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ENVIRONMENTAL FRIENDLY HIGH EFFICIENT LIGHT SOURCE

PLASMA LAMP

Annual Report 2006

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ABSTRACT

The work reported here has been achieved through collaboration with the company Solaronix. The present report describes innovative aspects that allow suppressing the rotation of the bulb and any other motion. The obtained performance is comparable to the one of the Solar-1000 at same power. Besides, we have been contacted by a large Korean trust, LG Electronics. Solaronix has request a patent to protect our invention. The year 2006 has been dedicated to the following tasks:

1. Thermodynamic analysis, assessment of the efficiency of the magnetron.
2. Thanks to a new microwave bench: tries of small bulbs, study of the standing wave ratio (microwave fluxes) and develop a new coupling system to allow ignition in very small bulbs.
3. Extend our knowledge about the fillings of the bulb and induced effects of the modulator.
4. Develop a second generation of modulator to enhance its effects of acoustic sustentation and of spectral shift to obtain higher efficiency at lower power.

The results confirm that scaling down the size of the bulb allows reducing the nominal power. At a third of the full power of the lamp Solar-1000, the luminous efficiency of our motionless lamp is still at 68 lm/W thanks to the modulator. At the same power, the solar-1000 outputs only 60 lm/W and a static bulb of standard size outputs a little less. Besides, clear evidences of the plasma modulation have been obtained and of its sustentation as well. As a result, a route to higher luminous efficiency at lower power is in view.

Although the Colour Rendering Index computed with standard CIE method is low for such sources, the continuity of the spectrum (anti-metamerism) makes this lamp unique, since such a quality was only met by low efficient lamps (halogens: ~ 25 Lm/W).

Goal of the project

Background

Lighting-related electricity production for the year 1997 was 2016 TWh. The corresponding carbon dioxide emissions were 1775 million tonnes. For the industrialized countries, national lighting electricity use ranges from 5 % to 15 %, while in developing countries the value can be as high as 86 % of the total electricity use [1].

More efficient use of lighting energy would limit the rate of increase of electricity consumption and the rate of construction of new power plans, and reduce the emissions of greenhouse gases and other pollutants.

Our research

We are working at the development of a very high efficient type of light source (target value: 140 lm/W) which provides colour rendering that meets the standard of buildings. Nowadays, most of the low-energy lamps on the market are of fluorescent type (~80 Lm/W), although they contain mercury, a very harmful substance which is strictly regulated. Environmental friendly alternatives, based on sulphur vapour excited by microwaves, are in development in different countries (South-Korea, USA, Nederland, Russia, Japan and probably also Germany). At high temperature, the vapour radiates a continuous spectrum that fits well to the human eye's sensitivity.

Our research in this field began thanks to the support of the University Of Applied Sciences Of Western Switzerland (HES-SO) by the project Nanosun Ph1 which was first dedicated to analyse the SOLAR-1000 lamp, the first commercialised sulphur lamp, a device of nominal input power of 1400 Watt. This device is fitted with a spinning bulb and uses a process discovered in 1995 by Ury et al. (patent [2]). We intend to improve the technology by suppressing this motion (longer life time). Our measures have shown that the rotation of the bulb does not only cool down the bulb, and therefore avoid melting at full power, but also increases the luminous efficiency obtained at a given power: at 500 Watts (magnetron input power), the efficiency of the SOLAR-1000 lamp goes up form 50 to 100 Lumen/Watt when the bulb is put into rotation at full speed. Besides, we have checked that the energetic cost of rotating the bulb is insignificant in regard to the consumption of the magnetron.

Goal of the present project

This project is dedicated to the reduction of the nominal power and the renouncement of any mobile mechanism but keeping the efficiency at a high level. This progress will allow matching a larger market segment, in addition to extending the life time of the lamp and reducing its cost of fabrication. These three points should mature the technology up to profit-earning state.

In the year 2005, we have solved the problem of standing high temperature in the bulb without any forced cooling (fans). Our lamp has reaches 86 Lm/W at half of the Solar-1000 nominal power. In 2006, we have concentrated our efforts on the following points:

1. Thermodynamic analysis, assessment of the efficiency of the magnetron.
2. Microwave impedance matching. Usefulness of retuning after ignition of the discharge.
3. Tries of small bulbs thanks to a tuneable microwave system. Develop a new coupling system to allow ignition in very small bulbs.
4. Write a request of patent to protect our invention.
5. Study of the standing wave ratio (microwave fluxes) at ignition and at steady state.
6. Consolidate our knowledge of the effects induced by the modulator and their control.
7. Extend our knowledge about the fillings of the bulb: chemical nature and amount.
8. Develop a second generation of modulator to enhance its effects of acoustic sustentation and of spectral shift to obtain higher efficiency at lower power.

Work done and reached results

Planning

The initial planning (cf. [3]) has been followed up to the task 'Tests of prototypes'. At the end of 2005, it has been agreed to extend the stage of laboratory tests in the following directions:

1. Tries of small bulbs. This needs a tuneable microwave bench; the one we use has been provided by Solaronix.
2. It came out that three additional parameters should to be studied: two are related to the innovative system and the third is the bulb filling.
3. An investigation of the plasma stability is necessary before stepping into the design of a final prototype

Thermodynamics analysis of the lamp

The plasma absorbs electromagnetic energy carried by the microwaves; this is of course how it stays hot. The absorption of microwaves outputs only heat. A flux of heat can however produce work. In steady state, all the electromagnetic energy dissipated inside the bulb is transferred to its outside, but not solely as heat. Indeed, the spectrum of the lamp does not obey Planck's law of thermal radiations; see Figure 8 (page 9). The origin of this optical emission (from 300 to 900 nm) is the following. Photons are emitted at the relaxation of diatomic molecules from a certain excited electronic state to the ground electronic state, a reversible process (photo-absorption) [4]. Being not due to thermal radiation, the optical emission is a production of work, in the sense of thermodynamics, as the resting part is a flux of heat. From this analyse we can define the thermodynamic efficiency of the plasma as the ratio of the optical emission to the net flux of microwave. The first parameter is obtained by integration of the spectrum between 300 to 900 nm. The second is the magnetron input power times its efficiency. An assessment of this last characteristic is thus needed.

Experimental set-up

Figure 1 Set-ups. One can see the microwave bench on the left and the photometric line on the right.

The new features are the followings:

- The microwave circuit is fitted up with flux meters (forward and backward fluxes) and is tuneable manually thanks to adjustable stubs and a sliding short at the termination of the waveguide (cf. Figure 1). These parts have been provided by Solaronix.

- The magnetron is water cooled and fitted with heat flux monitoring. This has also been provided by Solaronix.
- The magnetron is supplied by a switching power generator (ALTER CM 440) that delivers the needed high voltage (4 kV). The modulator is set between the generator and the magnetron.

Efficiency of magnetrons versus input power

The magnetron used up to now is a model 2M244-M1 (Panasonic). It radiates microwaves of around 2.45 GHz. According to the provider [5], it absorbs 1424W at full power for an output of 1010W; its efficiency is then of 71%. But what about if the power is lower?

Thanks to the heat flux monitoring set-up provided by Solaronix (water cooling fitted-up with a calibrated thermocouple), we have measured the power dissipated by the magnetron. Besides we have also monitored the flux in the microwave guide, both in forward and backward directions. The algebraic addition of the two, or their difference in positives values, gives the net flux of microwaves, or in other words, the magnetron output:

$$\left|\Phi_{Net}\right| = \left|\Phi_{Fwd}\right| - \left|\Phi_{Bwd}\right|$$ Équation 1

We have checked in steady state that the magnetron output plus its dissipation rejoins its consumption. This condition of energy conservation is respected at an uncertainty of 15% in all cases. Besides, the efficiency of the magnetron is by definition the ratio of the net microwave flux to the input power:

$$\eta = \left|\Phi_{Net}\right| / W_{InputMag}$$ Équation 2

On the other hand, the company Daewoo is offering 300 W magnetrons (type RM118'S) that radiate also microwaves of around 2.45 GHz. According to Daewoo, at 150 W of input power, its efficiency is of 64%.It is of 58% in the case of the 2M244-M1 (our measures). This discrepancy is not relevant regarding the precision of our thermal measurements. Hence, we can hardly rank the two models and we conclude by saying that the efficiency at 150 W of input power turns around 60% for both models.

Microwave impedance matching

The reflection coefficient is obtained by taking the square root of the ratio of the backward flux to the forward flux. These two parameters are monitored by the power meter.

$$\rho = \sqrt{\left|\Phi_{Bwd}\right| / \left|\Phi_{Fwd}\right|}$$ Équation 3

The Volt Standing Wave Ratio (VSWR) is the deduced by:

$$VSWR = \frac{1+\rho}{1-\rho}$$ Équation 4

In the starting procedure, the microwave circuit is tuned. Before ignition, the sulfur is condensed; the dielectric losses are therefore very small, as long as the magnetron do not goes into modding. At impedance matching the reflection coefficient tends to unity because there is only little absorption. And as a result, a standing wave grows inside the cavity (VSWR tends to infinity). We observe indeed on the flux meter that the forward flux and the backward flux get close to each other in value at the tuning of ignition. The quality factor reaches high value (in the magnitude of 7’000 according to our measures [6]). An electric anti-node lies at the centre of the cylindrical cavity, where the bulb is lying. Since the bulbs contain a gas, usually Argon or Xenon, a discharge is ignited if the cavity is feed with enough energy. To low this threshold, the bulbs are sealed under low pressure (Paschen’s Law). From our investigations, we have seen that the optimal pressure lies in the range of 30 mBar.

As the discharge heats up the bulb, we see that the backward flux decreases. This is because the microwave absorption inside the cavity increases. Thus the quality factor decreases and so does the standing as a result.

After the sulphur is fully evaporated and the plasma is stabilized, the lamp sets in steady state, the Voltage Standing Wave Ratio (VSWR) sets between 4 and 5 if the modulation is OFF and between 1 and 2 if it is ON. It is striking that the VSWR is systematically lower when the modulation is switched ON. The VSWR is then so low that it is not worth to fit up the lamp with an automatic tuner in order to retune the microwave circuit after the ignition.

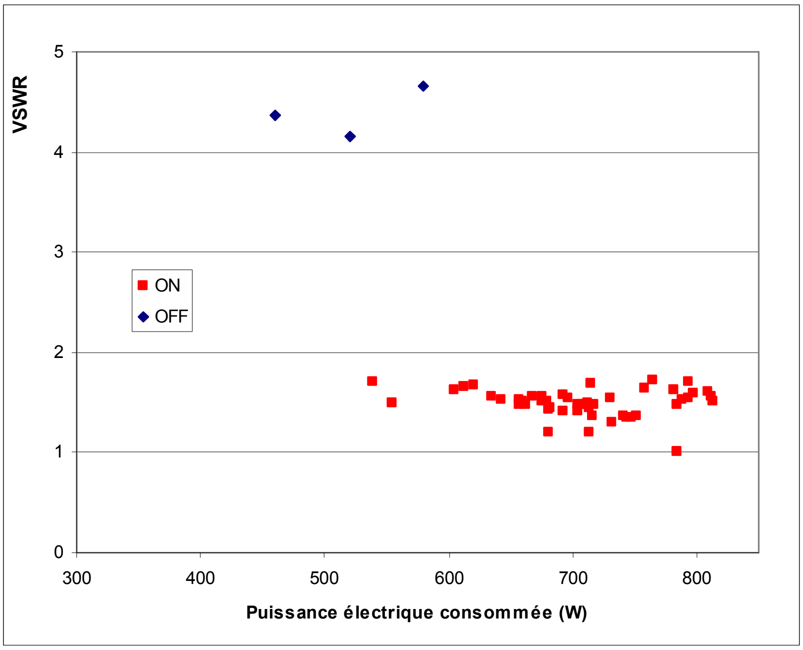

Figure 2 Voltage Standing Wave Ratio versus input power, modulation ON and OFF

Smaller bulbs

All the bulbs are spherical. We first consider a bulb of $25\,mm$ of external diameter; its volume is $5.4\,cc$ (measured value). It contains $1{,}50\ mg/cc$ of sulphur. Before sealing, it is filled under $25\ mBar$ of Xenon at room temperature.

The bulb is laying in the centre of electromagnetic cavity (cylindrical grid). This is the best position to ease the discharge ignition because that is where the electrical antinode of reasoning sets. A discharge appears at impedance matching, but only if the magnetron output is high enough. For such a small bulb, the ignition is unlikely to happen below one kilowatt of microwave. As expected, the backward flux falls as soon as the discharge is ignited.

To avoid damaging the bulb, its temperature is monitored through an infrared camera. When the temperature reaches 700°C, the input power is reduced. When all the sulphur is vaporized, the system sets in a steady state of non equilibrium (dynamic regime), which may be stable or not. We have found settings where the regime is stable.

As the sulphur vaporizes, the plasma extends and becomes brighter (Figure 3). In order to avoid blistering the bulb, we stay at low power (by 400W of magnetron input) and we don't prolong this tries in the time. Despite those precautions, we have noted after the bulb had returned to room temperature that it had been a little bit blistered.

Figure 3 After evaporation of sulphur, modulation OFF (~ 400 W)

Let's consider now the tests done with modulation switched on. The plasma extends greatly (Figure 4). Within the present range of power (magnetron input below 560 W), we haven't found any additional blisters by visual inspection through a filter.

Figure 4 After evaporation of sulphur, modulation ON (~560 W)

The luminous efficiency stays at high level from 490W to 626W of magnetron input power. In all this range, the light is white, but always drawing very slightly on blue, and the colour temperature stays between 8'000K et 10'200K. The plasma is perfectly stable: no vibration of lighting is perceptible at eye.

The red shift (spectral shift of the emission towards longer wavelength) is slightly more important when the command of the amplitude of modulation is at 9V instead at 10,5V or 9,5V. As a result, the fact that the luminous efficiency is a little higher in some cases (Figure 2) does not speak again the general rule we have noted up to now that says that the efficiency is a growing function of the input power, all others conditions of operation staying alike.

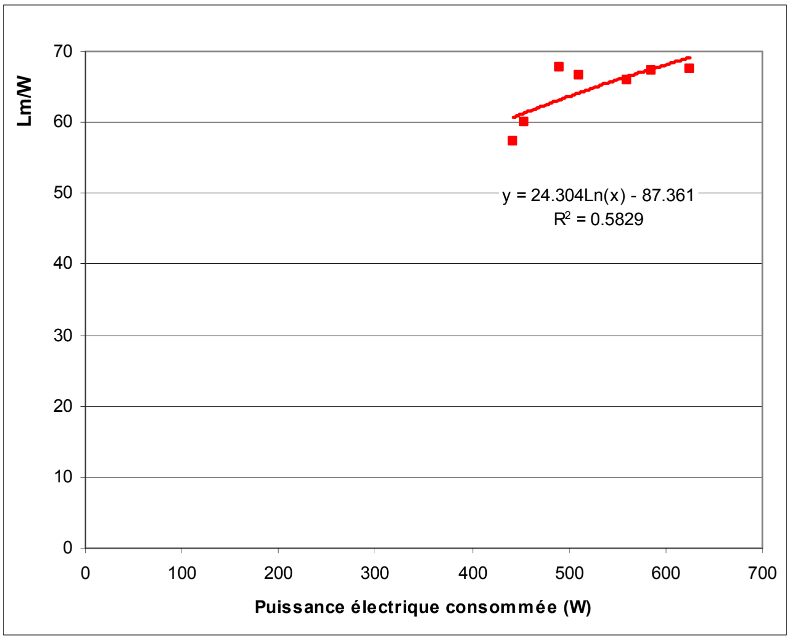

Figure 5 Luminous efficiency versus magnetron input power, modulation ON

The thermodynamic efficiency of the plasma passes over 43% at a microwave net flux of 340W. Like luminous efficiency, it is a growing function of the input power. After each increase of the microwave flux, the temperature of the bulb rises in consequence; but after one or two minutes, the temperature goes back a little down slowly during a few minutes. This is certainly the effect acoustic sustentation. As an effect of the modulation, the temperature on the bulb gets more uniform. Hence, the bulb can stand higher power without damage. But at the strongest power (magnetron input ~650 W), the bulb has suddenly opened itself making a brutal detonation. One of the two blisters that had appeared during the try without modulation has inflated till the opening of its top.

Tableau 1 resumes the tests of small bulbs in comparison to the one, which provides 86 Lm/W [7] (column I). The content was kept at 1.5 mg/cc. A stable regime has always been found.

Inside volume	cc		11,5	10,4	8,1	5,4
Magnetron input power	W	OFF	656	551	502	400
		ON	656	551		490

Luminous efficiency	Lm/W	OFF	41	34	33	
		ON	86	56		**68**
Thermodynamic efficiency of the plasma	$\%$	OFF	41	36	34	
		ON	63	47		44
Colour temperature	K	OFF	15'000			
		ON	7'500			8’240
CIE index of colour rendering		OFF	89	89	90	
		ON	81	85		88

Tableau 1 Performances (typical values) of smaller bulbs for modulation ON and OFF

Active substances

Our modulator has been tested on bulbs filled with two other chemical elements of the same column of the periodic table, selenium and tellurium. As they have a lower energy of dissociation, we expect that the plasma will be less hot at same light output. Likewise sulphur, these elements tend to form diatomic molecules with a double valence bound, in state of vapour. Tableau 2 resumes the tests the tests we made, including the tests on sulphur and tellurium we made last year [7]. We have tried to keep constant the ratio of the magnetron input power to the volume of the bulb in the comparison of the two situations « ON » and « OFF » (with and without modulation).

Active substance			Sulphur	Selenium	Tellurium
Inside volume	cc		11,5	17	17
Amount of diatomic molecules ([1])	$10^{-6}\ mol_2$		205	189	63
Stable regime?		OFF	yes	quasi	yes
		ON	yes	no	no
Absorbed µwave power per diatomic molecule ([1])	$10^{6}\ W \cdot mol_2$	OFF	2,2	1,5	6,8
		ON	2,2	3,0	6,8
Luminous efficiency	Lm/W	OFF	41	11	24
		ON	**86**	52	68
Wavelength of maximal emission	nm	OFF	455	460	520
		ON	516	550	575
Thermodynamic efficiency of plasma	$\%$	OFF	41	8	15
		ON	63	30	47
Bulb temperature	$°C$	OFF	640	680	820
		ON	880	700	810
Colour temperature	K	OFF	15'000	22'000	
		ON	7'500	4'000	
CIE index of colour rendering		OFF	89	82	80
		ON	81	81	75
Thermo mechanical resistance		OFF	blisters	ok	ok
		ON	?	ok	ok

Tableau 2 Performances (typical values) of different substances for modulation ON and OFF

[1] In absence of dissociation

We have observed that each of this substance is shining strongly at high temperature. Moreover, the modulation has increased the thermodynamic efficiency of the plasma by a factor 1.5 for sulphur, 3.8 for selenium and 3.1 for tellurium and the luminous efficiency by a factor 2.1 for sulphur, 4.7 for selenium and 2.8 for tellurium (Tableau 2). We note besides that the wavelength of maximal emission varies from one bulb to the other inversely to the absorbed power per diatomic molecule ([1]), except in one case. This order is in agreement with our analysis: the absorbed power per diatomic molecule sets the mean state of internal vibration. The amount of content is far from optimum, especially for tellurium. Our experiments have showed that this parameter has a great effect. Significant improvements can be expected form tuning it.

Variation of content in sulphur

In this section, all the bulbs are spherical and of the same diameter ($32\,mm$) and their inside volumes are of $12\,cc$. The active substance is sulphur for all of them, but the amount varies from one bulb to the other. Looking at the plasma through a filter give evidence of the acoustic sustentation that occurs when the acoustic wave produced by the modulation comes into resonance:

Figure 6 After evaporation of sulphur, modulation OFF (470 W)

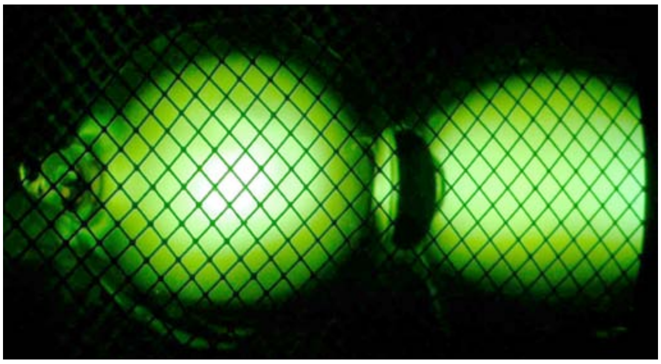

Figure 7 After evaporation of sulphur, modulation ON (697 W)

This phenomenon allows to increases greatly the limit of power at which the bulb open itself. For the bulb of the pictures above, the ratio power over inside volume is 73 W/cc at its best luminous efficiency (82 Lm/W). In the case of this bulb (filled at 1.19 mg/cc) we have compared the performances, modulation OFF and ON. Some spectrums are presented on Figure 8. The spectral density of radiation passes by a maximum at 473 nm when the modulation is ON as its maximum is found around 419 nm if it is OFF.

The best performance, 82 Lm/W, is reached by modulating at a magnetron input power of 785 W. In this situation, the light is white but drawing a little to the blue and the colour temperature is of 13'000K, which is somewhat too high. In counter part, the CIE index of colour rendering is very good since it reaches 86.

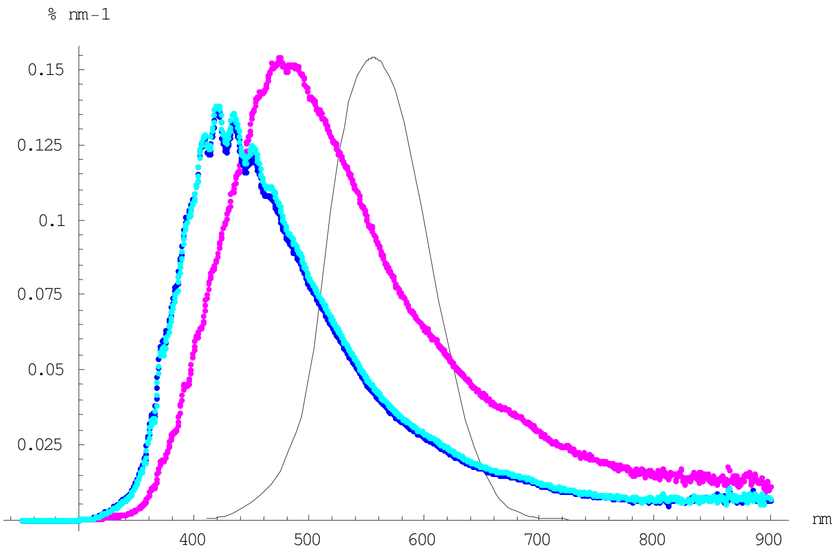

Figure 8 Ratio of the spectral density of radiation to the magnetron input power (including cathode heating). Modulation OFF: in blue. Modulation ON: purple. Magnetron input power at 580W (clear blue) and 550 W (dark blue) and 785W (purple).

As expected, the luminous efficiency is an increasing function of the input power (cf. Figure 9). When the modulation is OFF, the points fit very well a logarithmic function almost linear. The extrapolation says that the efficiency would be by 37 Lm/W at 650W and of 39 Lm/W at 700 W. The behaviour of this bulb is thus very close to the one of 11.5 cc filled with 1.47 mg/cc of sulphur [7] (41 Lm/W at 650W). The performance ranking is consistent with the content variation (the spectrum is shifted in the red as the content is increased). When the modulation is ON and by good settings, the present bulb passes over 75 Lm/W at 700W and reaches 82 Lm/W at 800 W. Hence, at same power, the modulation double the luminous efficiency, as it did with the bulb referred above [7].

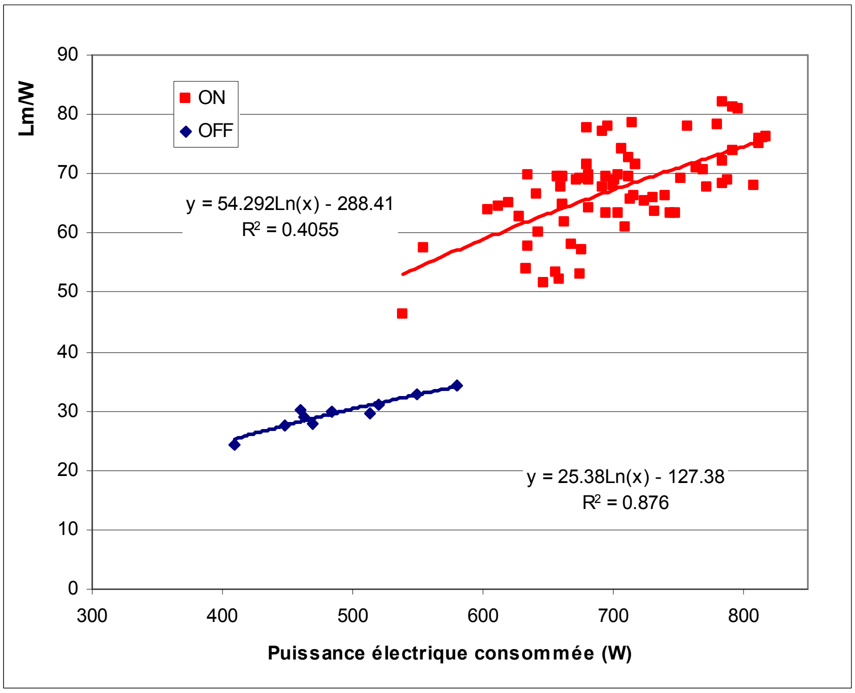

Figure 9 Luminous efficiency versus magnetron input power (including cathode heating)

The thermodynamic efficiency of the plasma has passed over 55% at a net microwave flux of 550W. Like the luminous efficiency, this parameter is much lower when the modulation is turned OFF (33%). This gives again evidence that making the plasma vibrates in the way our prototype does stimulates the non thermal radiations.

A fast photodiode has been mounted in order to analyse the variations in the time of the light. The delivered signal shows an oscillation at the exact frequency of the modulation of the magnetron; its amplitude is in the order of a percent of its mean value. This gives evidence that the modulation puts the plasma into vibrations.

Furthermore, we have observed that the reduction of the content enhances the thermodynamic efficiency of the plasma. It is in fact not suppressing since the less dense is the gas the lower is the heat conduction and convection, so the steeper is the gradient of temperature inside the bulb. As the boundary temperature is limited by fused quartz strain point (1120 °C), the gradient determines the central temperature. So a higher core temperature can be obtained when less stuff is put inside the bulb. Using the core temperature T_H (hot source) and the average peripheral temperature T_C (cold source), we write the thermodynamic efficiency η of the plasma as the Carnot efficiency η_C less the losses due to creation of entropy inside the bulb dS_{Int} for a given amount of absorbed microwave energy δQ [8, 9]:

$$\eta \cong \eta_C - \frac{T_L \cdot dS_{Int}}{\delta Q} \text{ with } \eta_C \cong \frac{T_H - T_L}{T_H} \qquad \text{Équation 5}$$

Hence, at same microwave power and same rate of entropy creation, the hotter is the core the better is the efficiency. Besides, we are about to enhance the acoustic sustentation of the plasma by improving the modulator and the electromagnetic coupling as well. As a result, higher core temperature are expected, and as a result, the higher efficiency as well.

Comparison with daylight

Daylight is by nature very variable. By clear sky, the maximum of spectral density of its emission lays generally around 490 nm. We use for the present comparison the global irradiation on a horizontal surface set at a height of zero above see by clear sky when the sun is at 30° above horizon:

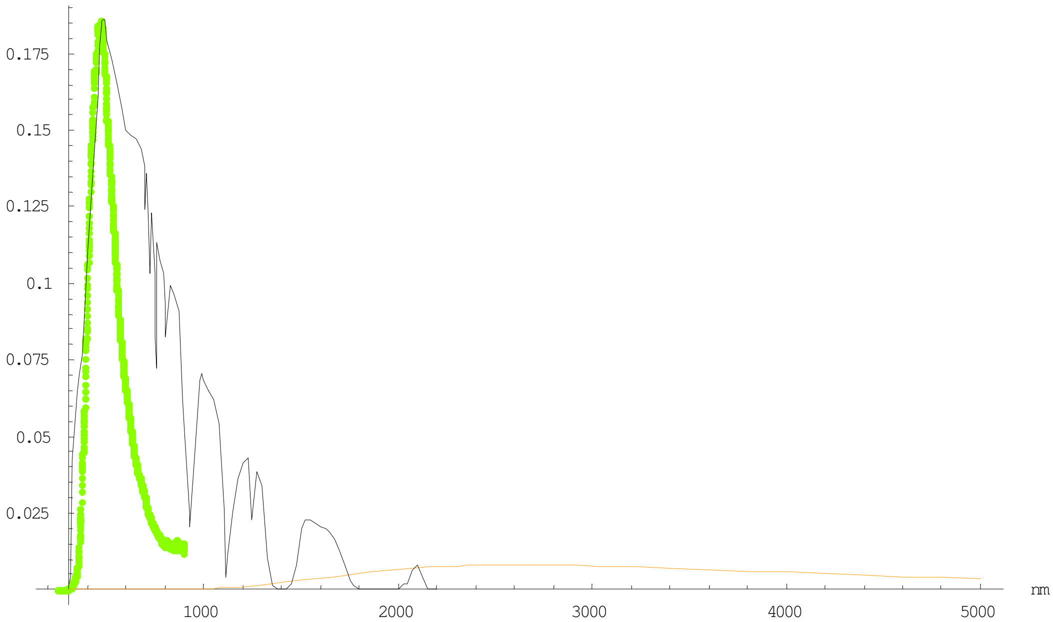

Figure 10 Spectrums of the sulphur lamp (in green and red) and of daylight (in black).

The resemblance with daylight by clear sky comes from the continuity of the spectrum (reduction of risk of metamerism) and nearness of their maximums as well (close colour temperature). But the lamp produces less ultraviolet and above all much less infrared (Figure 10). The weakness of ultraviolet in the spectrum of the lamp makes filtering unnecessary.

Concerning infrared, this type of radiations is a powerful mean of heat transfer. The emission of the bulb itself has been calculated using the Planck's law and the thermometry data the infrared camera has provided. Including this radiations, which adds to the one of the plasma as shown on Figure 10, we estimate that the infrared makes only a third of all the radiations [10]. As the heat dissipation is greatly dissociated from the light, the plasma lamp is particularly attractive in indoor lighting. This feature is most appreciated for lighting of sensitive goods or valuable fittings, like food, cloth, relics, paintings and pieces of art.

Although the Colour Rendering Index computed with standard CIE method is low for such sources, the spectrum of this lamp makes it unique, since continuous spectrums were only met by low efficient lamps (halogens: ~ 25 Lm/W).

Conclusion

As expected, the tuneable microwave bench allows testing bulbs which are very much different from the original. The results confirm that scaling down the size of the bulb allows reducing the power without degrading too much the performance. At a third of the full power of the lamp Solar-1000, the luminous efficiency of our motionless lamp is still at 68 lm/W thanks to the modulator, with a high color rendering index. If the magnetron had a cold cathode, this would have been 73 $lm \cdot W^{-1}$. At the same power, the solar-1000 outputs only 60 lm/W and a static bulb of standard size outputs a little less [11].

Fourier analyse of a signal provided by a fast photodiode has given evidence that the emission of the plasma is modulated. The plasma vibration is due to the ultrasonic wave made by modulating the magnetron. We have met cases where the temperature on the bulb is lower as the power is higher. This striking feature is the effect of acoustic sustentation of the plasma.

Our modulator has been tested on bulbs filled with two other chemical elements of the same column of the periodic table, selenium and tellurium. Both have lower energies of dissociation; we expect therefore that the plasma will be less hot at same light output. We have observed that each of this substance is shining strongly when heated. Indeed all the bulbs filled with selenium or tellurium were indeed preserved of any blister. Moreover, the effects of modulation we have first observed on the plasma of sulphur are also present in the plasmas of the two other substances (spectral shift towards longer wave length and enhancement of the thermodynamic efficiency). In all cases of pure substance, the modulation has increased the luminous efficiency by a factor 2.1 for sulphur, 4.7 for selenium and 2.8 for tellurium.

By comparative study of the content in sulphur, we observe first that the thermodynamic efficiency of the plasma is a decreasing function of this parameter. We have also observed that the increase of content shifts the spectrum towards longer wavelength, as in the case of a turning bulb [12]. Since such a red shift is also resulting from the modulation of the plasma, lower content are used to benefit from a higher thermodynamic efficiency. Besides, the CIE colour rendering index tends to decrease slightly when the colour temperature is pulled back to more convenient level (7'500K), but its stays beyond 80. The colour rendering is in fact always excellent since the spectrum is continuous and covers all the eye sensitivity range.

Besides we have found again a luminous efficiency beyond 80 lm/W like in the past experimentations [7]. We are comforted in the idea that the modulation allows enhancing the efficiency of a static bulb up to the performance of a rotating one. Without modulation, the points of measurement follow a linear growing function of the power, as in the past study [11]. The extrapolation says that the efficiency would be by 37 Lm/W at 650W, thus very close to the former (41 Lm/W). In addition, the performance ranking is consistent with the content variation (the spectrum is shifted in the red by increasing the content). As the experimental set-up was different, all these concordances give trust in our experimental techniques. It comes out of this study that the optimal content lays between 1.4 and 1.3 g/cc; this could however change with the modulator of second generation. By increasing the acoustic absorbed power, the spectral shift should be enhanced, and consequently, less stuff should be then put inside the bulb.

Moreover, we have taken pictures showing clearly the acoustic sustentation. For all the bulbs tested up to now, the modulation has enlarged the plasma. Now using a dark filter, one can observe that the plasma gets centred at some particular settings of the modulation. We have clear evidence of acoustic vibration. Indeed, an oscillation of the frequency of the modulation appears clearly on a number of samples of the signal taken with a fast photodiode mounted to detect variations of the light in the time.

By this study, we have also closed a technical question concerning the tuning of the microwave circuit after the discharge is ignited. Our analyse shows that this is not worth. But this part of the study has lead to the discovery that the Voltage Standing Wave Ratio is significantly smaller when the modulation is working.

In this study, we have also compared the emission of the sulphur plasma lamp with daylight. The plasma lamp has a continuous spectrum like daylight. This feature reduces greatly the risk of metamerism. Moreover, the spectral density passes by a maximum very close to the one of daylight. The lamp emission has hence a natural colour temperature. Although the Colour Rendering Index computed with standard CIE method is low for such sources, the spectrum of this lamp makes it unique, since continuous spectrums were only met by low efficient lamps (halogens: ~ 25 Lm/W).

As an addition advantage, the emission of the lamp carries much less energy in ultraviolet and most of all in infrared. This advantage holds in regards to incandescence lamps, halogens or classics. As the heat dissipation is greatly dissociated from the light, the plasma lamp is particularly attractive for in-door lighting. This feature is most appreciated when lighting sensitive goods or valuable fittings, like food, cloth, relics, paintings and pieces of art.

National collaboration

Solaronix SA (Aubonne, VD) mandated a patent expert to protect our invention (G. Courret, A.F. Meyer, M. Croci, Lampe à plasma, Patent pending). The collaboration with Solaronix is going on (bulb filling, modulator of second generation, etc). Furthermore, we are also working with Jelosil SA (Le Landeron, NE). This company is known by lighting industries from all over the world; it has provided machines for manufacturing bulbs of fused quartz to lighting majors (Philips, Osram, Sylvania,…) and also to LG Electronics (manufacture of the bulb of the Plasma Lighting System). Jelosil is going to provide us with bulbs.

International collaboration

We have been contacted by a large Korean trust, LG Electronics. Senior managers came to visit our laboratory and to have a demonstration of our prototype. Then we have visited LG Electronics in Korea concerning their Plasma Lamp System; we have been fully confirmed that LG management has a strong interest in our technology. We have proposed LG four mandates of development and they will answer by the end of the year.

Figure 11 At the restaurant with LG Management Staff (members of the PLS Division and of the Digital Appliance Research Laboratory)

Perspectives for 2007

The next version of modulator will enhance:

- the plasma sustentation in order to raise the core temperature of the plasma,
- the red shift in order to reduce the content.

Both features should increase the luminous efficiency of the lamp and allow lower nominal power.

In the present tests, the smallest bulb (1.15 cc) could not be ignited. This difficulty arises because of electronic recombination on the walls (Townsend's criteria). In agreement with the theory, the power of ignition became higher and higher as the bulb was sized down. Nevertheless, this problem has been solved by a new coupling. This feature has an additional great advantage: the grid that surrounds the bulb does not have to form a microwave reasoning cavity any more; it can be of any shape. Hence, this allows setting a reflector around the bulb, at closed distance, in order to reduce the size of the beaming optics. This will also bring additional cut in costs by suppressing the dielectric mirror and the cylindrical wire netting, since the Faraday closing can be achieved by coating the glassed aperture with a transparent conductive layer.

The confidential document 'Detailed program of extension up to September 2007' gives for more information on our perspectives for 2007.

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