Atmospheric Plasma application for dry cleaner, PR ashing & PI rework in the 5th generation and beyond LCD production

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Abstract

An AP plasma technology has been developed for the application of dry cleaner, PR ashing and PI rework in the large glass size. The technology is cost effective, environment friendly, and best fits for coming generation LCD production since the design is easily scalable to bigger size glasses. Surface cleaning results based on the contact angle study has been presented for 5th generation LCD bare glass. PR ashing results and various parametric studies have been also presented.

1. Introduction

TFT LCD business has grown up remarkably among Korea, Japan, and Taiwan. It is expected to grow continually further. The driving forces for the TFT manufacturing are larger glass size, lower cost, and better yield. LCD manufacturing equipment suppliers are providing innovative solutions to support much of this trend.

Currently LCD manufacturer widely adopts dry surface cleaning, utilizing VUV radiation from either 172nm Xe excimer lamp or low-pressure mercury lamp (185nm and 254nm). VUV radiation is known to remove the surface hydrocarbons through oxidation from UV/O_3, to improve the photoresist (PR) adhesion, and to remove PR residue[2-4,10,11]. However, the COO(cost of operation) is very high due to the high cost of VUV lamp replacement.

Current LCD PR ashing technology summarized in Table. 1 relies on either dry ashing or wet stripping. Wet striping has low initial equipment cost, but needs constant usages of ultra pure chemicals or solvents, disposal of large quantities of organic waste, and therefore environmentally hazardous. Dry ashing/PI rework has low running cost, good uniformity, and environmentally friendly, but has high equipment cost and low throughput [1].

For cost effective and environment friendly technology, there has been great effort to apply atmospheric pressure (AP) plasma for LCD manufacturing such as dry cleaning and PR ashing / polyimid (PI) rework[8].

In this paper, we present the AP plasma technology based on dielectric barrier discharge (DBD) for the application of dry cleaning, surface treatment, and PR ashing/PI rework. The presented technology is cost effective and environment friendly for these applications.

	Dry	Wet
Processing	Low-pressure plasma (PE, RIE)	Chemical
Gas/Chemical	$O_2(CF_4)$	H_2SO_4 etc.
Ashing Rate	<8000Å/min	Tact time = 40 sec/glass
Uniformity	<10%	<10%
Equipment Price	~$1.7 Million	~$1.1 Million
Consumable Cost	Low	High
Market Share	40%	60%

Table 1 Comparison of Wet and Dry Ashing Equipment

2. Experimental

A schematic of AP plasma module is shown in Fig. 1.

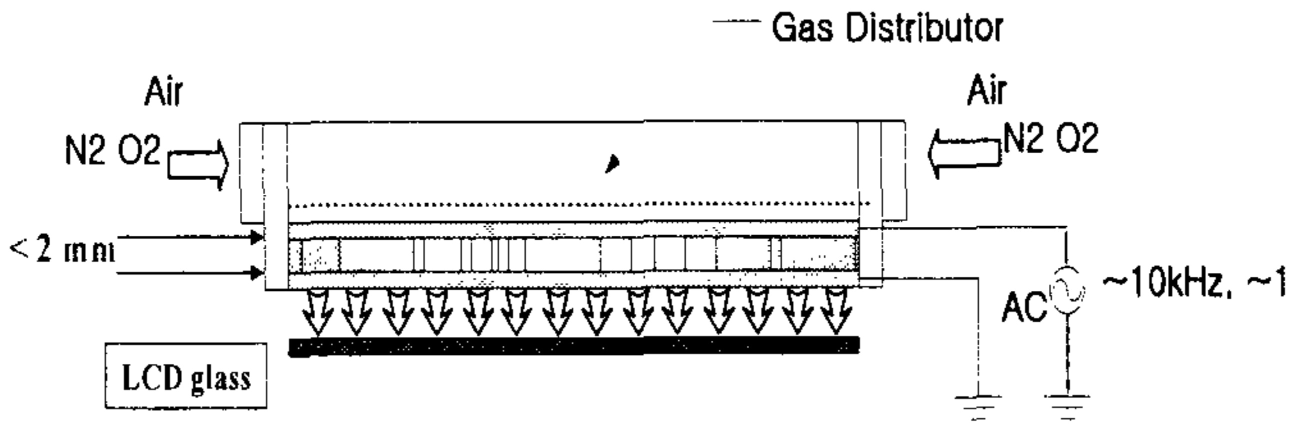

Figure 1 A schematic of AP plasma module

A gas mixture of N_2 and O_2 (99% vs. 1%: 400 lpm vs. 4 lpm for 5th generation LCD size) flows through the gas gap in between the two dielectric-metal electrode. When a high enough electrical field is supplied across the atmospheric-pressure gas gap, a gas discharge in the streamer mechanism occurs. Because of the presence of the dielectric barrier, the discharge can not develop into a thermal arc discharge. Instead, a multiple, short-lived micro-discharge is formed with electron energies of several eV at electron densities in the range of 10^{13}-10^{15} cm^{-3} [6-8]. Typically individual micro-discharge duration is a few ns to hundreds of ns[3]. The moving LCD substrate is exposed to the downstream radicals for surface cleaning, for better adhesion pre-treatment, and for ashing. The design minimizes the plasma damage and charging due to the downstream plasma and no potential difference between the bottom DBD electrode & the substrate. Plasma damage and/or charging cause severe surface damage and have negative impact upon the yield of TFT devices[5].

Compared to the previous DBD module which utilizes vertical dielectric-electrode design, shown in Fig. 2, our module has horizontal dielectric-electrode design. The gas inlets from the sides and comes out through the multitudes of uniform holes in the bottom dielectric. The flow rate and module design are optimized for uniform gas distribution through the fluent code simulation. The module is designed such that over pressure in the upper gas chamber ensures uniform gas distribution through the holes in the bottom dielectric plate. The gas flow dynamics is crucial for cooling of the upper plate and has been optimized. The horizontal design is unique and most effective since its area can be scaled up as the glass substrate size gets bigger. For traditional vertical style, plasma effective area is limited to the gap dimension. Therefore, it requires multiple modules to increase its cleaning efficiency. However, the horizontal design has no such limitation. Scaling simply requires uniform power density to be maintained as the module size grows up. The design best fits for continuous inline processing, ideal for LCD manufacturing.

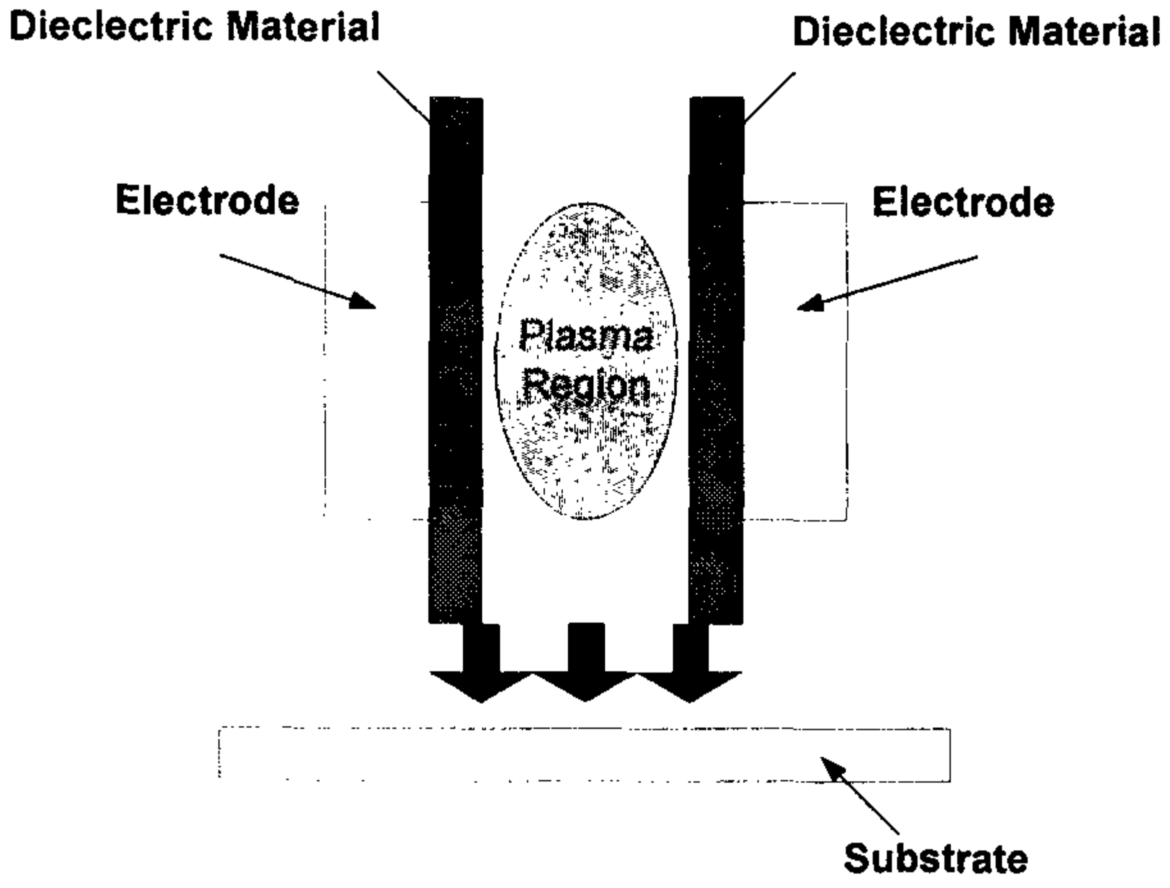

Figure 2 A schematic of traditional AP plasma module

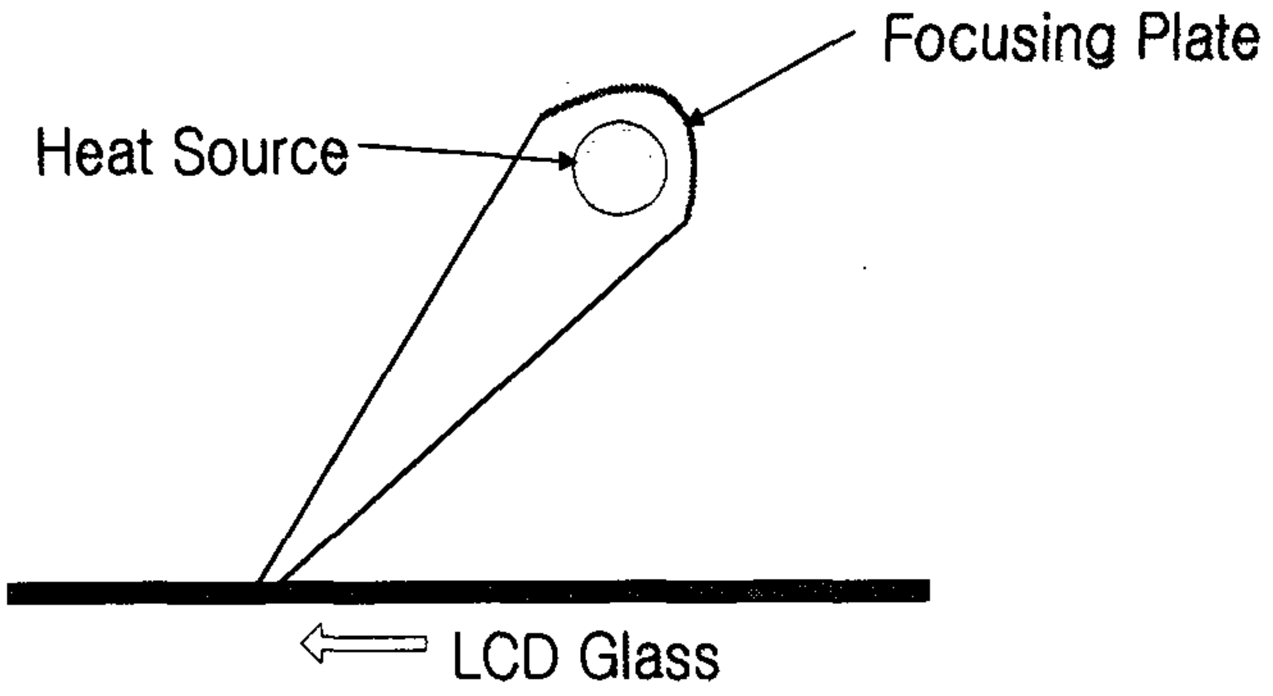

Figure 3 A schematic of the surface heater

The same AP plasma module can be applied to photoresist (PR) removal or polyimid (PI) rework when the module is combined with the pre-heating module. In order to increase the removal rate of PR (or PI), higher temperature is required. Carbon & Hydrogen bonding of PR/PI softens as the temperature goes up. A schematic of the pre-heating module is shown in Fig. 3. The focusing plate reflects the heat from radiant heating source to the ashing surface. The heating module locates in front of the AP plasma module. It heats the surface of the substrate up to 150°C in a few mili-seconds without significant substrate heating.

3. Results and discussion

The cleanliness of the surfaces can be measured through the contact angle. Fig. 4 illustrates the contact angle of droplets of water on 5th generation LCD bare glass before and after AP plasma cleaning. Nine point measurements (typical LCD manufacturer sampling requirement), all show <5°C, indicating the surface contaminants having been removed and hydrophilic surface. Treated glass also shows good uniformity. The plasma processing conditions for cleaning were the power density 3.4W/cm^2, the distance of the glass from the AP plasma cleaner 2mm, and the glass transfer rate 4m/min. The processing conditions were maintained for the other following experiments unless otherwise noted.

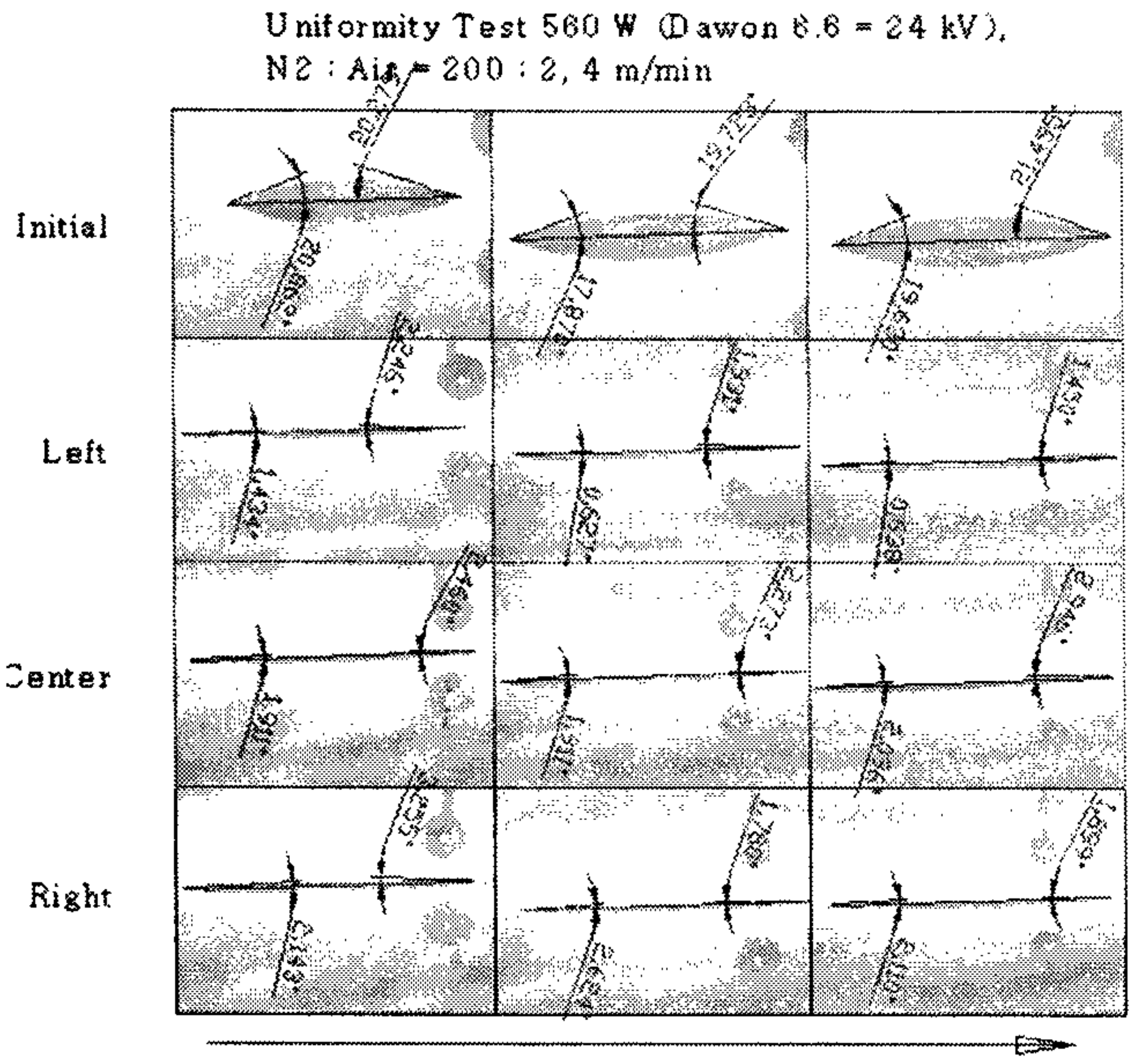

Figure 4 The water droplet contact angle measurement before (initial) and after (9point measurements) AP DBD treatment for 5th generation LCD bare glass

The results of a parametric study, where the contact angle of a water droplet on LCD glass substrate was measured as a function of the LCD glass moving speed are shown in Fig. 5. Initial column represents the contact angle before AP plasma cleaning. The difference in initial contact angle between 1mm vs. 2mm gap is from glass to glass variation before cleaning. In fact, glass substrate loses its surface cleanliness and hydrophilic nature over time. The result shows that the contact angle drops as the glass moving speed slows (longer AP plasma exposure). Minimal sensitivity is seen at 1mm gap between the substrate and the AP plasma module by glass moving speed. However, at 2mm gap, contact angle increases exponentially. Therefore, the cleaning efficiency drops rapidly as the gap increases, which is reasonably expected since the radicals will rapidly lose its radicality by the traveling distance in the atmospheric pressure.

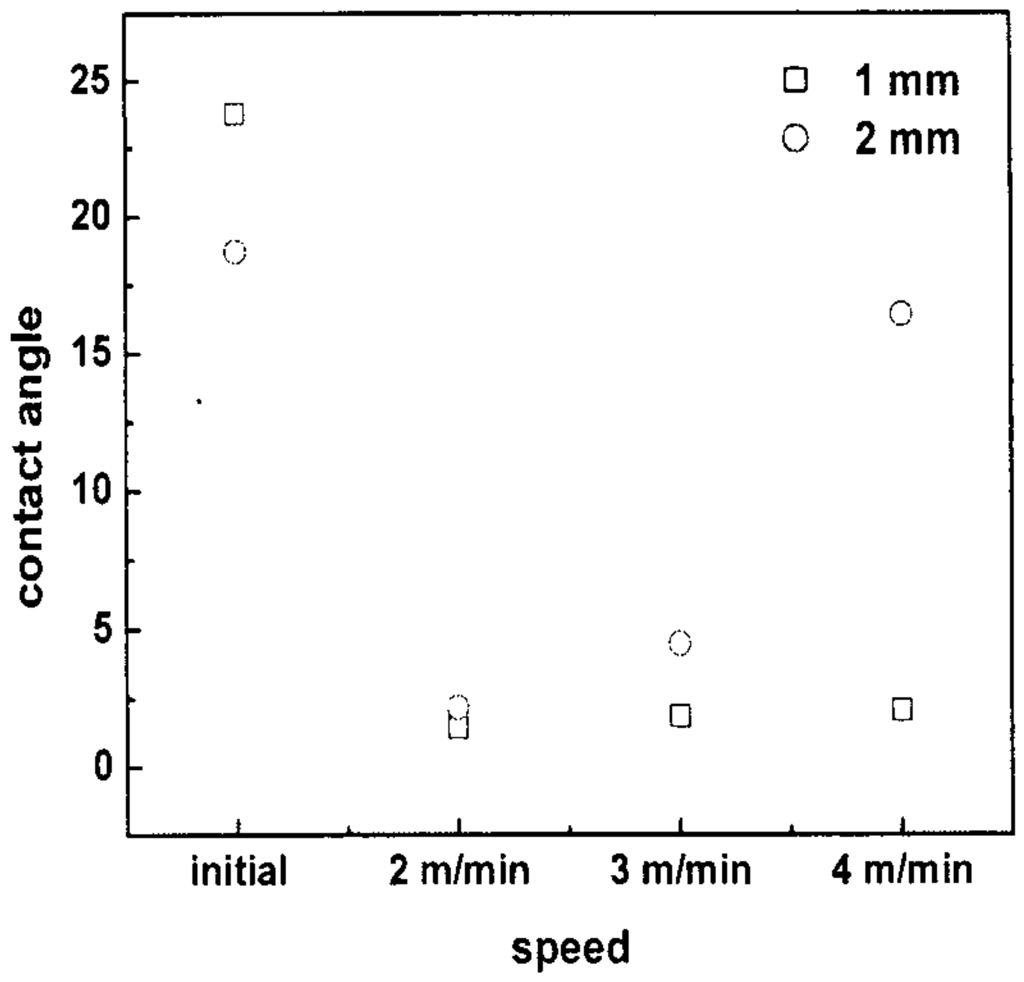

Figure 5 The contact angle measurement of water droplet before (initial) and after AP DBD cleaner treatment as the glass moving speed is varied.

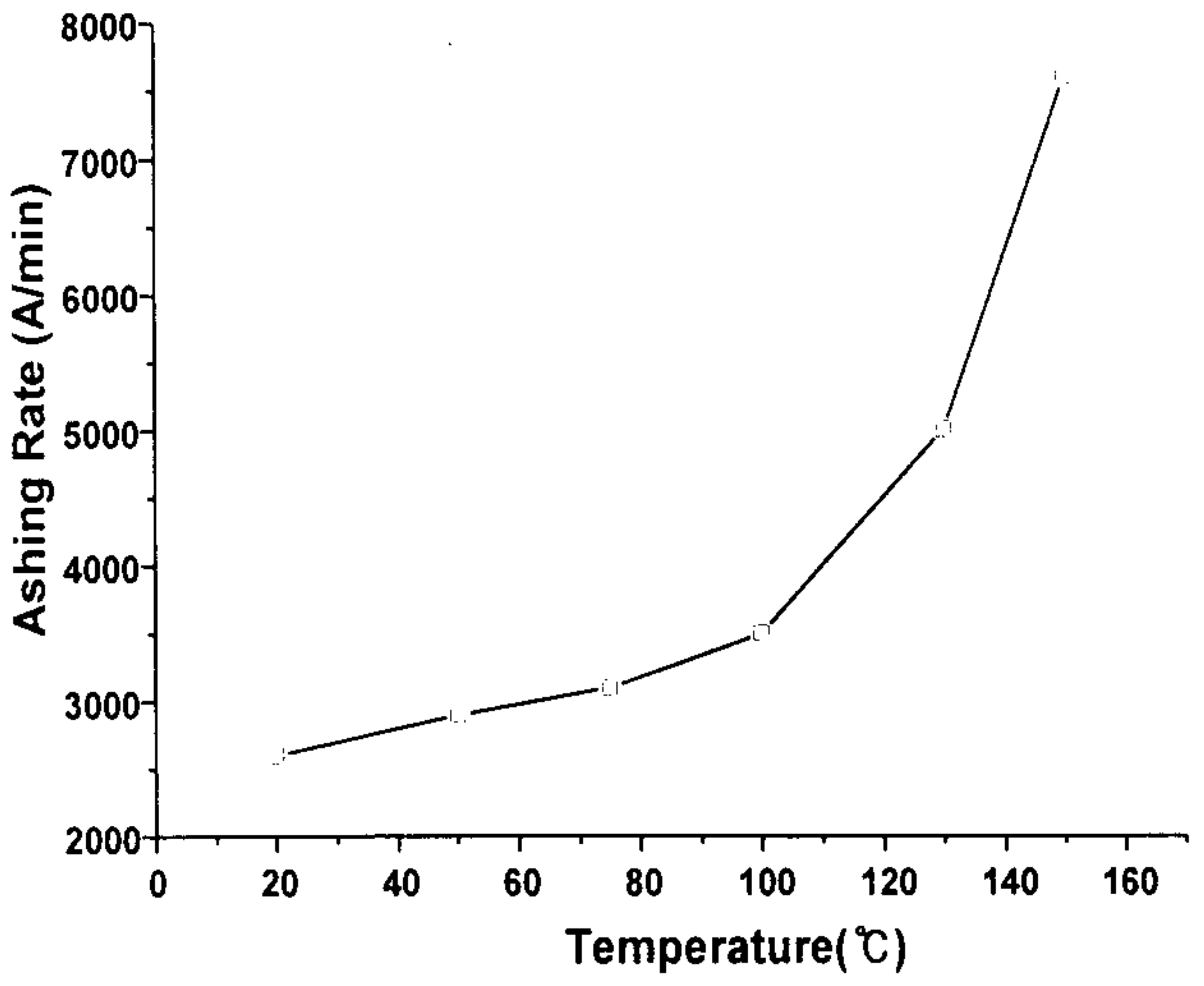

Figure 6 The ashing rate dependence on the temperature of the PR.

Fig. 6 shows the exponential increase of ash rate as the DBD module is combined with the heater. The temperature is measured by IR detector at the surface of the PR. Higher temperature is desirable to increase the ash rate. However, too high temperature has detrimental effect on the substrate since the heating can not be completely surface only. Practical limit seems to be ~150°C in the current setup.

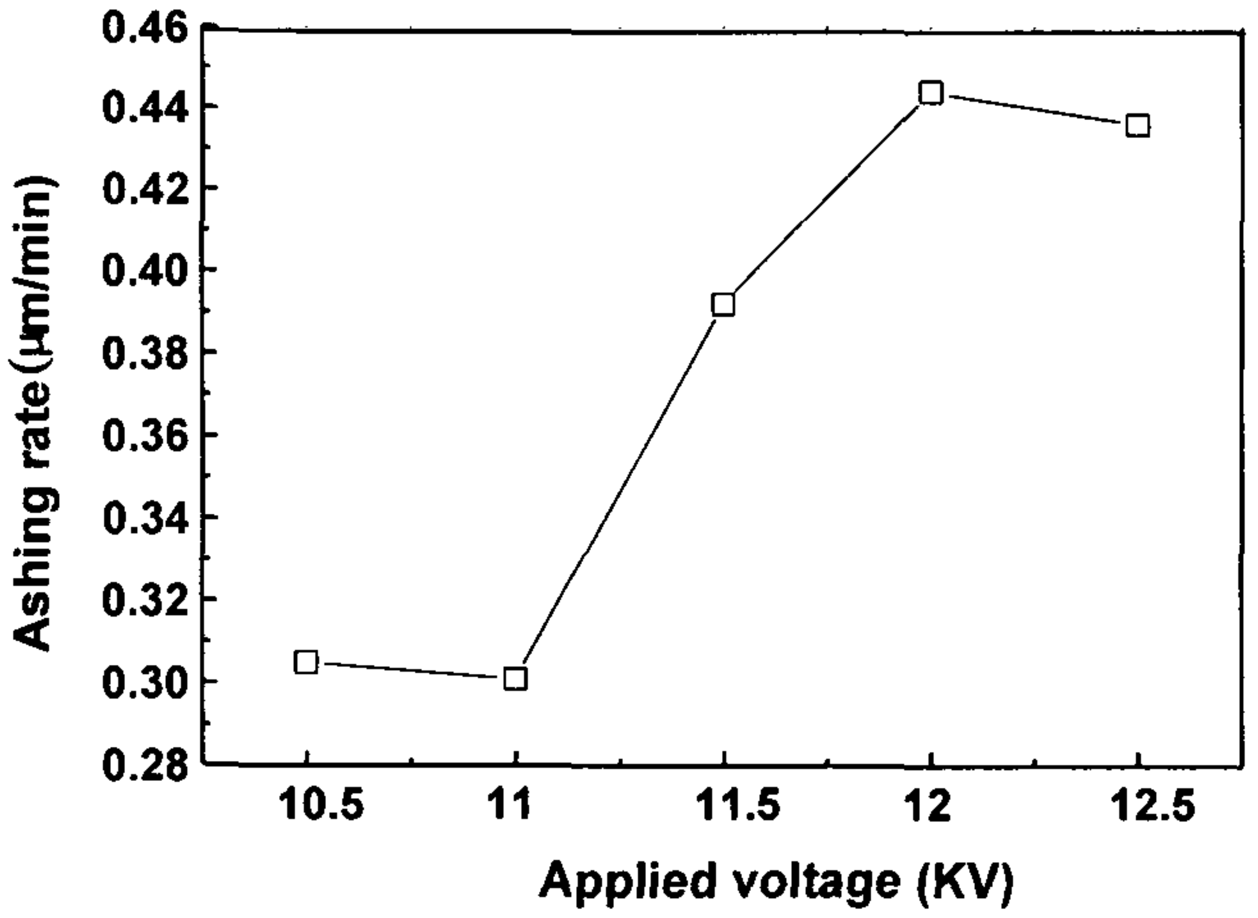

Figure 7 The ashing rate dependence on the applied plasma generation voltage.

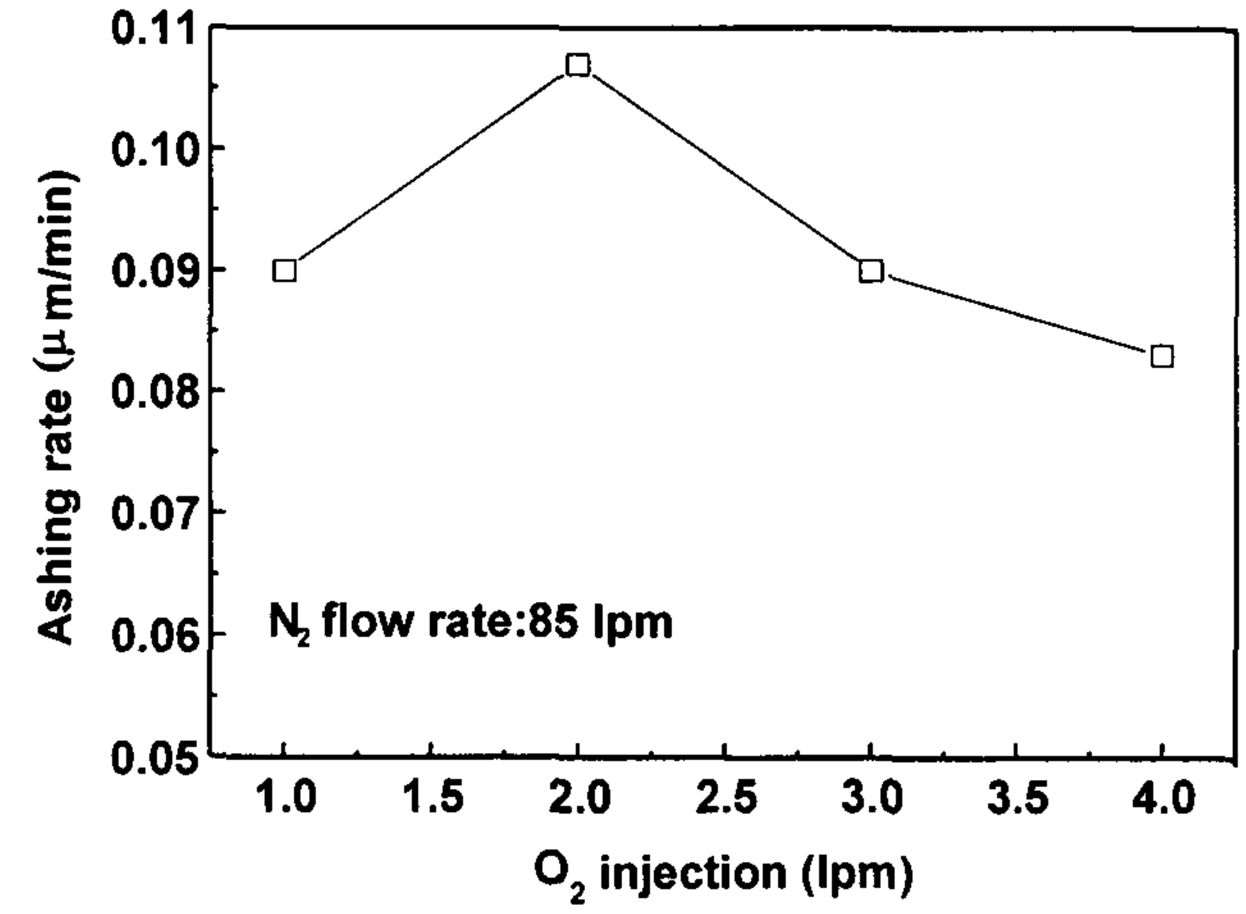

Figure 8 The ashing rate dependence on the O_2 flow rate.

The ashing rate dependence on the applied plasma generation voltage is shown in Fig. 7. The ash rate starts to increase at ~11KV and reaches its saturation at ~12KV. The result indicates the AP plasma fully develops at this voltage. The plasma onset voltage is roughly 5KV. Fig. 8 shows the dependence of the ashing rate upon oxygen flow rate. The ashing rate reaches its maximum efficiency at around ~2% oxygen. Less oxygen lacks oxygen active species due to the shortage of supplied oxygen concentration, and more oxygen tends to degrade effective plasma generation. Therefore, optimal oxygen concentration for ashing occurs.

4. Conclusion

AP plasma technology has been developed for the application of dry cleaner on surface cleaning, PR ashing and PI rework. The module has demonstrated the effective cleaning for 5th generation LCD bare glass. The module design is unique and cost effective as it can be scaled up for forth coming large glass sizes. The AP plasma module can be combined with heating module for PR ashing and PI rework. Key parameters that affect ashing rate have been identified and studied. Based on the current performance, it meets the tact time requirement for surface cleaning and PI rework. Currently PR ashing needs further improvement in ashing rate. Otherwise, the size becomes too costly.

5. References

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