# A Parametric Study on Secondary Electron Emission from MgO

*Sang-Hoon Yoon and Yong-Seog Kim*
**Dept. of Materials Sci. and Eng., Hongik University, Seoul 121-791, Korea**
**Phone:82-2-320-1616, E-mail: yskim@wow.hongik.ac.kr**

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**ABSTRACT**
*Using the theoretical model of Auger electron emission, effects of MgO properties which include band gap energy, escape probability, gas ion, and doping elements on the yield of secondary electron emission were examined. The results indicated that the band gap of MgO must be decreased and escape probability must be enhanced in order to increase the yield of secondary electrons from Xe ions and that may proved to be a critical for achieving high luminance efficacy in ac-PDPs.*

## INTRODUCTION

It has been demonstrated that the luminance efficacy of ac-PDPs could be enhanced to three times the typical efficacy by increasing Xe content of the discharge gas up to 50% [1]. This is due to improved efficiency of VUV generation at high Xe contents. The increase in Xe content, however, results in higher firing voltages, thus, raising the cost of electronic components and increasing the power consumption of the drive circuit as well as displacement currents in the panel. Power loss caused by panel capacitance is proportional to the frequency, panel capacitance, and second power of the voltage. Thus, the higher firing and sustaining voltages lead to higher non-discharge related power loss.

The increased firing voltage at high Xe contents is caused by negligible yield of secondary electrons by Xe ions from MgO films. The yield of secondary electrons from Xe ions has been measured to be close to zero [2-3]. As the ionization energy of Xe atoms is small compared with other inert gases, they do not satisfy the cut-off rule of secondary electron emission as stated in following equation:

$$E_i > 2(E_g + \chi) \quad \text{eqn 1.}$$

where $E_i$ is the ionization energy, $E_g$ is the band gap energy and $\chi$ is the electron affinity of MgO. If typical MgO values are inserted into eqn 1), for example, $E_i$ = 12.13eV, $E_g$=7.8eV, and $\chi$ =0.85eV, it is evident that Xe ions do not satisfy the cut-off rule of secondary electron emission. Therefore, the basic physics dictate us that emission of secondary electrons is not feasible from MgO by Xe ions.

There has been numerous attempts to make the emission of secondary electrons possible with Xe ions during glow discharge of ac-PDPs [4-9]. Those attempts may be grouped into two categories: one is to create defect levels within MgO band gap and the other is to develop new materials such as SrO, and (Ca, Sr)O. Motoyama et al[4] has shown that creation of F-type defect levels in MgO by controlling oxygen partial pressure during its deposition can reduce the firing voltage almost 100 volt with Xe discharge gas. Theoretical modeling of the F-type centers on the yield of secondary electrons, however, predicted the yield to be in a range of 0.0003-0.027. Although the theoretical yields were obtained by assuming extremely high defect concentration (0.2 for F and F+ centers, respectively. Normally, the fraction is less than a few hundred ppms), they are insignificantly small compared with those of Ne ions.

Whang et al[6] doped MgO with Si to create defect levels within the band gap. They showed that that the ion-induced secondary electron coefficient is increased about 25% with the Si-doping of MgO. They claimed that the increase is well correlated with the reduced discharge voltage ( ~15 V) with Si-doped MgO. Lee et al [7] also showed that the firing voltage could be decreased significantly with doping elements of which information was not revealed in their paper though. They also showed that the doping does not necessary lead to the reduction of firing voltages. These conflicting results warrant the detailed analyses on the role of defect levels for the emission of secondary electrons.

The other category of approach to enhance the emission of secondary electrons from Xe ions to use SrO-based materials. Uchiike et al [8] showed a possibility of using SrO as the electron emission material for Xe ions. Although the backgrounds for selecting such material were not elaborated in the paper, the results clearly showed that the

firing voltage could be decreased by using the material. Motoyama et al[9] showed that its yield of secondary electrons from Xe ions can be as good as Ne ions because of its small band gap energy (6.8eV vs 3.0~5.9eV). However, actual replacement of MgO with SrO was not materialized because of poor resistance of SrO against sputtering of high energy ions in the glow discharge.

These previous experimental results suggest that the yield of secondary electron emission may dependant on the concentration of defect levels within the band gap and band gap energy of MgO. These experimental results, however, are scattered in nature and conflicting each other sometimes, making very difficult to develop materials for electron emission suitable for discharge gases of high Xe content. Thus, in this study, a parametric study was conducted in order to elucidate the effect of material's characteristics on the yield of secondary electron emission. A simple model of Auger neutralization proposed by Hagstrum[11] was used. The materials parameter investigated include band gap energy, type of ion, and escape probability.

## THEORETAL MODEL of AUGER EMISSION

Figure 1 shows a schematic illustration of electron emission mechanisms from insulator by an approaching ion: Auger neutralization and resonance neutralization followed by deexcitation process. In this study, electron emission by Auger neutralization process (step 1 & 2 in Fig. 1) was considered only. The band structure was assumed to have similar values to that of MgO as shown in Table 1. In addition, the valence band was assumed to have a constant density of state irrespective of its energy. A previous study [10] showed that the density of state function does not influence significantly the yield of the secondary electron emission.

Table 1. Materials properties of insulator

| property | Band gap | Valence band width | Electron affinity |
|---|---|---|---|
| eV | 7.8 | 5.0 | 0.85 |

Figure 2 shows the effect of ions on the yield of secondary electron emission. The results indicate that ionization energy of Ar, Kr and Xe is not large enough to emit secondary electrons by Auger neutralization process. This is the main reason why we have higher firing voltages with discharge gases with high Xe content.

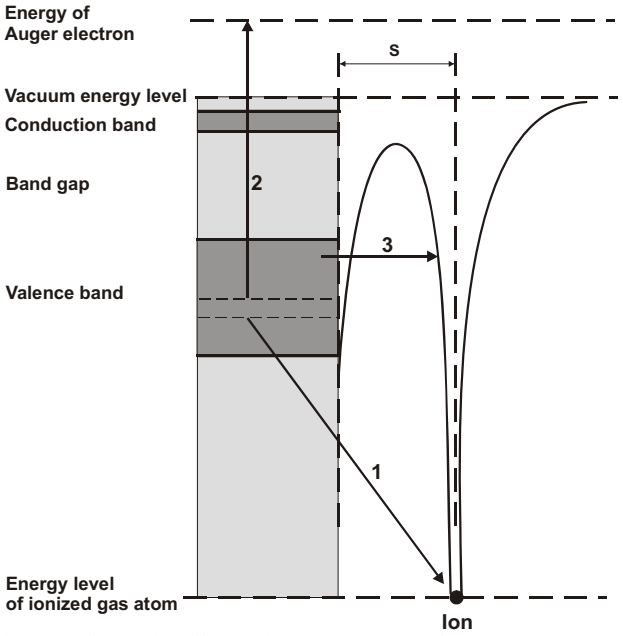


Fig.1. Schematic illustration of Auger electron emission mechanism.

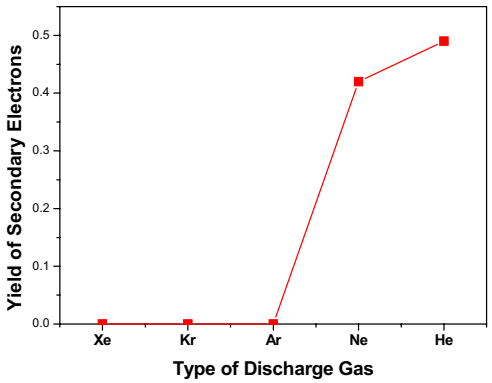


Fig. 2. Effect of discharge gas type on the yield of secondary electron emission.

Fig. 3 shows the effect of band gap energy on the yield of secondary electron from the Auger neutralization reaction with Xe ions were predicted. The secondary electron yield remained zero until the band gap energy is decreased to less than 5.2eV. As the band gap energy gets smaller than that value, a slight reduction band gap energy resulted in significant increase in the yield. Thus, it would be desirable to reduce the band gap of MgO in order to have the secondary electrons from the Auger neutralization reaction of $Xe^+$ ion. The secondary electrons emitted from Auger neutralization reaction of $Xe^+$ ions are essential in keeping

the firing voltages low with discharge gases of high Xe contents.

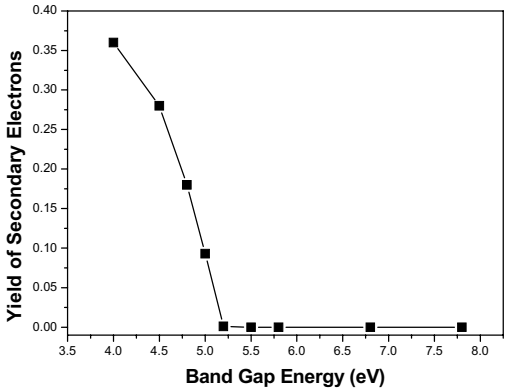


Fig.3. Effect of band gap energy on the yield of secondary electrons from the Auger neutralization reaction with Xe ions.

Impurities, dopants, or defects within MgO can have a significant influence on the yield of secondary electron emission by affecting the escape probability function. Since MgO is a material of mostly ionic bonding characteristic, the impurities, the dopants, or the defects have effective charges. Therefore, those disorders can trap or scatter free current carriers such as the excited electrons by the Auger neutralization reaction. The higher the density of such disorders, the higher the probability of trapping or scattering of the excited electrons. In addition, $F^+$-type centers can also trap an electron by electro-static attractive force, to decrease the population density of excited electron and that will reduce the yield of secondary electron emission. In addition, the scattering reaction may reduce the energy of some excited electrons below the vacuum level. This should decrease the density of electrons excited above the vacuum energy level and will also reduce the yield.

Using several escape probability curves proposed by Hagstrum [11] in Fig. 4, the effect of escape probability on the yield of secondary electron emission was examined. The curve 3 represents the MgO with high purity and low defect concentration and the curve 1 MgO with low purity and high defect concentration. Naturally the material with high escape probability (curve 3) showed a higher yield of secondary electron emission (Fig. 5). With the increased impurities and defects, the yield can be decreased dramatically, indicating the quality of MgO film produced by e-beam evaporation process must have better crystallinity and high purity in order to have enhanced yield of secondary electrons.

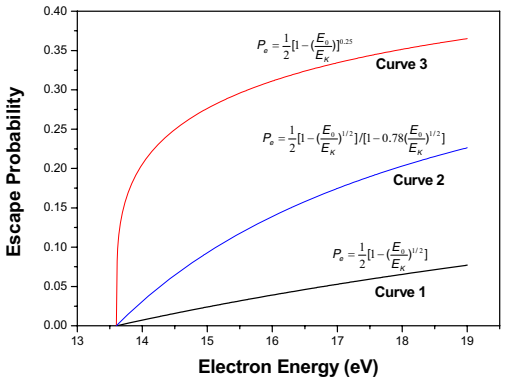


Fig. 4. Several escape probability curves proposed by Hagstrum [11 ].

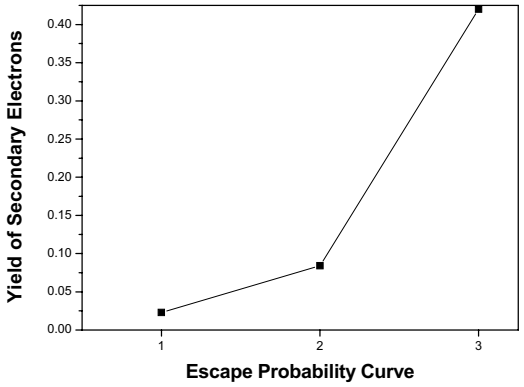


Fig. 5. Effect of escape probability on the yield of secondary electron emission.

Finally, the disorders like impurities, dopants, and defects in MgO create energy levels within the band gap. For example, the F-type centers are located about ~3eV above the top of the valence band and contain one or two electrons. The electrons trapped in those energy levels may be excited above the vacuum level with less energy than the electrons in valence band. The electrons trapped at those defect levels, therefore, may be able to contribute to the emission of secondary emission.

With the defect, there are four possible Auger neutralization reactions that may occur with $Ne^+$ ion when MgO has a F-type center as shown in Fig. 6. According to the time-dependant perturbation theory, the probability of transition of electron from MgO to the approaching ion is proportional to the density of state. The probability of such

electrons at trapped levels should be proportional to its mole fraction as shown in following equation:

$$\gamma_i = N_v^2\gamma_{vv} + N_vN_F(\gamma_{vF} + \gamma_{Fv}) + N_F^2\gamma_{FF} \quad \text{eqn. 2)}$$

where $N_v$ and $N_F$ is mole fraction of electrons at valence band and at F-type center, respectively. In typical case, $N_F$ is far less than 1,000 ppm ($N_F$=0.001) and it can be seen from eqn. 2) that the contribution from the electrons trapped at defect levels to the emission of secondary electron would be negligible. Therefore, it would be desirable to have high quality and low defect concentration MgO in order to achieve improved yield of secondary electron emission.

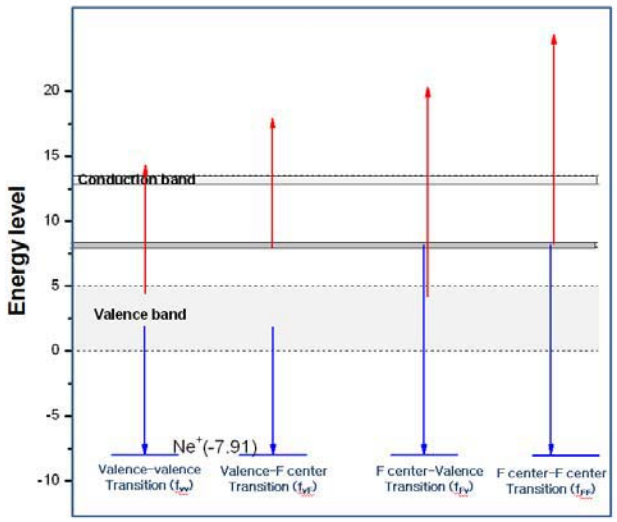


Fig. 6. Reaction types of $Ne^+$ ions approaching MgO with a defect level within band gap.

## SUMMARY

This theoretical study showed that the band gap energy of electron emission materials must be reduced to less than a critical value and the impurity and defect contents must be reduced in order to emit secondary electrons from the Auger neutralization reaction from Xe ions. Thus it is necessary to develop new material of low band gap energy in order to achieve high luminance efficacy of PDPs.

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