total energy, and due to finite recombination times, are often not in equilibrium with kinetic temperatures in flowing plasmas. Due to the relatively poor collisional coupling between the electrons and the kinetic energy of the heavy particles (atoms), the excess energy that the electrons may have or acquire in the recombination process can result in the electron temperature being elevated (by a few tenths of an ev at atmospheric pressures) over the kinetic temperature of the heavy species. At low electron densities the ground state is connected to the excited states through only the very high energy tail of the electron energy distribution. Hence only a few of the total number of electrons serve to mix the excited levels and the ions with the ground state. This results in over population of the ground state. In addition, diffusion in the strong gradients on the periphery of the plasma and transport of resonance radiation can also contribute to departures from equilibrium. The composition of the plasma can also be altered by entrainment of ambient gases and diffusion driven demixing of the plasma gases.

Traditional diagnostic techniques, such as emission spectroscopy, which rely on the assumption of local thermodynamic equilibrium are questionable at best for high velocity flow fields. To characterize modern, high velocity plasma guns, techniques are required for the direct measurement of heavy particle temperature, electron temperature, electron number density, plasma velocity, and composition. In general, nonintrusive, laser based techniques are preferable. However, intrusive methods, such as enthalpy probes, can also provide useful information. Because of nonequilibrium and demixing effects, direct measurements, which do not rely on assumptions of local thermodynamic equilibrium or plasma composition are necessary.