Precise Correction Method of the Copper Emission Spectra obtained from the Pulsed Plasma Jet

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Recently, plasma injection has been suggested as a means to enhance and control combustion rates of propellant materials. It is also of interest for applications in fields such as rocket propulsion, electrothermal-chemical (ETC) launchers, and hypersonic mass acceleration technology.(1) In order to characterize the plasma fundamental measurements such as the plasma excitation temperature and electron number density are essential. However, those emission spectral lines, which are directly related to the excitation temperature and electron number density, may be distorted by the spectral response of the optical instruments employed. In this paper, therefore, we discuss efforts to deduce the correction methods of the emission copper spectra obtained from pulsed plasma jet, which is issued freely into an open air from the open end of the capillary.

The method most frequently used for determination of excitation population temperatures is the "Boltzmann plot method".(2) In the Boltzmann plot method, if the relative intensities of the spectral lines of a given species are measured, the associated excitation temperature (T_{exc}) can be determined from

$$\ln(I\lambda / Ag_u) = B - E_u / kT_{exc}$$

where I is the relative intensity of an emission line, λ is the emission wavelength, A is the spontaneous emission rate, g_u is the statistical weight factor for the excited state, E_u is the energy of the excited state,(3) and k is Boltzmann's constant.

A Lorentzian line shape can be used generally to represent the distinct atomic lines observed in a dense low-temperature plasma emission, where *Stark broadening* that results from the perturbations of the atomic system by charged particles is the dominant broadening mechanism.(4) In order to correct the spectral response of the diode arrays in the CCD detector of the spectrometer (TN-6500, 512×512-diode array) we tried tracking a specific line from a calibration lamp across the diode array as the grating of the spectrophotometer is rotated. We used three representative spectral lines; *Hg* line (253.7 nm) for UV-response of the CCD detector, *Hg* line (546.1 nm) for the UV-VIS response, and *Ne* line (659.9 nm) for the VIS-response of the CCD detector, respectively. Fig.1 shows a typical plasma jet image freely

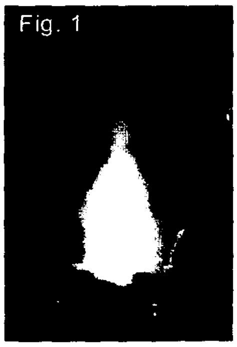

Fig. 1.

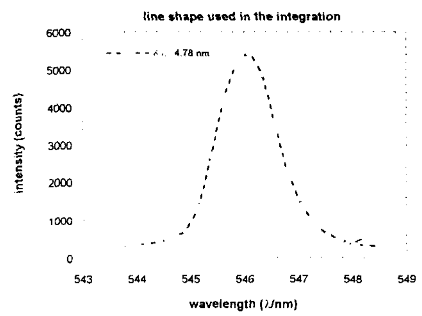

Fig 2.

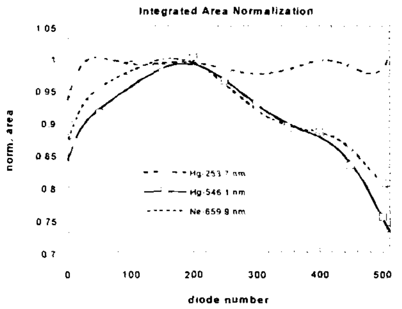

Fig. 3

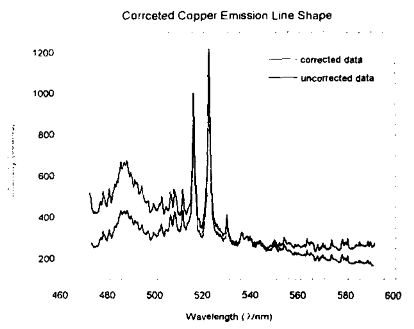

Fig. 4.

expanding into an atmosphere. Fig. 2 is an example of the emission line shape of the *Hg* calibration lamp whose emission line shape is used in the CCD detector correction. The central wavelength (λ_c) of Hg calibration lamp emission spectra is 546.1 nm. The half bandwidth ($\Delta\lambda$) of 2.39 nm was used in the integration to get the integrated area of the emission spectra. The atomic emission line shape is reasonably well represented by the Lorenzian shape analysis. However, it should be noted that the obtained emission spectra in our measurements were neither strictly followed the Lorenzian shape nor the Gaussian shape. Instead, we interpolated it and performed the numerical integration of the emission line shape to get the best approximation of emission area. The normalized integrated area *versus* diode array number of the detector is shown in Fig. 3 with three representative lines illustrated above. The symbols represent the measurements and the lines are the polynomial best fits of these measurements.

The detailed experimental methods to improve the measurement accuracy of the plasma-jet spectra are developed in this study. A significant amount of spillage near the ends of the CCD photodiode array (512×512) was corrected (for example, for the both the UV-VIS and VIS lines approximately 15% difference in the pixel number of 20 and 25% in the pixel number 500, respectively). As shown in Fig.4 the raw copper emission lines were corrected and the measurement accuracy in temperature were increased approximately 2.8%. Although the benefit of the correction techniques in this work seemed to be trivial in that specific Cu(I) regions, however, it should be noted that more deviation from this spectral region will get more improvement from the correction techniques.

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