Journal of Electrostatics 90 (2017) 54–60

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Characteristics of VUV ionizer in a vacuum chamber of flat panel displays

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A R T I C L E I N F O

Article history:
Received 9 November 2016
Received in revised form
29 August 2017
Accepted 8 September 2017

Keywords:
Ionization
Vacuum
Ions
VUV ionizer

A B S T R A C T

Flat panel displays are often exposed to the electrostatic damage during various panel manufacturing processes. In this paper, we report the electrostatic discharge failure in a unique process condition of OLED display process during which the substrate of OLED display is turned over while in the vacuum chucking condition. In order to solve this failure, we adopted newly developed technology of VUV (Vacuum Ultraviolet) radiation to neutralize the electrostatic electricity. This technology generates ions and electrons by ionizing residual molecules in vacuum chamber such that it enables the charged substrates to be neutralized in the chamber. While this new neutralization method is certainly effective in high vacuum process, the lifetime and performance of the VUV ionizer are not validated. To understand the lifetime and performance of VUV ionizer, we conducted the experiments in the vacuum chamber of an 8th generation display facility with various operating time of UV lamp. We analyzed the characteristic of VUV lamp and suggested the neutralization mechanism of VUV ionizer in a low pressure. Based on the experiments, this new neutralization method performs well under the high vacuum environment and is able to completely reduce the electrostatic potential down to 0 V within a short time.

1. Introduction

Electronic visual displays have been used around the world and information displays are very essential devices for human life. Smartphones, Tablets, TVs and Wearable displays exploit LCD (liquid crystal display) and OLED (organic light emitting display) technologies for the display panel. The substrate of common display is a glass, which is known as a highly insulating material capable of both generating a high level of electrostatic charge and maintaining the charge for a relatively long time [1]. In manufacturing of display panel, air ionization has been recognized as the most effective means of neutralizing static charge on glass substrates. Air ionizers using soft X-ray and corona discharge have been widely utilized to generate charges in atmosphere [2–5]. Air ionizer works properly under atmospheric pressure, but are not suitable for vacuum condition. Recently, OLED panels become thinner, lighter and flexible. Also, flat panel displays are more likely to adopt LTPS (low temperature poly-silicon) or IGZO (indium gallium zinc oxide) rather than a-Si base TFTs (thin film transistors). The evolutionary changes of display technology make the panel manufacturing process more electro-statically sensitive and complex. Therefore, to protect sensitive display devices [6], the flat panel industry is in need of a high performance ionizer for use in a vacuum environment.

VUV ionization technology introduced a long time ago [7], but, this technology has not attracted much attention in semiconductor and display industry. Because many vacuum processes consist of plasma process, and plasma treatment is the more effective way to eliminate electrostatic charge than any other methods such as ionizer. However, since recent OLED manufacturing process avoids plasma treatment in high vacuum condition, an alternative method is needed. A VUV ionizer is known for ionizing solution in vacuum condition, but it is difficult to find studies of neutralizing characteristics with quantitative data in its usage.

In this work, an experimental study of understanding the VUV ionizer has been performed. This paper shows the limitations of using X-ray ionization technology to neutralize charge on glass depending on vacuum conditions and ESD failure during high vacuum transfer process. Finally, this paper proposes an evaluation method of VUV ionizer with a charge plate monitor in 8th generation display vacuum chamber.

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https://doi.org/10.1016/j.elstat.2017.09.001
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2. Background theory for static elimination by VUV ionizer

2.1. ESD damage in vacuum transfer

Fig. 1 shows the 3 basic steps of OLED process in chamber without vacuum break [8]. The first step is a substrate pre-treating process is cleaning glass substrate for subsequent evaporation fabrication with baking and plasma treatment. The Second is OLED deposition of thin film molecular organic electronic devices between two electrodes, which emit light when electric field is applied to OLED device. The third step is OLED encapsulation process to protect OLED devices from external environments such as moisture, air, etc. The glass handling in each step is done in vacuum condition; the typical vacuum pressure is 10^{-4} Torr.

Fig. 2 shows the evaporation diagram and substrate direction; Up-Deposition, Down-deposition, and side deposition. Among three approaches [9], the direction of up-deposition is mainly used. It is because side-deposition and down-deposition bring particle contamination and more maintaining is required. For the Up-deposition process, the organic material is heated in crucible and evaporated through a novel onto the downward facing of the glass substrate. The back side of the substrate is fixed to stage or chuck for stable evaporation process, If the strength of attachment between the substrate and the chuck is lower than the gravity force, the substrate would sag in the middle or is completely separated from a holding object during the substrate rotation process. Thus, the substrate should be strongly attached with chuck. Eventually, it brings a serious issue for electrostatic charging and discharge in substrate detaching or separation process.

It is known that static charging issues are occurred whenever two surfaces in close contact are separated. Therefore, the electrostatic issues happened during a glass separation process, which is followed by OLED deposition or when turning over the glass process in vacuum transfer chamber. Fig. 3 is an example of ESD damage in separation process from chuck after OLED deposition. Various devices are damaged along the gate line by generated charges from its backside as shown in Fig. 3(b).

2.2. Principles of VUV ionizer

Even at high vacuum, some residual atoms or molecules remain in the vacuum chamber and can be ionized by VUV radiation ionizer using ultraviolet light. VUV radiation has been found to introduce photoionization effect and the physical process in which an ion is formed from the interaction of a photon with an atom or molecule, can make electron-hole pair of ion generation [10]. A simple photoionization reaction can be expressed as

$$R + h\nu = R^{+} + e^{-}$$

where R is the residual molecular in a vacuum chamber, h is Planck's constant and ν is the frequency of the light in Hz, R^{+} is the ion of residual molecular, e^{-} is the photo-emitted electron.

The electrons and ions generated by VUV irradiation may be separated due to their initial energies and the presence of an electric field within charged substrates or chamber wall as shown in Fig. 4. When a DC voltage is applied at CPM electrode, the electrons or ions drift velocity will increase the speed proportionally to the strength of the electric field. Therefore, if the charge generates on a surface of product, electrons and ions are attracted into the product and it becomes neutralized. The core techniques of ionization performance are VUV lamp that is low-pressure lamp filled with noble gases and excited by microwave or radio frequency discharge. It provides a simple means for a stable, continuous source of VUV photons that may be used to ionize a vapor plume of organic molecules. Even though the VUV ionizer is known to be the most effective way of neutralizing static charges in vacuum, more investigation is required to better understand the neutralization mechanisms and to develop ways to enhance lamp efficiency.

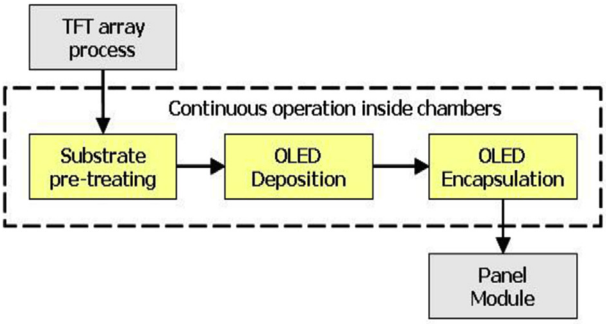

Fig. 1. OLED process flow.

3. Experiment

3.1. Experiment apparatus

The experiments were carried out in a vacuum chamber for 8th generation LCD of which dimension is 1500 mm × 2600 mm to understand the performance and lifetime of VUV ionizer (L12542, Hamamatsu, Japan) as shown in Fig. 5 (c). The CPM (156A, Trek, USA) was installed in a vacuum chamber and VUV ionizer was mounted at the side of the chamber wall instead of viewing port to radiate UV from the sidewall to the inside of the chamber. The CPM is placed in the edge of the chamber, so that the distance of CPM far from VUV ionizer was 2600 mm and the maximum distance was 3100 mm in a diagonal direction not to directly hit by vacuum UV as shown in Fig. 6(b) and (c). The UV radiation neutralization method is mainly used to clean dry air (CDA) and the condition of vacuum pressure was from 10^{2} to 10^{-5} Torr. The decay test involves in the charging the test object to ±1000 V then recording it's time to decay to 100 V.

3.2. Measurement of VUV irradiance

In this work, five VUV ionizers were used each with a different operational history having been used prior to the start of the experiment for a period of 1500 h, 3000 h, 6000 h, 9000 h and new one, respectively. The difference of each vacuum UV lamp can be expressed the irradiance which is a measure of the energy output from lamp and depends upon the intensity and distance of the light source by considering the common unit. To identify the effect of VUV ionizer in the same system according to operating time, we measured the irradiance of the UV lamp for each ionizer by using an UV monitoring system (VUV-S172, Ushio, Japan). The irradiance E expresses radiation power received by the unit area of the illuminated surface. The unit of irradiance is $\mathrm{mW/cm^2}$.

4. Results and discussion

4.1. Irradiance of vacuum UV lamp

The irradiance dependency of a vacuum UV ionizer used in the evaluation is presented on Fig. 7(a). The irradiance versus distance dependency can be exhibits an inverse square law dependence of which the general character applies to many other phenomena such as electrostatic field of point charges. The result in Fig. 7(b)