

Low-Voltage EUV and Visible Light Source Due to Catalysis of Atomic Hydrogen

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ABSTRACT

Plasmas of certain catalysts that provide a net enthalpy equal to an integer multiple of the potential energy of atomic hydrogen $m \cdot 27.2 \text{ eV}$, such as Sr^+ and Ar^+ mixed with hydrogen produced strong EUV and visible emission. These hydrogen plasmas called resonant transfer- or rt-plasmas were observed to form at low temperatures (e.g. $\approx 10^3 \text{ K}$) and an extraordinary low field strength of about 1-2 V/cm when argon and strontium were present with atomic hydrogen. Plasma formation was studied relative to mixtures of hydrogen and a chemically similar control that does not have electron ionization energies which are a multiple of 27.2 eV . Atomic hydrogen was generated at a tungsten or titanium filament, and strontium was vaporized by heating the metal. The plasma formed when the strontium vapor pressure was about 200 mTorr. The hydrogen kinetic energy determined from the H Balmer α line increased from an initial 1 eV to an extraordinarily fast 25 eV over a six-hour period. To further characterize argon-strontium rt-plasma as a low-voltage light source, another cell type was heated externally and the voltage across two pin electrodes was varied as the visible emission was recorded. The Balmer lines recorded by visible spectroscopy confirmed that an energetic hydrogen plasma was present having H energy states greater than 12 eV corresponding to $n \geq 3$ in the Rydberg formula. The hydrogen plasma occurred with voltages (e.g. $< 5 \text{ V}$) that were lower than the energy of the Balmer emission.

Key Words: H catalysis, fast H, EUV and visible emission, low-voltage light source

1. Introduction

A new chemically generated or assisted plasma source based on a resonant energy transfer mechanism (rt-plasma) has been developed that may be a new EUV and visible light source. One such source operates by incandescently heating a hydrogen dissociator and a catalyst to provide atomic hydrogen and gaseous catalyst, respectively, such that the catalyst reacts with the atomic hydrogen to produce a plasma. It was extraordinary that intense extreme ultraviolet (EUV) emission was observed by Mills et al. [1-6] at low temperatures (e.g. $\approx 10^3 K$) and an extraordinary low field strength of about 1-2 V/cm from atomic hydrogen and certain atomized elements or certain gaseous ions which singly or multiply ionize at integer multiples of the potential energy of atomic hydrogen, 27.2 eV. A number of independent experimental observations confirm that the rt-plasma is due to a novel reaction of atomic hydrogen which produces as chemical intermediates, hydrogen in fractional quantum states that are at lower energies than the traditional "ground" ($n = 1$) state. Power is released [1, 7-8], and the final reaction products are novel hydride compounds [1, 9-11] or lower-energy molecular hydrogen [12]. The supporting data include EUV spectroscopy [1-6, 8, 13-17, 20-21, 23-24], characteristic emission from catalysts and the hydride ion products [1, 3, 5, 16-17, 23-24], lower-energy hydrogen emission [8, 13-15], chemically formed plasmas [1-6, 16-17, 23-24], extraordinary (>100 eV) Balmer α line broadening [1-3, 5, 8, 13-14, 16, 18-24], population inversion of H lines [1, 16, 21, 23-25], elevated electron temperature [14, 18-20], anomalous plasma afterglow duration [1, 6], power generation [1, 7-8], and analysis of novel chemical compounds [1, 9-11].

The theory given previously [4, 13-15, 26] is based on applying Maxwell's equations to the Schrödinger equation. The familiar Rydberg equation (Eq. (1)) arises for the hydrogen excited states for $n > 1$ of Eq. (2).

$$E_n = -\frac{e^2}{n^2 8\pi\epsilon_0 a_H} = -\frac{13.598 \text{ eV}}{n^2} \quad (1)$$

$$n = 1, 2, 3, \dots \quad (2)$$

An additional result is that atomic hydrogen may undergo a catalytic reaction with certain atoms, excimers, and ions which provide a reaction with a net enthalpy of an integer multiple of the potential energy of atomic hydrogen, $m \cdot 27.2 \text{ eV}$ wherein m is an integer. The reaction involves a nonradiative energy transfer to form a hydrogen atom that is lower in energy than unreacted atomic hydrogen that corresponds to a fractional principal quantum number. That is

$$n = \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots, \frac{1}{p}; \quad p \text{ is an integer} \quad (3)$$

replaces the well known parameter $n = \text{integer}$ in the Rydberg equation for hydrogen excited

states. The $n = 1$ state of hydrogen and the $n = \frac{1}{\text{integer}}$ states of hydrogen are nonradiative, but a transition between two nonradiative states, say $n = 1$ to $n = 1/2$, is possible via a nonradiative energy transfer. Thus, a catalyst provides a net positive enthalpy of reaction of $m \cdot 27.2 \text{ eV}$ (i.e. it resonantly accepts the nonradiative energy transfer from hydrogen atoms and releases the energy to the surroundings to affect electronic transitions to fractional quantum energy levels). As a consequence of the nonradiative energy transfer, the hydrogen atom becomes unstable and emits further energy until it achieves a lower-energy nonradiative state having a principal energy level given by Eqs. (1) and (3). Processes such as hydrogen molecular bond formation that occur without photons and that require collisions are common [27]. Also, some commercial phosphors are based on resonant nonradiative energy transfer involving multipole coupling [28].

He^+ fulfills the catalyst criterion—a chemical or physical process with an enthalpy change equal to an integer multiple of 27.2 eV since it ionizes at 54.417 eV which is $2 \cdot 27.2 \text{ eV}$. Ar^+ may also serve as a catalyst since its ionization energy is about 27.2 eV . The product of the catalysis reaction of He^+ , $H(1/3)$, may further serve as a catalyst to form $H(1/4)$ and $H(1/2)$ [14-15, 26]. The product of the Ar^+ catalysis reaction, $H(1/2)$, may further serve as both a catalyst and a reactant to form $H(1/4)$ [2, 3, 5, 14-15, 26]. Novel emission lines with energies of $q \cdot 13.6 \text{ eV}$ where $q = 1, 2, 3, 4, 6, 7, 8, 9, \text{ or } 11$ were previously observed by extreme ultraviolet (EUV) spectroscopy recorded on microwave discharges of helium with 2% hydrogen [14-15]. These lines matched $H(1/p)$, fractional Rydberg states of atomic hydrogen wherein $n = \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots, \frac{1}{p}$; ($p \leq 137$ is an integer) replaces the well known parameter $n = \text{integer}$ in the Rydberg equation for hydrogen excited states. Two $H(1/p)$ may react to form $H_2(1/p)$ that has vibrational and rotational energies that are p^2 times those of H_2 comprising uncatalyzed atomic hydrogen [26, 29]. Rotational lines were observed in the 145-300 nm region from atmospheric pressure electron-beam excited argon-hydrogen plasmas. The unprecedented energy spacing of 4^2 times that of hydrogen established the internuclear distance as $1/4$ that of H_2 and identified $H_2(1/4)$. $H_2(1/p)$ gas was isolated by liquefaction using an high-vacuum (10^{-6} Torr) capable, liquid nitrogen cryotrap and was characterized by mass spectroscopy (MS). The condensable gas had a higher ionization energy than H_2 by MS [12].

Water bath calorimetry was used to demonstrate one more peculiar phenomenon associated with rt-plasmas. Specifically, $He/H_2(10\%)$ (500 mTorr), $Ar/H_2(10\%)$ (500 mTorr), and $H_2O(g)$ (500 and 200 mTorr) plasmas generated with an Evenson microwave cavity consistently yielded on the order of 50% more heat than non rt-plasma (controls) such as

He, *Kr*, *Kr/H₂*(10%), under identical conditions of gas flow, pressure, and microwave operating conditions. The excess power density of rt-plasmas was of the order $10 \text{ W} \cdot \text{cm}^{-3}$. In addition to unique vacuum ultraviolet (VUV) lines, earlier studies with these same rt-plasmas demonstrated that other unusual features were present including dramatic broadening of the hydrogen Balmer series lines [1-3, 5, 8, 13-14, 16, 18-24], and in the case of water plasmas, population inversion of the hydrogen excited states [1, 16, 21, 23-25]. Both the current results and the earlier results are completely consistent with the existence of a hitherto unknown predicted exothermic chemical reaction occurring in rt-plasmas.

Since the ionization energy of Sr^+ to Sr^{3+} has a net enthalpy of reaction of $2 \cdot 27.2 \text{ eV}$, respectively, Sr^+ may serve as catalyst alone or with Ar^+ catalyst. It was reported previously that an rt-plasma formed with a low field (1V/cm), at low temperatures (e.g. $\approx 10^3 \text{ K}$), from atomic hydrogen generated at a tungsten filament and strontium which was vaporized by heating the metal [2-3, 5]. Strong VUV emission was observed that increased with the addition of argon, but not when sodium, magnesium, or barium replaced strontium or with hydrogen, argon, or strontium alone. Characteristic emission was observed from a continuum state of Ar^{2+} at 45.6 nm without the typical Rydberg series of Ar I and Ar II lines which confirmed the resonant nonradiative energy transfer of 27.2 eV from atomic hydrogen to Ar^+ [3, 5, 17]. Predicted Sr^{3+} emission lines were also observed from strontium-hydrogen plasmas [3, 5] that supported the rt-plasma mechanism.

Significant Balmer α line broadening corresponding to an average hydrogen atom temperature of 14, 24 eV, and 23-45 eV was observed for strontium and argon-strontium rt-plasmas and discharges of strontium-hydrogen, helium-hydrogen, argon-hydrogen, strontium-helium-hydrogen, and strontium-argon-hydrogen, respectively, compared to $\approx 3 \text{ eV}$ for pure hydrogen, krypton-hydrogen, xenon-hydrogen, and magnesium-hydrogen. To achieve that same optically measured light output power, hydrogen-sodium, hydrogen-magnesium, and hydrogen-barium mixtures required 4000, 7000, and 6500 times the power of the hydrogen-strontium mixture, respectively, and the addition of argon increased these ratios by a factor of about two. A glow discharge plasma formed for hydrogen-strontium mixtures at an extremely low voltage of about 2 V compared to 250 V for hydrogen alone and sodium-hydrogen mixtures, and 140-150 V for hydrogen-magnesium and hydrogen-barium mixtures [2, 3, 5]. These voltages are too low to be explicable by conventional mechanisms involving accelerated ions with a high applied field.

To further characterize argon-strontium rt-plasmas, plasma formation was studied relative to mixtures of hydrogen and a chemically similar control that does not have electron ionization energies which are a multiple of 27.2 eV , the Balmer lines were recorded by visible spectroscopy to confirm that an energetic hydrogen plasma was present having H energy states

greater than 12 eV corresponding to $n \geq 3$ in Eqs. (1-2), and the broadening of the Balmer α line was also recorded as a function of time. The cell comprised a titanium or tungsten filament to heat and vaporize some strontium as a source of the catalyst, Sr^+ , and to dissociate molecular hydrogen to atomic hydrogen. The addition of argon to the plasma further provided the catalyst Ar^+ .

Since a conventional discharge power source was not present, the formation of a plasma would require an energetic reaction. The origin of Doppler broadening is the relative thermal motion of the emitter with respect to the observer—in this case the spectrometer. Line broadening is a measure of the atom temperature, and a significant increase was expected and observed for catalysts, Sr^+ or Ar^+ , with hydrogen. The observation of a high hydrogen temperature with no conventional explanation would indicate that an rt-plasma must have a source of free energy. An energetic chemical reaction was further implicated since it was found that the broadening is time dependent. Therefore, to further characterize argon-strontium rt-plasma as a low-voltage light source, another cell type was heated externally and the voltage across two pin electrodes was varied as the visible emission was recorded. The hydrogen plasma occurred with voltages (e.g. <5 V) that were lower than the energy of the Balmer emission which required an internal source of energy to explain the light-emission behavior. We report the results of these characterizations and discuss the implications regarding the rt-plasma mechanism in Secs. 3A-C.

2. Experimental

An argon-hydrogen (90/10%)-strontium rt-plasma was generated in the experimental set up described previously [1-3, 5]. The so called Type I light source shown in Figure 1 comprised a thermally insulated quartz cell with a cap that incorporated ports for gas inlet, and outlet. A tungsten filament (800 cm long, 0.508 mm diameter, total resistance ~ 2.5 ohm) or titanium filament (55 cm long, 0.5 mm diameter) that served as a heater and hydrogen dissociator was in the quartz tube. 2.5 g of magnesium or strontium metal (Alfa Aesar 99.95%) was placed in the center of the cell under more than one atmosphere of dry argon in a glovebox. The cell was sealed and removed from the glovebox. The cell was maintained at 50 °C for four hours with helium flowing at 30 sccm at a pressure of 0.6 Torr. The tungsten filament was operated at 300 W for strontium and as high as 600 W for magnesium. The filament temperature at 300 and 600 W was estimated at 1800 and 2500 °C, respectively. The insulation package used provided a wall temperature of 700 °C at 300 W.

The titanium filament power was increased to 120 W in 20 increments every 20 minutes. At 120 W, the filament temperature was estimated to be in the range 800 to 1000 °C. A second insulation package provided an external cell wall temperature of about 700 °C. The

cell was then operated with and without an argon-hydrogen (90/10%) flow rate of 5.5 sccm maintained at 0.6 Torr. Additionally, the cell was operated with hydrogen and argon-hydrogen (90/10%) gas flow and no metal. Each metal was vaporized by the filament heater. The presence of a hydrogen plasma was determined by recording the visible spectrum over the Balmer region with a Jobin Yvon Horiba 1250 M spectrometer with a PMT detector described previously [3, 18-19] using entrance/exits slits of 200/100 μm , 0.1 \AA step size, and a 3 s integration time. The width of the 656.3 nm Balmer α line emitted from the argon-hydrogen (90/10%)-strontium rt-plasma having a titanium filament was measured initially and periodically during operation.

A low-voltage-discharge rt-plasma light source called a Type II light source in this paper comprised a thermally insulating vacuum chamber containing a plasma chamber with two tungsten pin electrodes and a ceramic heater external to the plasma chamber is shown in Figure 2. Referring to Figure 2, the system was assembled and operated as follows: The quartz tube was inserted through opposing ports of the vacuum chamber, and the chamber was sealed at the protruding sections of the tube using Swagelok fittings and at the top with a stainless steel vacuum flange. The Mullite rod with embedded W electrodes was inserted into the quartz tube, aligned axially, and fastened into position by tightening two Swagelok fittings (with Teflon ferrules) which also sealed the plasma chamber of the quartz tube. The quartz window was installed using an Ultra-Torr (UT) connection. The gas and electrical connections were made to complete the assembly.

The vacuum and plasma chambers were pumped down while the operating the plasma-tube heater at ~ 10 W until the pressure reached a stable minimum; then, the system was cooled to room temperature. With the pump isolated, argon was continuously flowed through the quartz tube at a flow rate and pressure of ~ 900 sccm and 1 atm, respectively, while loading strontium pieces into the quartz tube. To gain access to the quartz tube, the quartz window was removed by first removing an Ultra-Torr nut which held it in place. ~ 1.5 g of strontium was distributed from the electrode area to the boundary of the heated section. The window assembly was reinstalled before the argon flow was shut off. Then, the pump valve was slowly opened to evacuate the tube for about 1 h.

Pure argon was flowed through the tube at 1 Torr and 18 sccm. The heater power was increased from 0 to 100 W in 10 W increments over 10 hours. Hydrogen gas flow was added to the argon gas to obtain a mixture of $\sim \text{Ar}/\text{H}_2(90/10\%)$ with the pressure adjusted to 1 Torr. The plasma was initiated by applying power to the electrode power supply. The supply voltage was incrementally lowered to observe low-voltage plasmas until the plasma could no longer be observed. Spectral data was recorded through a quartz window of the plasma cell with a visible spectrometer (Ocean Optics S2000) and stored by a personal computer.

3. Results and discussion

A. RT-plasma emission

The cell was operated without any test material present to establish the baseline of the spectrometer. The intensity of the Lyman α emission as a function of time from the Type I light source is shown in Figure 3. An argon-hydrogen (90/10%)-strontium rt-plasma formed with a low field (1V/cm), at low temperatures (e.g. $\approx 10^3$ K), from atomic hydrogen generated at a tungsten filament and strontium which was vaporized by heating the metal. Strong EUV emission was observed as shown by the VUV spectrum (90 – 130 nm) of the cell emission recorded at about the point of the maximum Lyman α emission in Figure 4. No plasmas formed when magnesium replaced strontium or with hydrogen, argon/hydrogen, or strontium alone. This result indicates that the emission was due to a reaction of hydrogen with vaporized strontium. No possible chemical reactions of the titanium filament, the vaporized strontium, and 0.6 Torr argon-hydrogen mixture at a cell temperature of 700°C could be found which accounted for the EUV emission. In fact, no known chemical reaction releases enough energy to excite Lyman emission from hydrogen. In addition to known chemical reactions, electron collisional excitation, resonant photon transfer, and the lowering of the ionization and excitation energies by the state of “non ideality” in dense plasmas were also rejected as the source of ionization or excitation to form the hydrogen plasma [6]. The formation of an energetic reaction of atomic hydrogen was consistent with a source of free energy from the catalysis of atomic hydrogen by Sr^+ and Ar^+ .

B. Balmer α line widths

The method of Videnovic et al. [18-19, 30] was used to calculate the energetic hydrogen atom energies from the width of the 656.3 nm Balmer α line emitted from RF rt-plasmas. The full half-width $\Delta\lambda_G$ of each Gaussian results from the Doppler ($\Delta\lambda_D$) and instrumental ($\Delta\lambda_I$) half-widths:

$$\Delta\lambda_G = \sqrt{\Delta\lambda_D^2 + \Delta\lambda_I^2} \quad (5)$$

$\Delta\lambda_I$ in our experiments was 0.006 nm. The temperature was calculated from the Doppler half-width using the formula:

$$\Delta\lambda_D = 7.16 \times 10^{-7} \lambda_0 \left(\frac{T}{\mu} \right)^{1/2} \quad (6)$$

where λ_0 is the line wavelength, T is the temperature in K ($1 \text{ eV} = 11,605 \text{ K}$), and μ is the molecular weight (=1 for atomic hydrogen). In each case, the average Doppler half-width that

was not appreciably changed with pressure varied by $\pm 5\%$ corresponding to an error in the energy of $\pm 10\%$.

The 656.3 nm Balmer α line widths recorded on the argon-hydrogen (90/10%)-strontium rt-plasma having a titanium filament initially and after 70 hours of operation are shown in Figure 5. Significant broadening was not observed initially. However, the Balmer α line profile of the plasma emission after 70 hours comprised two distinct Gaussian peaks, an inner, narrower peak corresponding to a slow component with an average hydrogen energy of 1 eV and an outer broader peak corresponding to a fast component of 20 eV. Only the hydrogen lines were broadened. These results are consistent with the catalysis of hydrogen to lower-states followed by subsequent transitions with increasing energy release by an autocatalytic mechanism previously reported with spectroscopic evidence [14-15].

We have assumed that Doppler broadening due to thermal motion was the dominant source to the extent that other sources may be neglected. This assumption was confirmed when each source was considered. In general, the experimental profile is a convolution of two Doppler profiles, an instrumental profile, the natural (lifetime) profile, Stark profiles, van der Waals profiles, a resonance profile, and fine structure. The contribution from each source was determined to be below the limit of detection [3, 5, 18-19].

The formation of fast H can be explained by a resonant energy transfer from hydrogen atoms to Sr^+ or Ar^+ ions of two and one times the potential energy of atomic hydrogen, respectively, followed by a collisional energy transfer to yield fast $H(n=1)$ as well as the emission of $q \cdot 13.6 eV$ photons reported previously [14-15]. For example, the exothermic chemical reaction of $H + H$ to form H_2 does not occur with the emission of a photon. Rather, the reaction requires a collision with a third body, M , to remove the bond energy- $H + H + M \rightarrow H_2 + M^*$ [27]. The third body distributes the energy from the exothermic reaction, and the end result is the H_2 molecule and an increase in the temperature of the system. In the case of the catalytic reaction with the formation of states given by Eqs. (1) and (3), the temperature of H becomes very high.

C. Low-voltage plasma emission

The UV-VIS spectra of the plasma formed in the Type II light source with the source operated at 7 V and 8 V are shown in Figures 6(a) and 6(b), respectively. H Balmer α , Sr (I), Sr(II) and Ar(I) lines were observed. In several cases plasma was obtained at voltages as low as 5 V. The Balmer lines recorded by visible spectroscopy confirm that an energetic hydrogen plasma was present having H energy states greater than 12 eV corresponding to $n \geq 3$ in Eqs. (1-2). The formation of energetic states of higher energy than possible from the applied voltage supports a chemical energy source for the plasma.

Other studies support the possibility of a light source from a novel reaction of atomic hydrogen which produces a rt-discharge under extraordinary low field conditions. An rt-plasma with hydrogen-potassium mixtures has been reported in an experiment identical to the present VUV experiments [13] with Type I cells except that the reactants were hydrogen-potassium mixtures. Observations of intense hydrogen Lyman emission, a stationary inverted Lyman population, excessive afterglow duration, highly energetic hydrogen atoms, characteristic alkali-ion emission due to catalysis, predicted novel spectral lines, and the measurement of a power beyond any conventional chemistry [1] matched predictions for a catalytic reaction of atomic hydrogen to form more stable hydride ions designated $H^-(1/p)$ [1, 9-11, 16-17].

The enthalpy of ionization of K to K^{3+} has a net enthalpy of reaction of $81.7426 eV$. Characteristic emission was observed from K^{3+} that confirmed the resonant nonradiative energy transfer of $3 \cdot 27.2 eV$ from atomic hydrogen to K . The product hydride ion $H^-(1/4)$ was observed spectroscopically at $110 nm$ corresponding to its predicted binding energy of $11.2 eV$. The 1H MAS NMR spectrum of novel compound KH^*Cl relative to external tetramethylsilane (TMS) showed a large distinct upfield resonance at $-4.4 ppm$ corresponding to an absolute resonance shift of $-35.9 ppm$ that matched the theoretical prediction of $p = 4$. The predicted catalyst reactions, position of the upfield-shifted NMR peaks for $H^-(1/4)$, and spectroscopic data for $H^-(1/4)$ were found to be in agreement with the experimental observations as well as previously reported analysis of KH^*Cl containing this hydride ion. The power source of the Type II cell may also be due to such a reaction.

4. Summary

An rt-plasma formed with a low field ($1V/cm$), at low temperatures (e.g. $\approx 10^3 K$), from argon and atomic hydrogen generated at a titanium filament with strontium which was vaporized by heating the metal. Strong Balmer emission was observed that indicated an energy source of $> 12 eV$. The energetic reaction of atomic hydrogen was anticipated to form energetic hydrogen atoms. Significant Balmer α line broadening corresponding to an average hydrogen atom temperature of $20 eV$ was observed. The time-dependence of the appearance of fast H supported an energetic chemical reaction as the source.

To further characterize argon-strontium rt-plasma as a low-voltage light source, another cell type was heated externally and the voltage across two pin electrodes was varied as the visible emission was recorded. The Balmer lines recorded by visible spectroscopy confirmed that an energetic hydrogen plasma was present having H energy states greater than $12 eV$ corresponding to $n \geq 3$ in the Rydberg formula. The hydrogen plasma occurred with voltages (e.g. $< 5 V$) that were lower than the energy of the Balmer emission. Incorporating previous

results, the possibility that a novel catalytic reaction of atomic hydrogen to form more stable hydrides may be new light source is supported by spectroscopic, chemical, and thermal data.

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Figure 1. The experimental set up of a Type I light source and a VUV spectrometer that was differentially pumped.

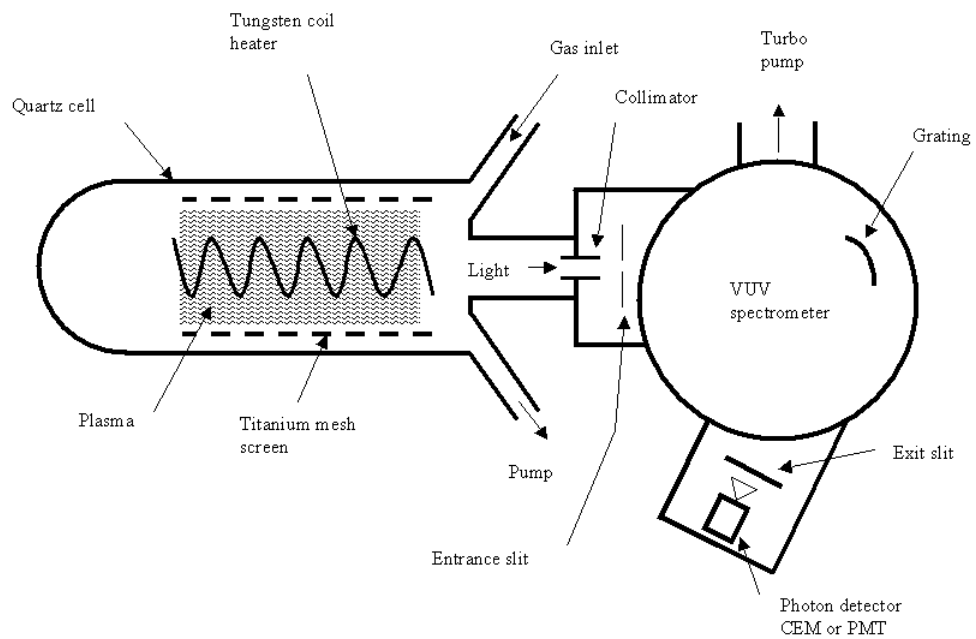


Figure 2. The experimental set up of a source Type II light source to generate a low-voltage-discharge rt-plasma comprising a thermally insulating vacuum chamber containing a plasma chamber with two tungsten pin electrodes and a ceramic heater external to the plasma chamber.

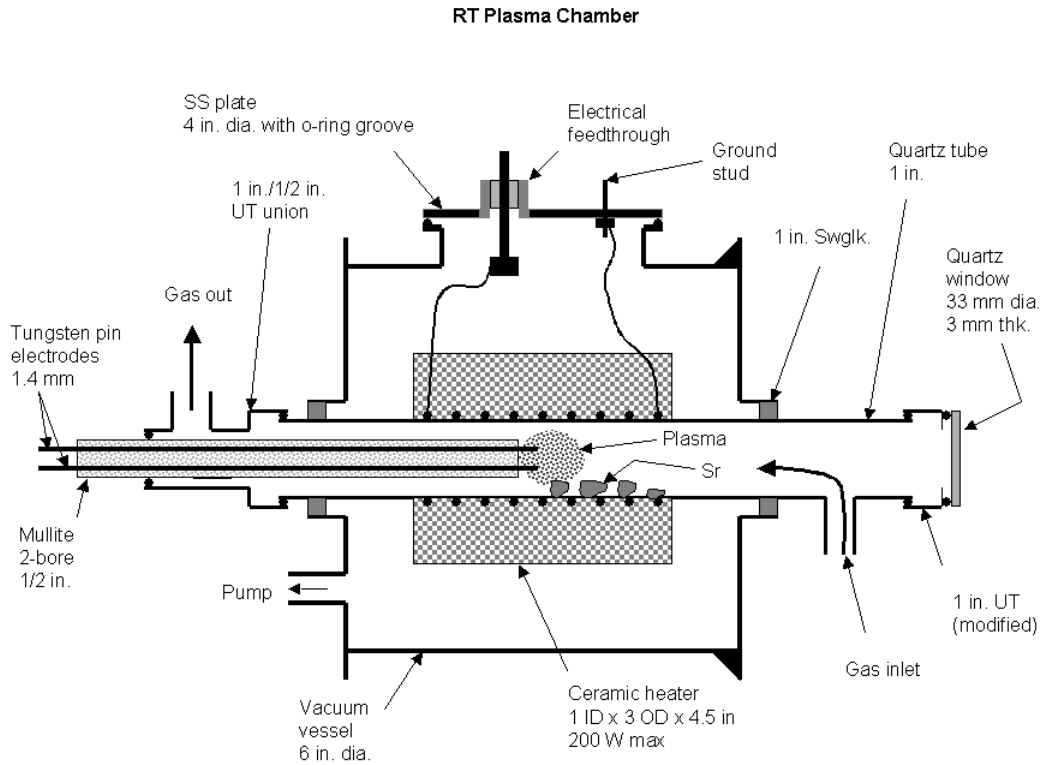


Figure 3. The intensity of the Lyman α emission as a function of time from the Type I light source that was recorded with a CEM. The gas cell at a cell temperature of 700°C comprised a tungsten filament, vaporized strontium metal, and 0.6 Torr argon-hydrogen (90/10%).

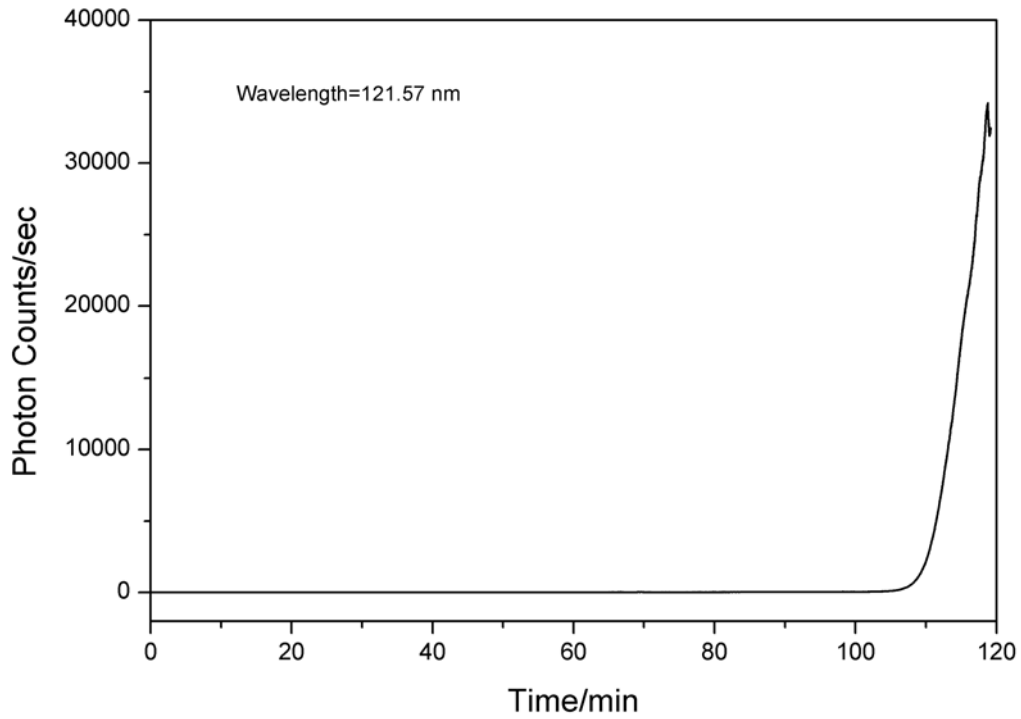


Figure 4. The VUV spectrum (90–130 nm) of the Type I light source emission recorded with a CEM at about the point of the maximum Lyman α emission.

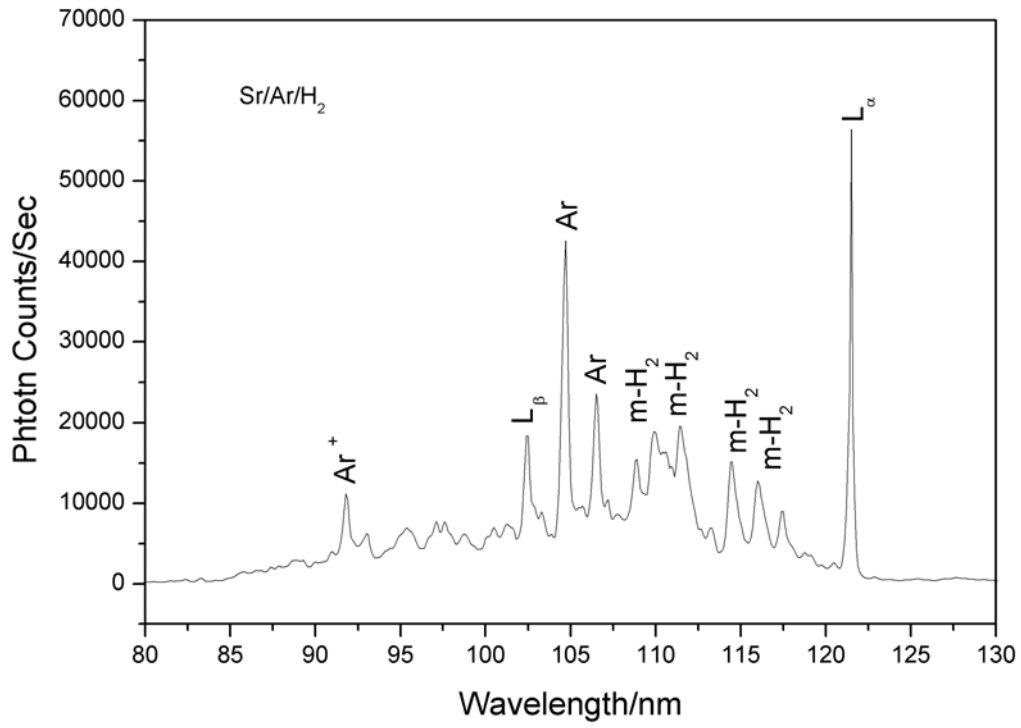


Figure 5. The 656.3 nm Balmer α line width recorded with a high resolution visible spectrometer on the initial emission of a Type I light source and the emission at 70 hours of operation. Significant broadening was observed over time corresponding to an average hydrogen atom temperature of 20 eV.

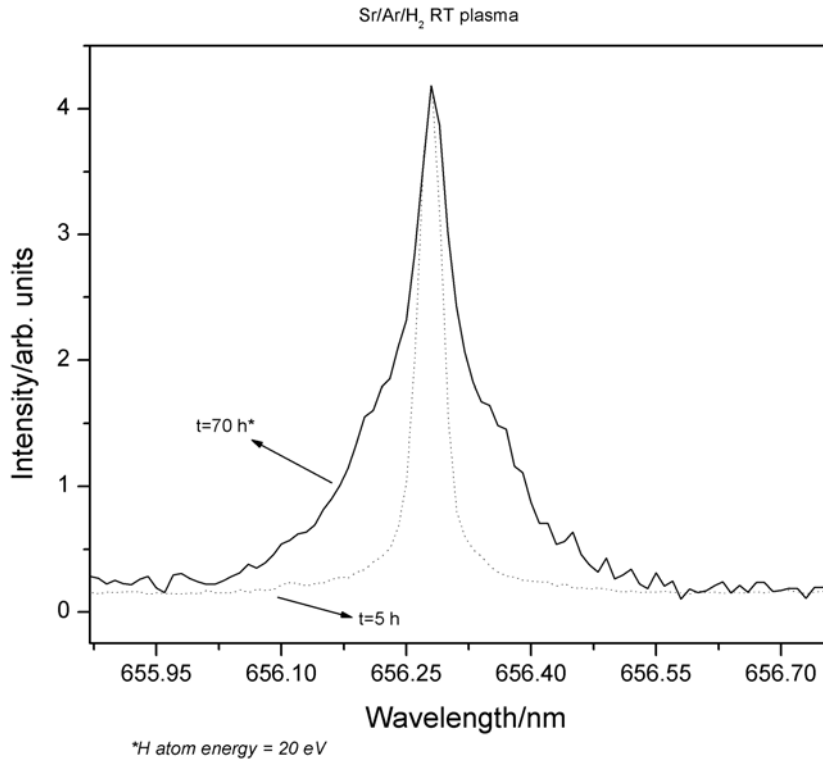


Figure 6. The UV-VIS spectra of the plasma formed in the Type II light source with the source operated at 7 V (a) and 8 V (b). H Balmer α , Sr (I), Sr(II) and Ar(I) lines were observed.

