KINETIC AND RADIATION PROCESSES IN CLUSTER PLASMAS.

Boris M.Smirnov

Institute of High Temperatures, Russian Academy of Sciences, Izhorskaya 13/19, Moscow 127412, Russia.

Abstract.

The analysis of processes is made for a cluster plasma which is a xenon arc plasma of a high pressure with an admixture of tungsten cluster ions. Because cluster ions emit radiation, this system is a light source which parameters are determined by various processes such as heat release and transport of charged particles in the plasma, radiative processes involving clusters, processes of cluster evaporation and attachment of atoms to it that leads to an equilibrium between clusters and vapor of their atoms, processes of cluster generation, processes of the ionization equilibrium between cluster ions and plasma electrons, transport of cluster ions in the discharge plasma in all directions. These processes govern by properties of a specific cluster plasma under consideration.

Introduction.

Measurements of absorption cross sections of metallic cluster ions [1-4] shown this process to be identical to that for bulk small particles so that the absorption cross section is proportional to a number of cluster atoms starting from about ten atoms in a cluster. This fact and a profitable form of spectrum make clusters effective radiators for a light source. Therefore, starting from Weber and Scholl paper [5] of 1992, several types of cluster light sources were analyzed both by experimental and theoretical methods [6-9]. In all the cases clusters are located in a plasma. Below we consider an arc discharge plasma of a high pressure with clusters as a profitable version of a cluster light source.

Peculiarities of a cluster plasma for a light source.

Since clusters give a small contribution in the total plasma charge, general properties of the plasma under consideration does not depend on clusters. Clusters are formed in a generation region outside the discharge plasma and are introduced in the discharge region. The simplest way of cluster generation consists in heating of a metallic wire by an electric current in atmosphere of a relative cold gas. Subsequent introduction of clusters in a discharge plasma leads to their heating and then clusters emit radiation. It is essential that the generation region is separated from the gas discharge one by a grid, so that the number density of electrons in the generation region is relatively small. Then the cluster temperature in the generation region is equal to the gaseous one, while in the discharge region it is higher and ranges between the gaseous and electron temperature. It is of importance for cluster radiation. The other peculiarity of a cluster plasma respects to transport of clusters over the discharge region due to a cluster charge and action of electric fields of the discharge.

Then introduction of clusters in the plasma near the anode leads to their propagation over all the plasma region.

Plasma processes.

The plasma must provide a sufficient cluster temperature for their radiation and must not ionize a vapor resulted from evaporation of clusters. Practically, the gaseous temperature T is about 2000 K and the electron temperature T_e does not exceed 6000K. Hence we take xenon as a buffer gas. The above gaseous temperature at small ionization degree leads to a high gaseous pressure ($p \sim 1\ atm$). Considering this arc discharge of a high pressure in a cylindrical tube, one can conclude that usually it is contracted, i.e. the electric current radius ρ_o is small compared to the tube radius. This current distribution is supported by heat transport processes resulted from the electron and gaseous thermal conductivity.

The general properties of the plasma under consideration are as follows. The electron temperature of the plasma differs from the gaseous one and this difference is supported by discharge electric fields. The local ionization equilibrium in the plasma follows from high values of the parameter $\zeta = \tau_{dr}/\tau_{rec}$, where τ_{dr} is a typical time of the electron drift through a plasma region, τ_{rec} is a typical time of recombination of electrons and ions. Since $\zeta >> 1$, the Saha formula connects the electron and atom number densities.

Cluster processes.

Clusters introduced in the plasma are found in the ionization equilibrium with plasma electrons, and clusters have an average positive charge Z which is of importance for cluster transport processes in the plasma. In particular, they move toward the cathode with the mean drift velocity v_d. We use the measured absorption cross sections for Ag, Li and K-clusters [1-4] as model ones. Note that clusters are more effective radiators than blackbody due to their absorption spectrum. The specific power of clusters per unit mass P_{rad} increases strongly with increase of the cluster temperature, so that we take tungsten as a cluster material. Though one can use other refractory metals and ceramics for this goal [5-7], parameters of analyzing processes are known in the tungsten case.

A specific character of processes corresponds to an equilibrium between clusters and atomic vapor which they support. First this vapor results from evaporation of clusters, and then it is in an equilibrium with clusters through processes of attachment of atoms to clusters and evaporation of clusters. Ionization equilibrium of this atomic vapor with electrons leads to formation of atomic ions, and the requirement of a small number density of ions $[W^+]$ compared to the atom number density $[W]$ restricts the electron temperature of the plasma. The equilibrium between clusters and their atomic vapor is not stationary. Finally, clusters decay on walls and cathode, and in the course of the transport of clusters through the plasma their distribution on sizes is changed, so that large clusters are grown and small clusters are evaporated. Thus, we have different times of the cluster-vapor equilibrium. The first one corresponds to establishment of the equilibrium number density of atoms, and the second time respects to change of the cluster distribution on sizes. Note that the total number density of cluster atoms is enough high under considering conditions and exceeds remarkably the atom number density in the saturated vapor.

Examples of cluster plasmas.

All the above processes determine parameters of the cluster plasma under consideration. Table gives some examples of parameters of this plasma if xenon is a buffer gas and tungsten is the cluster material. The average cluster size is taken 1000 atoms in one cluster, and basic parameters of Table are explained above in the text. Because in the end clusters decay on walls and cathode, dm/dt is the rate of tungsten consumption. The radiative efficacy η of the cluster plasma accounts for the energy consumption for plasma heating and cluster radiation which are of the same order of magnitude. The Table efficacy η corresponds to experimental data [5-7] for tungsten clusters and exceeds the blackbody one at the cluster temperature. Though these values are lower than those of discharge lamps (100 lm/W) , cluster lamps have some advantages which attract attention to them.

Table.
Parameters of a xenon arc discharge plasma with tungsten clusters.

p,atm	1	3	2	3	3	3
T, 1000K	2	2	2	2	2	2
T_e, 1000K	5.5	5.5	5.6	5.6	5.7	5.8
N_a, $10^{18}cm^{-3}$	3.67	11	7.3	11	11	11
N_e, $10^{15}cm^{-3}$	0.48	0.84	0.87	1.1	1.4	1.7
E, V/cm	5.0	15	11	16	17	18
I, A	5.8	1.6	2.8	1.7	1.8	2.0
p_o, W/cm^3	20	103	77	140	190	260
ρ_o, cm	1.04	0.42	0.53	0.38	0.34	0.32
ζ	9800	43000	30000	52000	63000	76000
$[W^+]/[W]$	0.095	0.055	0.073	0.059	0.064	0.070
Z	3.0	2.8	2.9	2.8	2.8	2.8
T_{cl}, 1000K	3.45	2.96	3.36	3.17	3.40	3.65
P_{rad}, $10^7 W/g$	9.4	4.1	7.9	6.0	8.6	13
v_d, cm/s	5.3	4.8	5.4	5.2	5.5	5.8
dm/dt, $mg/hour$	10	2.9	3.2	1.9	1.3	0.89
η, lm/W	46	30	43	39	44	50

References.

[1] C.Brechignac, Ph.Cahuzac, F.Carlier and J.Leygnier, Chem.Phys.Lett.. **164**(1989)433

[2] J.Tiggesbbaumker, L.Koller, H.O.Lutz and K.H.Meiwes-Broer, Chem.Phys.Lett. **190**(1992)42

[3] C.Brechignac, Ph.Cahuzac, N.Kebaili, J.Leygnier and A.Sarfati, Phys.Rev.Lett. **68**(1992)3916

[4] C.Brechignac, Ph.Cahuzac, J.Leygnier and A.Sarfati, Phys.Rev.Lett. **70**(1993)2036

[5] B.Weber and R.Scholl, J.Illum.Eng.Soc., Summer 1992, p.93.

[6] R.Scholl and B.Weber, in: "Physics and Chemistry of Finite Systems : from Clusters to Crystals". Ed. P.Jena, S.N.Khana,
B.K.Rao. Kluwer Academic Press, Dodrecht,1992.vol.II.p.1275.

[7] B.Weber and R.Scholl, J.Appl.Phys.**74**(1993)607

[8] B.M.Smirnov, Phys.Uspekhi **37**(1994)621.

[9] B.M.Smirnov, Physica Scripta **51**(1995)380; **53**(1996)608