High efficacy PDP

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Abstract

Main PDP panel efficacy improvement factors are discussed. A large panel efficacy improvement can be obtained through a combination of discharge efficiency improvement and phosphor improvement. Important design elements are a high Xe-content gas mixture, the application of a TiO_2-layer, and a new green phosphor with little saturation at high VUV-load.

In a 4-inch color test panel with a conventional stripe-type cell configuration a white efficacy of 4.4 lm/W and a luminance of 5000 cd/m^2 is obtained for sustaining at 250V in addressed condition.

1. Introduction

Efficacy improvement is a major objective in plasma display research to improve panel performance and reduce cost[1,2,3].

The efficacy of an alternating current surface-discharge plasma display (PDP) can be broken down into contributions from successive conversion factors [4]: vacuum-ultraviolet (VUV) photon generation in the discharge, VUV-capture by a phosphor coating, VUV-to-visible light conversion, and visible-light losses. The discharge is a predominant factor limiting the overall efficiency. For a default PDP design with a (Ne, Xe)-gas mixture containing about 5% Xe the discharge efficiency is typically 10%[5,6]. For higher Xe partial pressure the discharge efficiency increases markedly, however, the discharge firing voltage also increases significantly [5,7,8]. Clearly, higher voltages are disadvantageous for the electronics cost. Also, for higher operation voltages a decrease of the drive margin is expected [9]. Therefore it is desired to achieve a high efficacy at the lowest attainable firing voltage.

Another efficacy limiting factor, particularly at high VUV-load, is the saturation of Willemite, the default green phosphor [9].

In this article the influence on the panel efficacy of several cell design parameters is evaluated. Subsequently, the influence of the Xe-content in binary Xe-Ne gas mixtures and ternary mixtures of He, Ne, Xe, Kr, and Ar , the use of a TiO_2-layer underneath the phosphor, and the performance of a new green phosphor is investigated in 4-inch, mostly monochrome test panels. Finally, the acquired knowledge is applied in a color test panel.

2. Experimental details

The design of the 4-inch test panels with 256 columns and 64 rows, which resembles the one used in main stream commercial products, has been described previously [10]. The panel luminance and efficacy is measured for continuous sustaining at 50 kHz.

Several types of test panels are used, monochrome and color. In the monochrome green test panels, used to investigate discharge efficiency trends, a Tb-activated pentaborate phosphor is used. It was found that phosphor saturation for increasing UV-load, as reported for the Willemite phosphor [9], is no issue in this case, although the quantum efficiency is somewhat lower. In all monochrome test panels the channels are formed by powder blasting in a glass substrate, resulting in semi-circular channel geometry.

The influence of a TiO_2-layer underneath the phosphors is investigated in a color panel.

Finally, in the color panel, used to demonstrate a high panel efficacy at a high luminance, state of the art blue and red phosphors and a dedicated green phosphor are applied. This Tb-activated triborate, $YBO_3:Tb^{3+}$, combines a high quantum efficiency and little saturation at high UV-load[9]. The powder blasting process is adapted to yield larger more U-shaped channels, which implies lower wall losses. The reflective TiO_2-layer is applied under the phosphor layer to enhance luminance and efficacy. The luminance and efficacy of the color panel is measured in addressed conditions.

3. Results and discussion

3.1 Xe-content

Although the increase of the efficacy for increasing Xe-concentration, or gas pressure, is well known [5], panel data are rare. The measured dependence of the test-panel efficacy and the firing voltage on the Xe-content in binary Ne,Xe-mixtures is shown in figure 1, for a Xe-concentration series at 600 hPa. The efficacy is normalized with respect to its lowest value and measured at a high sustain voltage of 320 V, to allow sustaining well above the minimum sustain voltage at highest Xe-concentration. As expected, the efficacy increases for increasing Xe though there is a "leveling off" at a Xe content of approximately 50 %. The leveling off is anticipated. As already noted above, the typical discharge efficiency for default conditions is 10 %, which is the result of a multiplication of a 30 % electron heating efficiency and a 35 % Xe-excitation efficiency [5,6]. This limits the theoretical gain factor to 10. Naturally, ion-heating losses cannot be completely avoided since the discharge requires ionization. Also, the electron energy will be distributed, and consequently the Xe-excitation efficiency is sub-optimal for parts of the spectrum. Therefore a leveling-off at higher gain factor is expected.

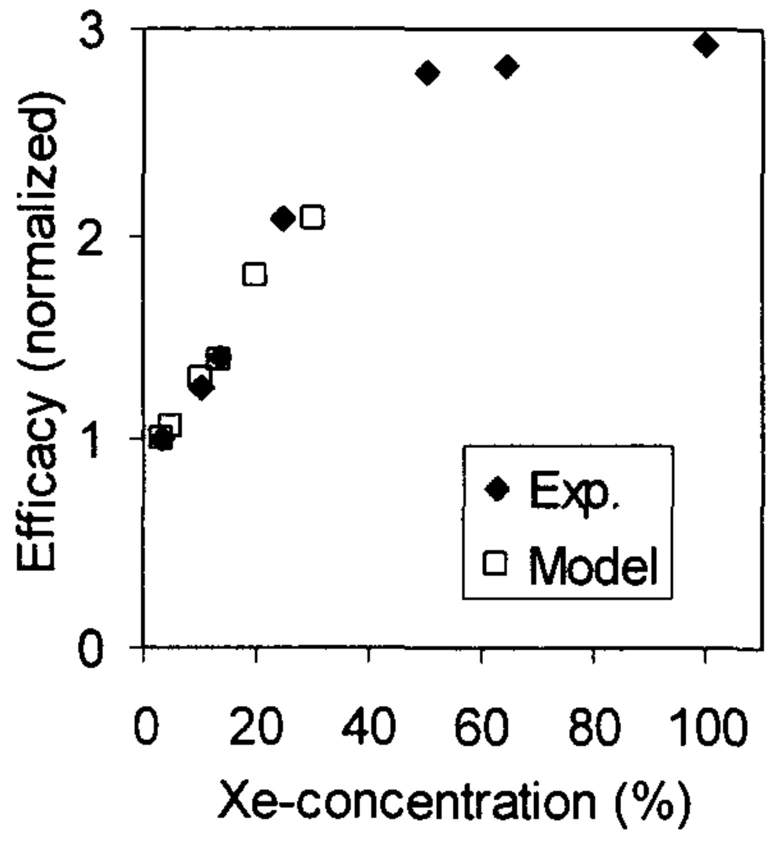

FIG.1 Dependence of the experimental panel efficacy, and the simulated discharge efficiency (both normalized to their lowest value) on the Xe concentration.

Present-day commercial panels apply a Xe-concentration of 4 to 5 % at a pressure of about 600 hPa. A significant efficacy improvement, about a factor 3, thus appears conceivable. Simulation results of the normalized plasma efficiency, for Xe-concentrations up to 30%, and obtained using a 2D numerical fluid model [6,10] are also shown in figure 1. Although the voltages and pressures in the simulation are somewhat different, 270 V and 650 hPa respectively, the experimental trend is well reproduced. The model allows an evaluation of several contributions. The plasma efficiency is the product of the electron heating efficiency and the Xe-excitation efficiency and both contribute about equally to the overall increase of the plasma efficiency [11].

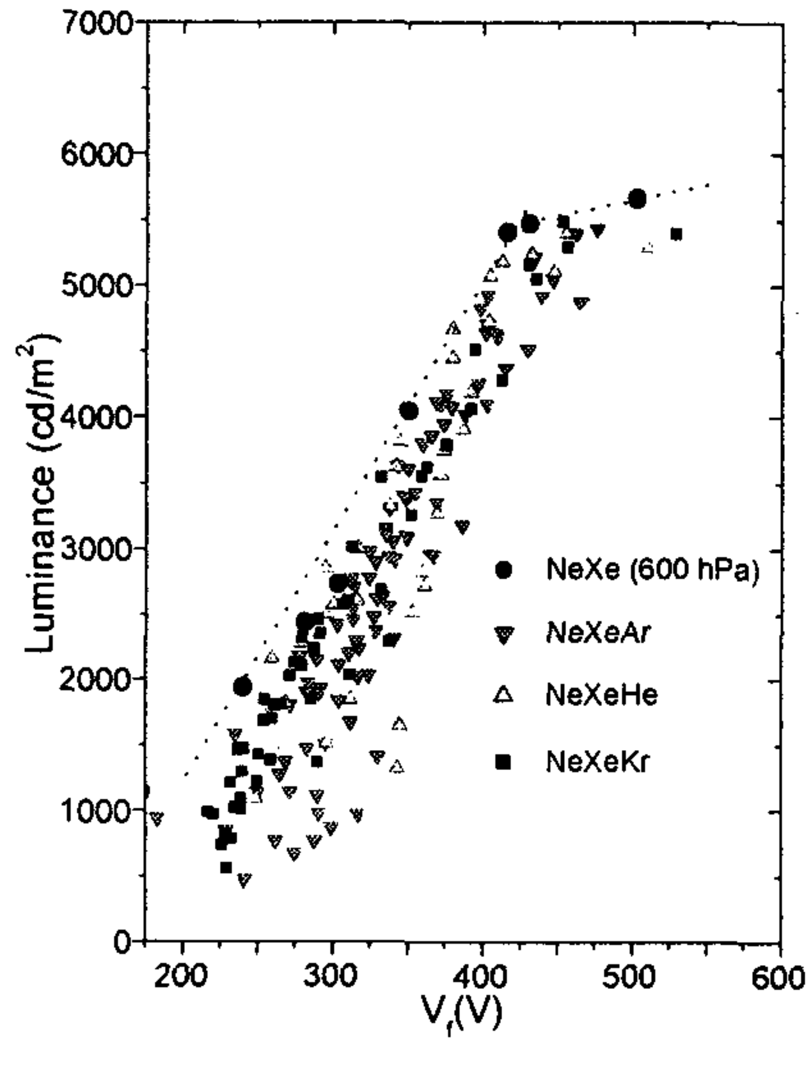

Fig 2. Luminance versus firing voltage for various gas mixtures at various pressures.

Next, ternary gas mixtures, containing Ne,Xe and either Kr, Ar, or He, are explored [8] . A full build-up of the wall charge occurs for the sufficiently high sustain voltage. In that case the power input is not affected by the gas mixture composition and the luminance variation is a good monitor of the efficacy changes. Luminance data taken at 320V from monochrome test panels with various Xe-concentrations and pressures are plotted versus the firing voltage in figure 2 to illustrate their trade-off. It is seen that for Ne,Xe-mixtures optimal luminance (efficacy) values are realized at the lowest firing voltage. Adding a third gas may increase the efficacy at low Xe-concentration, it also increases the firing voltage to such an extent that the data point stays below the Ne,Xe-line in figure 2. In other words, any increase in efficacy which can be achieved by adding a third gas can also be achieved by increasing the Xe concentration in a binary NeXe mixture, at the expense of a smaller firing voltage increase.

3.2 TiO_2-layer

In figure 3 the ratios of efficacy, visible luminance, and IR-emission of color test panels, with and without a TiO_2-layer underneath the phosphor is compared.

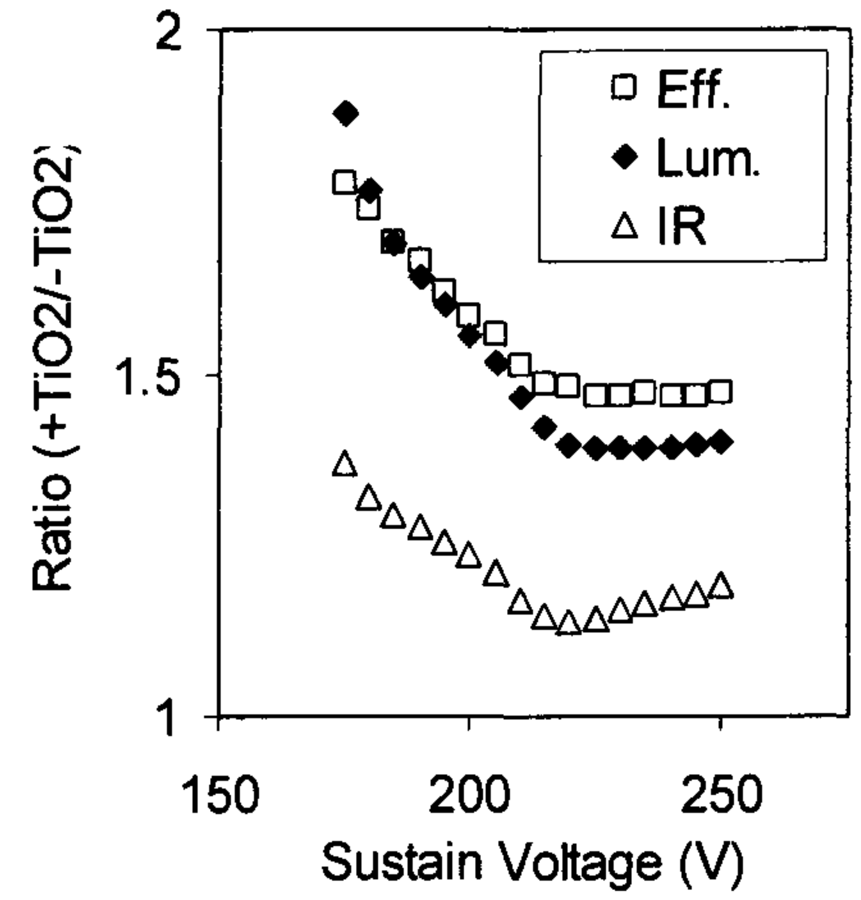

FIG.3 Comparison of the ratios of the efficacy and the visible luminance and IR-emission for color test panels with and without a TiO_2-layer underneath the phosphor.

The efficacy (squares) is seen to increase by about a factor 1.5 upon addition of a TiO_2-layer underneath the phosphor. The luminance (diamonds) and the efficacy ratios show a similar dependence, indicating that the power input is not affected by the TiO_2-layer. For panels without such a layer the visible light emission at the backside is about 20%. Thus, recovery of this backside emission cannot fully account for the efficacy improvement, which also appears to be dependent on the sustain voltage. Apparently the discharge efficiency increases. Also the voltage dependency of the ratios itself indicates that the improvement involves the discharge.

As noted above the discharge efficiency is the product of the electron heating efficiency and the Xe-excitation efficiency. An indication for an increased Xe-excitation efficiency can be derived from the panel emission [11].

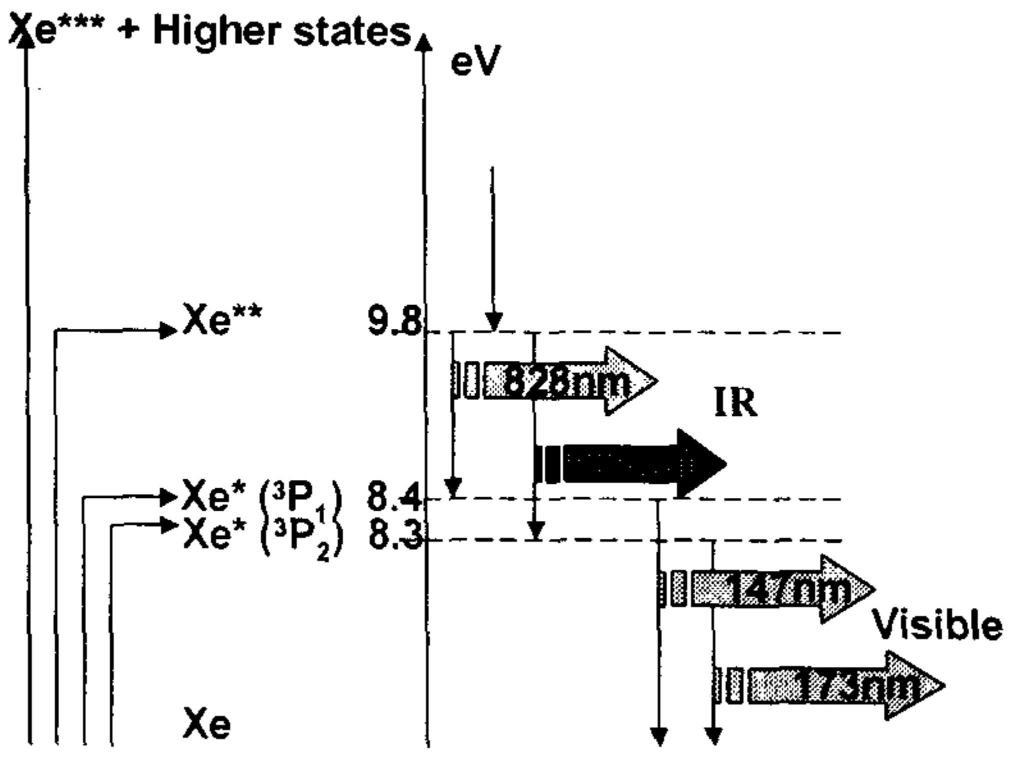

FIG.4 Xe-excitation diagram.

A typical spectrum contains emission in the visible region from the phosphors, and Xe-emission with interesting lines at 823 nm and at 828 nm in the near infrared (IR), is also prominent (see figure 4). The 828 nm line is due to relaxation from a higher excited Xe-state to the level Xe($^3P_1$), the source of the resonant 147 nm emission, and the 823 nm line is due to relaxation from a higher excited Xe-state to the Xe($^3P_2$) metastable level, a precursor for Xe-dimer radiation at 173 nm.

Xe is excited in higher Xe*-levels as well as directly into the Xe($^3P_1$) and Xe($^3P_2$) metastable levels; see figure 4. Direct excitation in these levels involves less relaxation losses and no 823 nm or 828 nm emission. Finally, both resonant and dimer radiation excite the phosphor with a comparable efficiency and the visible emission intensity can be taken as a measure for the total VUV-intensity.

The IR-ratio also plotted in figure 3 is much smaller than the Lum.-ratio. This suggests that the creation of visible luminance involves less IR-generation, i.e. a larger fraction of direct excitation into the lower Xe($^3P_1$) and Xe($^3P_2$), corresponding to an increase of the Xe-excitation efficiency. The roughly corresponding voltage dependence of the ratios implies that an increasing Xe-excitation efficiency is indeed a dominant contribution.

3.3 Green phosphor saturation

The excitation of the luminescent centers in PDP phosphors proceeds by inter-band absorption in the host lattice. The inter-band host absorption is very high. For instance, for YVO_4 an absorption coefficient of 10^6 cm^{-1} was reported, implying that the bulk of the UV radiation is absorbed within the first 10 nm from the surface. [12] Such a small penetration depth of the exciting radiation causes a high sensitivity for surface deactivation. Furthermore, a high sensitivity for saturation due to activator depletion results, especially if the decay time of the luminescent centers is rather large. Decay time values of several milliseconds are common, and at a sustain frequency of 100 kHz consecutive pulses may cause a progressive depletion. Thus, the Willemite phosphor, with a relatively long decay time of about 15 ms, is sensitive to saturation at high VUV-load, implying an efficiency decrease at high luminance. Indeed, the saturation of Willemite for default PDP excitation conditions has been established.[9] Therefore a green phosphor with a faster decay time, also beneficial for a decrease of the green after image effect[13], was developed. In figure 5 the efficacy as a function of sustain frequency is compared for Willemite and the newly developed $YBO_3:Tb^{3+}$ (YBT)with a decay time of about 9 ms. For each phosphor the efficacy is normalized per pulse to its low frequency value. Willemite shows a decrease of the luminance starting at about 2 kHz, due to saturation. These data were obtained for continuous sustaining at 225 V and a 10% Xe in Ne gas mixture.

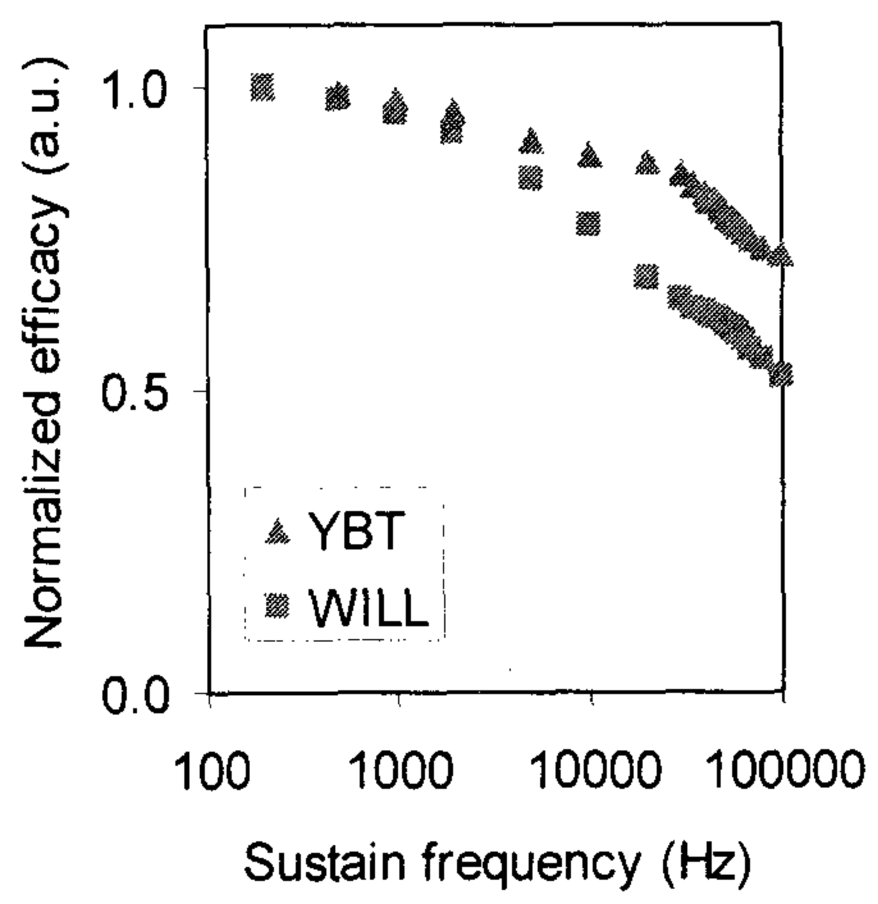

FIG.5 Normalized efficacy as a function of the sustain frequency for Willemite (default) and YBT phosphors.

It is apparent that the use of the newly developed $YBO_3:Tb^{3+}$ (YBT) implies a significant efficacy increase at high VUV-load, although some saturation remains. Apart from the continuous decline that is attributable to phosphor saturation, the curves in figure 4 also show some substructure. This is tentatively ascribed to priming induced changes in discharge efficiency[14].

3.4 High efficacy color panel

The acquired knowledge is applied in 4-inch color test panels, where the new green phosphor, a TiO_2-layer underneath the phosphor, and a high Xe-content are combined. The dependence of panel efficacy and luminance on the sustain voltage is shown in figure 6. In addressed condition, an efficacy of 4.4 lm/W and a white luminance of about 5000 cd/m^2 are concurrently obtained at a sustain voltage of 250 V for a panel containing a 30% Xe in Ne gas mixture. These values represent a large improvement in comparison with present day commercial panels, where about 1.5 lm/W

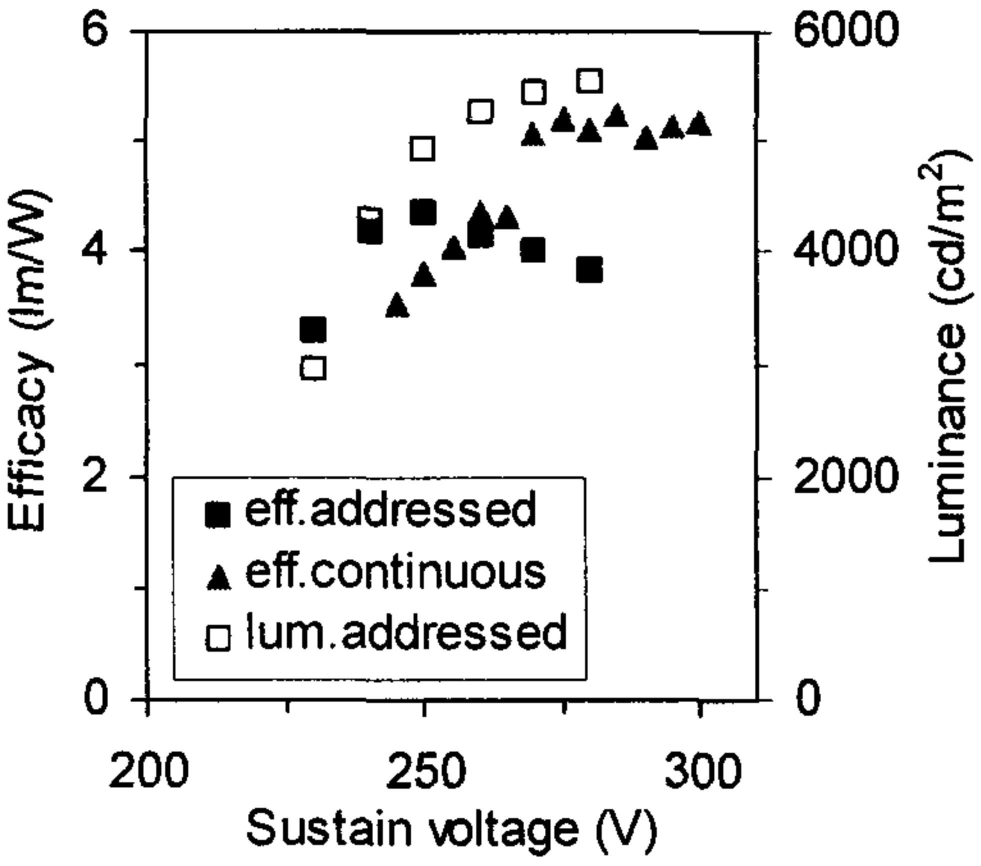

FIG.6 Efficacy and luminance as a function of sustain voltage for two high Xe partial pressure color test panels: measured in addressed conditions for a 30% Xe in Ne gas mixture, and measured in continuous sustain condition for a 50% Xe in Ne mixture.

and 600 cd/m^2 is usual. Moreover, in continuous sustaining condition at V>270V a panel efficacy of more than 5 lm/W has been realized in a 50% Xe-panel. Experiments in addressed condition at this high Xe-concentration are in progress.

The concurrence of a high luminance and a high efficacy further confirms that plasma saturation is not significant for practical AC-PDP operating conditions[15].

4. Conclusion

It is concluded that, the discharge efficiency, for a cell geometry that is used in present-day commercial products, can be increased significantly by using a larger Xe-content and a TiO$_2$-layer underneath the phosphor. The combination of the efficient generation of VUV-light with phosphors that show little saturation at high VUV-load results in a large increase of the panel efficacy.

In addressed conditions, an efficacy of 4.4 lm/W and a white luminance of about 5000 cd/m^2 are concurrently obtained at a sustain voltage of 250 V. Moreover, at V > 270V a panel efficacy of more than 5 lm/W has been realized in continuous sustaining condition.

The discharge efficiency increase is attributed to an increase of both the electron heating efficiency and the Xe-excitation efficiency. Plasma saturation is not limiting. However, although the basic physical phenomena involved in the energy conversion processes appear rather straightforward, a detailed understanding is not yet available and further studies of PDP characteristics can be exploited to improve product performance at reduced cost.

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