OPTICAL EMISSION SPECTROSCOPIC DIAGNOSTICS OF SODIUM IMPURITIES IN WATER USING HIGH CURRENT DENSITY UNDERWATER COPPER WIRE EXPLOSIONS

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ABSTRACT: *Present work proposes spectroscopic analysis of exploding copper wire as a tool for determination of impurities in ordinary drinking water. Exploding copper wire plasma was generated using 4x4 capacitor bank providing 12.8 J discharge energy and spectrum was recorded with a temporal window at 1µSec. Spectrum recorded was analyzed for electron temperature which is important plasma parameter, deeper qualitative analysis of spectrum revealed dissociation of water molecules along with fingerprints of soluble impurities. The whole experiment was repeated in air and in de-ionized water for cross verification of results.*

KEYWORDS: Exploding Wire; Plasma; Copper; De-ionized Water; Impurity Detection

1. INTRODUCTION

Availability of clean and contaminant free drinking water had always been dream for a large population of Pakistan and other developing countries. Water purification processes as well as testing techniques have developed rapidly. The phenomena associated with exploding wires are investigated for a variety of applications. It is common to observe exploding wire cited for pressure vessel testing[1], method of propulsion, controlled ignition system for solid state fuelled ammunitions[2], thin film production[3], generation of blast wave[4] ignition system for confined fusion research[5], and production of high purity metallic and alloy nanoparticles[3, 6]. Exploding wires were first reported by Edward Nairine in 1780[7]. During early 20th century research into exploding wires increased due to military interest and reports are not published due to their classified nature. Mechanisms involved during wire explosion where highly dependent upon local experimental conditions, furthermore slight differences affects repeatability of experiments[8]. Orientation of metal wire, crystal size, orientation of cold pre-drawn metal wire, circuit differences, pressure surrounding metal wire, and initial temperature differences are few of the reasons behind differences in repeated experimentation[9]. Instantaneous current densities are strongly dependent on experimental conditions and are generally in range of 10^7 to 10^9 A/cm^2 [10-12]. Plasma properties, plasma parameters, effects of laser parameters and plume dynamics of laser induced plasmas have been a topic of great interest using various theoretical models and experiments results [13-17]. Laser induced copper plasma has been studied using Nd-YAG and Excimer lasers [18-20].

Present work reports study of exploding copper wire plasma generated by high current density copper wire explosions in air, de-ionized water and ordinary tap water using capacitor bank. Optical emission spectroscopy of exploding wire plasma was recorded and was analyzed for presence of ionic impurities soluble in ordinary drinking water, which were cross verified by performing same experiment in de-ionized water.

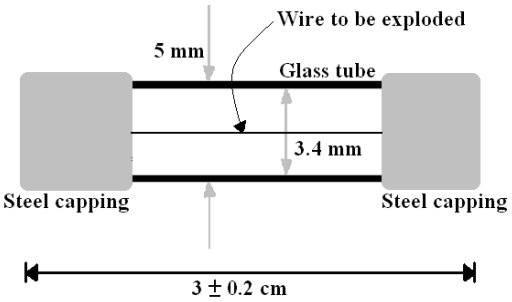

Fig 2.1 Shape and dimensions of tube in which wire is being exploded

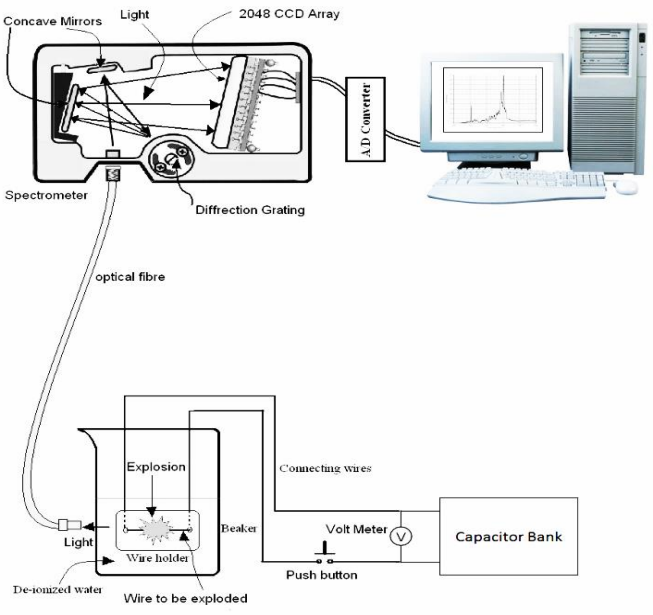

Figure 2 Experimental arrangement of generation of exploding wire plasma in de-ionized water.

Table 1. Spectroscopic parameters of Cu(I) lines

Wavelength (nm)	Transitions	Upper level statistical weight (g)	Transition probabilities (10^8 s^{-1}) (A)	Excitation energy (eV) (E_n)
406.26	$3d^{10}5d\,^2D_{5/2} \rightarrow 3d^{10}4p\,^2P^0_{3/2}$	6	1.26	6.94683
510.55	$3d^{10}\,4p\,^2P^0_{3/2} \rightarrow 3d^9\,4s\,^2D_{5/2}$	4	0.02	3.81669
515.32	$3d^{10}\,4d\,^2D_{3/2} \rightarrow 3d^{10}\,4p\,^2P^0_{1/2}$	4	0.6	6.19117
521.82	$3d^{10}\,4d\,^2D_{5/2} \rightarrow 3d^{10}\,4p\,^2P^0_{3/2}$	6	0.75	6.19203
570.02	$3d^{10}\,4p\,^2P^0_{3/2} \rightarrow 3d^9\,4s^2\,^2D_{3/2}$	4	0.0028	3.81669
578.21	$3d^{10}4p^2P^0_{1/2} \rightarrow 3d^9 4s^2\,^2D_{3/2}$	4	0.0028	3.81669
793.31	$3d^{10}5s^2S_{1/2} \rightarrow 3d^{10}4p^2P^0_{1/2}$	2	-[a]	5.34833
809.26	$3d^{10}5s^2S_{1/2} \rightarrow 3d^{10}4p^2P^0_{3/2}$	2	-[a]	5.34833

[a] Transition probabilities not yet reported in literature

2. EXPERIMENTAL DETAILS

4x4 capacitor bank of total capacitance 10 µF rated at 1800 V was used to give high current density discharge in thin copper wire causing it to explode. Cylindrical copper wires of length 3 ± 0.2 cm were exploded for each experiment in a glass tube of typical glass cylinder with internal and external diameter of 3.4 mm and 5 mm respectively shown in figure 1. Capacitor bank was constructed by connecting 10 µF, 450 V capacitors with 15mm x 6mm aluminum strips, which was further connected with 3AWG (5.827 mm diameter) copper wire with rated current of 100 A (fuse current of 8.1 kA for 1s and 45 kA for 32 ms) at 38°C. The glass tube was mounted on a fixed stage and radiation from plasma was collected by fiber optics (600 µm core diameter) having a collimating lens with 45° field of view, placed on perpendicular bisector of glass tube at 3.62 cm from glass tube in order to collect all the light produced during explosion. Optical fiber was connected with PC2000 spectrometer (Ocean Optics Inc.) having slit width 25 µm is equipped with 2048 elements CCD array to record optical emission. Spectrum was recorded in range from 350 nm to 850 nm with a resolution of 0.36 nm. Temporal window was set at 1µs delay which was sufficient enough for plasma to be assumed in local thermodynamic equilibrium. Average of five sets of spectra were recorded under same experimental condition. Whole experimental arrangement is shown in figure 2.

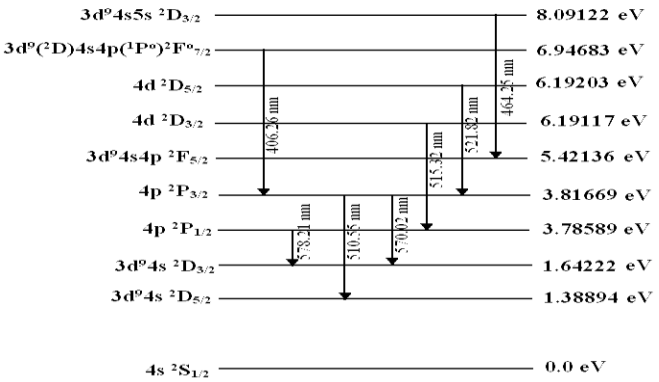

Fig.3 Partial Energy level diagram of Cu(I) showing the most probable transitions.

3. RESULTS AND DISCUSSION

Exploding copper wire plasma generated in air, de-ionized water and ordinary tap water by large current pulse expands in a cylindrical pattern away from exploded wire towards inner surface of glass tube due to shockwave [1]. In the present work copper spectra were recorded at 1600 V across 160µm diameter copper wire with discharge energy 12.8 J. Figure 3 shows the plasma emission spectrum of copper generated by applying 1600 V across 160 µm thick copper wire covering range of 350-850 nm. Dominating lines belong to emission of neutral copper, with strongest being observed at 406.24, 510.55, 515.32, 521.82, 570.02, 578.21, 793.31 and 809.26 nm corresponding to transitions shown in table 1 based on data listed in tables of National Institute of Standards and Technology (NIST)[21]. Partial energy level diagram of observed copper lines is shown in figure 3. It is evident from figure 4 that there are strong lines of hydrogen and oxygen in copper wire explosions in water representing dissociation of water molecules in water. Sodium line is observed at 589.3 nm which is fingerprint of presence of sodium in ordinary drinking water and spectra recorded in air due to residual sodium salts on the inner walls of glass tube during cleaning which is not observed when same tubes were cleaned with de-ionized water. Electron temperature was calculated using Boltzmann plot method assuming plasma in local thermodynamic equilibrium (LTE) [22-24] using:

$$ln\left(\frac{I_{nk}\lambda_{nk}}{A_{nk}g_n}\right)_i = a - \frac{E_i}{kT} \qquad \ldots \qquad (1)$$

where I_{nk} is integrated line intensity of transition involving upper level (n) to lower level (k), λ_{nk} is wavelength associated with the transition, A_{nk} is the transition probability, g_n is upper level (n) statistical weight, E_n is energy of upper level (n), a is ratio of total number density and partition function which remains constant for a certain spectrum, k is Boltzmann constant and T is excitation temperature. Boltzmann plot between $ln(I\lambda/gA)$ and upper level energy E_n with slope equals ($-1/kT$) gives electron temperature. Error originating from uncertainty in transition probabilities and integrated intensities is determined to be ≈10%. Line identification and different spectroscopic parameters such as wavelength(λ), transition levels, transition probabilities (A), statistical weight

(*g*) and upper level energy are listed in table 1 taken from NIST atomic spectroscopy database[21]. For electron temperature calculation neutral copper lines at 464.25 nm, 510.55 nm, 515.32 nm, 521.82 nm and 570.02 nm were used. Electron temperature calculated was 16900±200 K, 13100±200 K in ordinary drinking and de-ionized water respectively.

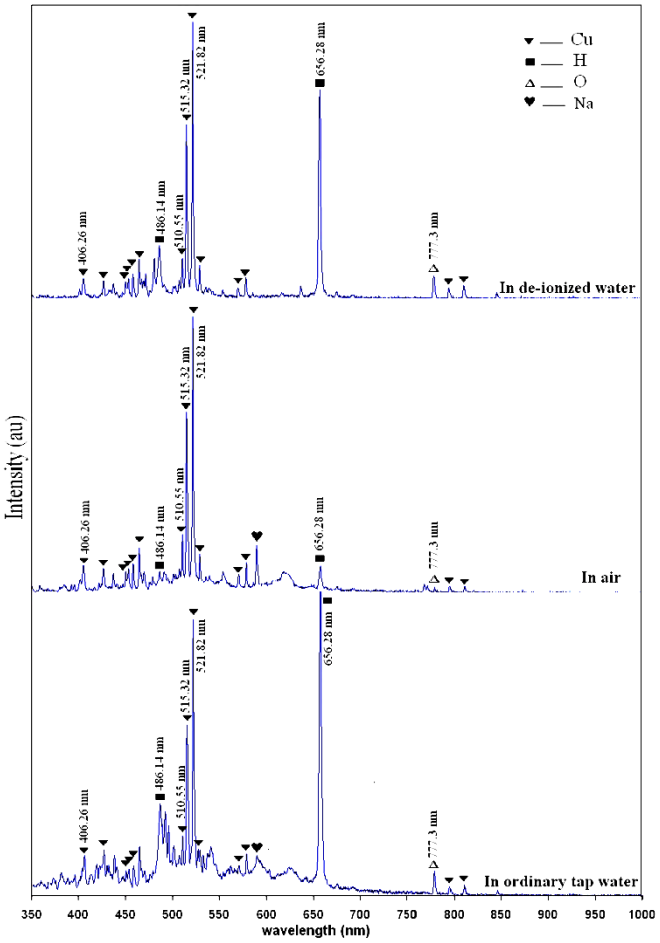

Figure 4. Comparison of emission spectra of copper wire in air, de-ionized water and in ordinary tap water

4. CONCLUSION

Present work reports exploding wire phenomenon as a tool for the qualitative analysis of impurities in drinking water by using optical emission spectroscopy and Boltzmann plot method is used for determination of electron temperature. Deeper analysis of the emitted spectra could lead us the quantitative analysis of impurities which would be reported elsewhere.

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