Advanced laser tools for display device production on super large substrates

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Abstract

Exitech has developed a range of advanced laser ablation tools for the manufacture of display device structures on super large glass and plastic substrates. Technical information and cost of ownership data about these tools together with key areas of application are presented

1. Introduction

As FPD sizes increase the lithography and etching processes necessary to create high resolution patterns in many of the materials become expensive and have low yield. Hence there is considerable interest by manufacturers in the replacement of these multi-step, resist based manufacturing processes by single-step, dry, laser etching methods.

Such laser methods are appropriate for the high resolution structuring of the thin conductive oxide (TCO) films (ITO or SnO_2) found in almost all FPDs but are particularly important for forming the complex TCO electrode structures needed in all high resolution plasma display panels (PDPs), field emission devices (FEDs) and organic and inorganic electro-luminescent devices (ELDs).

Producers of these displays are moving to super large substrate sizes in order to reduce manufacturing costs. Laser etching methods are ideally suited for even the largest (2 meter plus) substrates presently being considered.

This paper provides details of a robust TCO laser patterning process technology that has been established at Exitech over the last 3 years and describes a production tool that has been developed for the high yield, high rate, high resolution patterning of PDP front plates.

2. Process Development

It has been well known for many years that lasers operating at 1.06μm wavelength can be used for removal and deletion of ITO from glass substrates. Such laser tools are used extensively already on thin film solar panel production lines for fine line scribing using lasers with typically a few tens of Watts of power [1]. To transfer this process technology successfully to the FPD industry has been a major task at Exitech for some years and has required some major advances both in laser technology and also in beam transport, beam shaping and beam delivery systems [2]. All this has now been successfully demonstrated culminating in the construction of a pre prototype production tool.

The main features of the special beam delivery systems developed and the key advances in technology made are shown in fig 1.

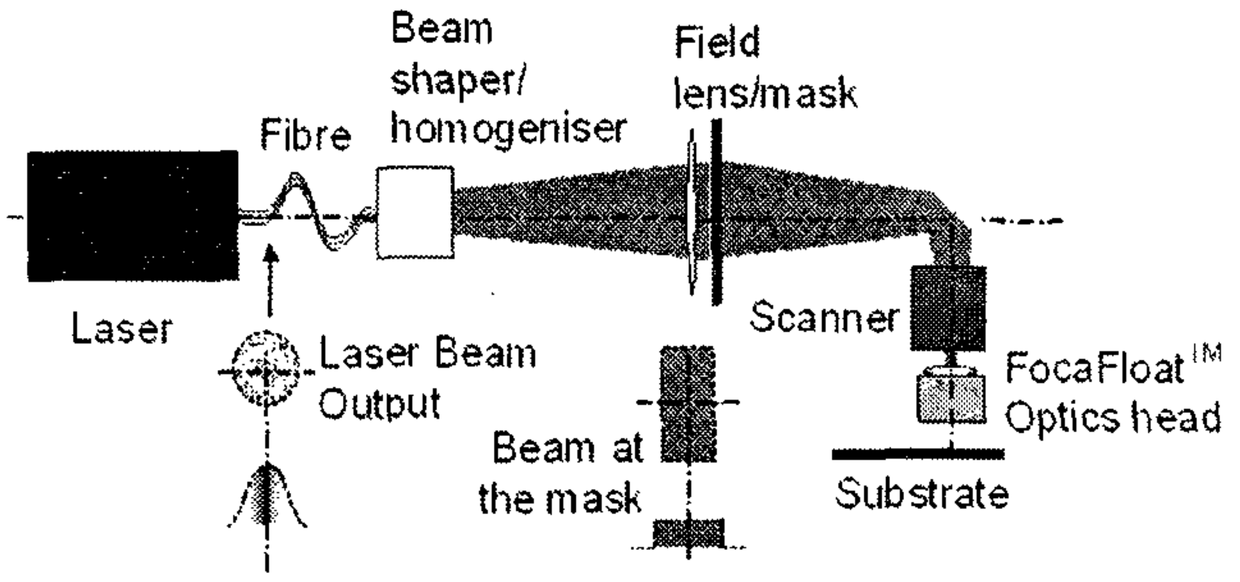

Figure 1. Beam delivery optics for TCO patterning

A high power (350W), multimode ($M^2 > 10$), diode pumped solid state (DPSS) laser delivers its output via a fibre to a beam shaping optics unit. This unit transforms the round output from the fibre to a highly uniform "top hat" beam with rectangular (3:1 aspect ratio) cross-section to match the shape of the individual RGB subpixels in the display. Relay optics image this plane onto a mask which defines the detailed structure of a single subpixel. Because of the high M^2 value of the laser and the beam scrambling effect of the fibre the beam uniformity achieved at the mask is at the ±10% RMS level. The optical transport efficiency from laser output to shaped beam at the mask plane is at the 70% level.

A special telecentric scan lens images the mask pattern onto the substrate via a custom optimized 2D scanner unit. The lens field is 30mm with an optical resolution of 5μm (NA=0.15). The system scan rate exceeds 100Hz.

Operation is in 'bow tie scanning' mode as shown in fig 2 with the PDP display moving slowly (typically <75mm/sec) along its short axis below the oscillating beam with the laser firing carefully timed to ensure each subpixel is positioned correctly to an accuracy of ±1μm with respect to its neighbours. After each 30mm wide region has been patterned the sheet is stepped sideways (along the PDP long axis) and the movement direction reversed.

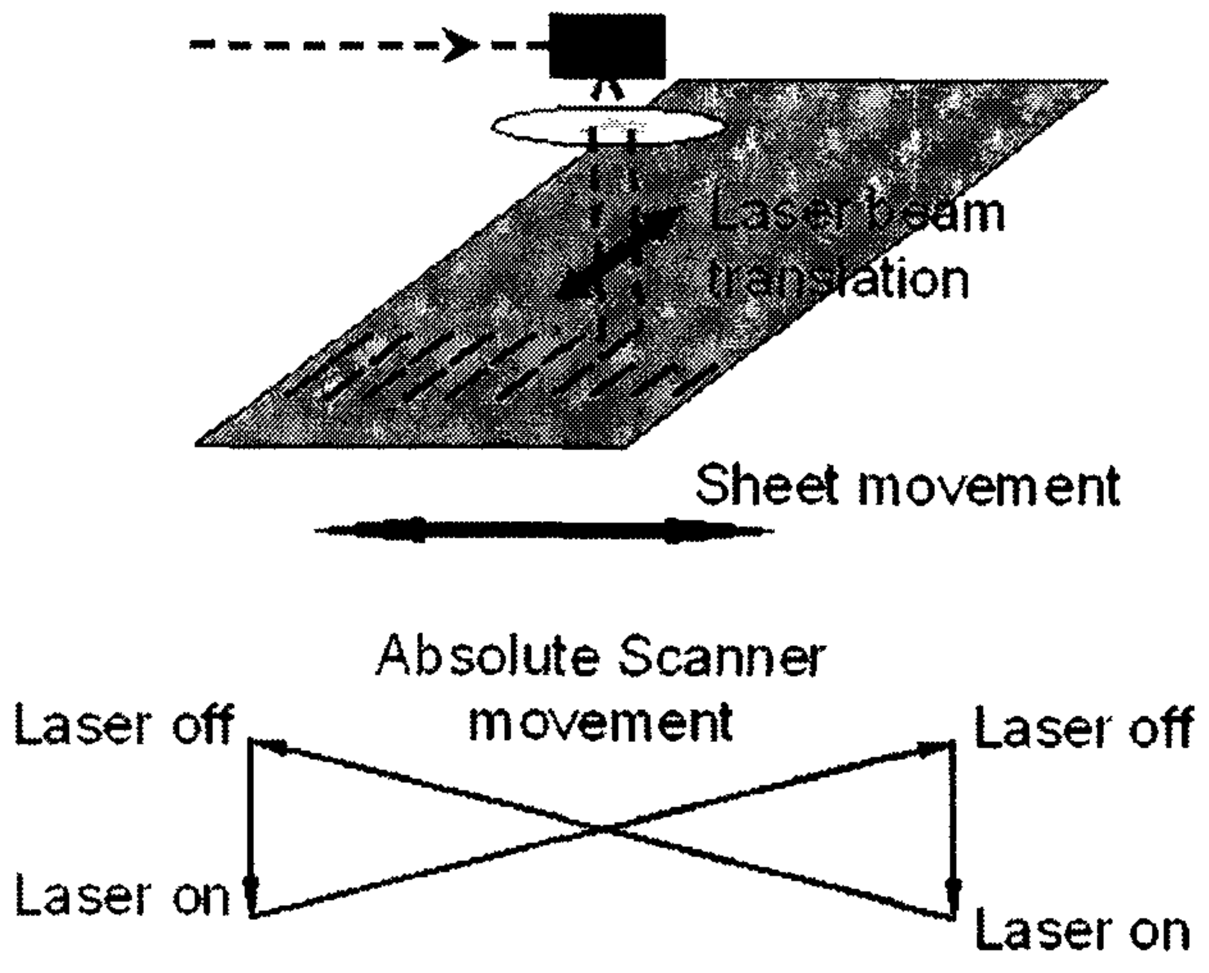

Figure 2. Bow tie scanning (BTS) concept

3. Demonstrator tool

All these key optical features have been incorporated into a demonstration tool completed at the end of 2002 and shown in fig 3. This tool has been used to optimize the ITO deletion on 42" PDP front plates. Key problems that have previously prevented the take up of DPSS laser dry etching such as pattern stitching at scan field boundaries, laser first pulse amplitude control, complete TCO film removal and debris elimination and (particularly) pattern reproducibility and accuracy over the full substrate area have all been solved on this test tool. The key breakthrough in achieving high pattern reproducibility was made by developing a novel 'FocaFloat' optics head that ensures the plate front surface is positioned to within ±5μm of the lens image plane at all times even on sheets with significant variations in thickness (±100μm) and with significant sag (1mm).

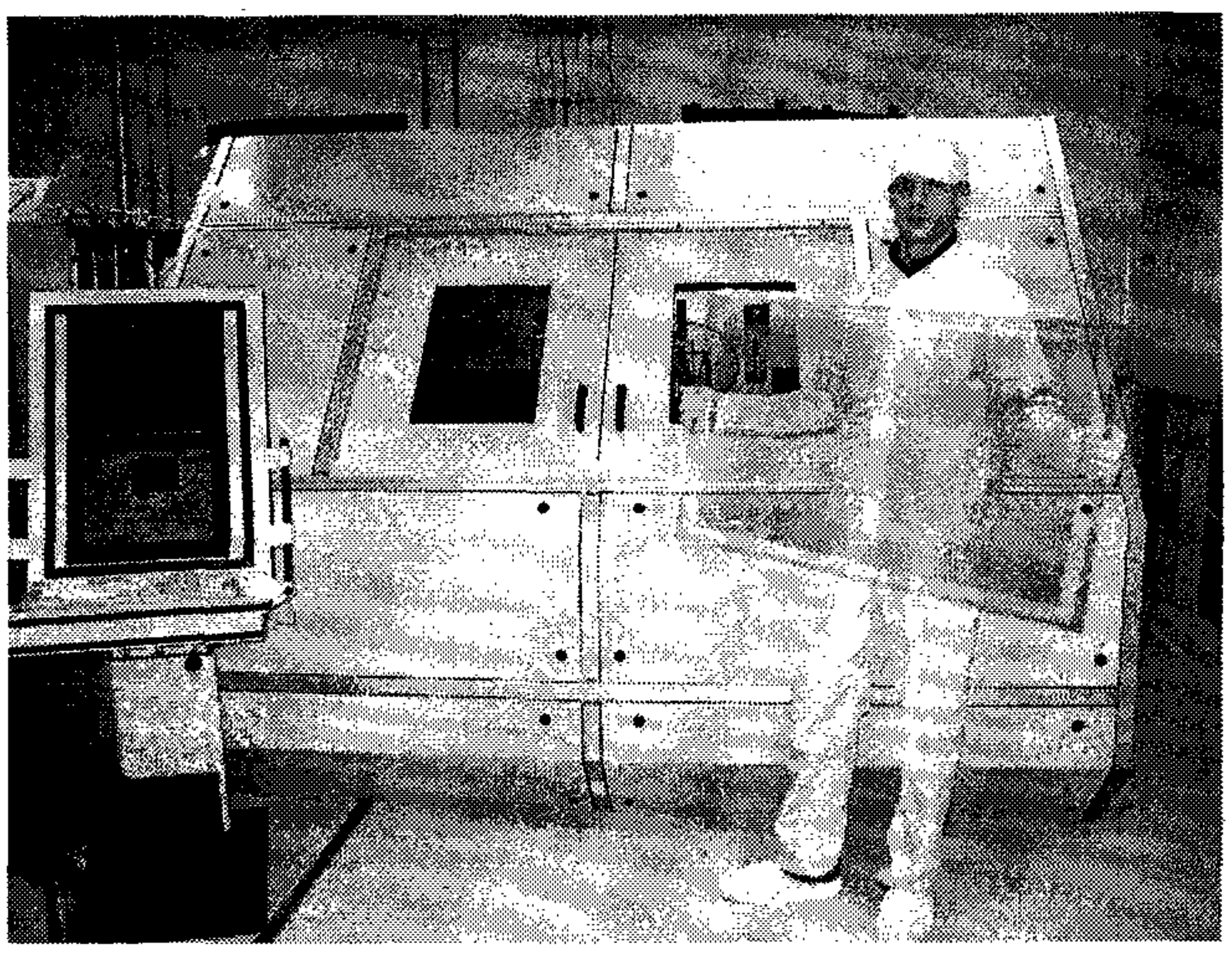

Figure 3. M9000 PDP demonstrator tool

The M9000 demonstration tool has now produced well over 50 42" PDP front plates with pattern resolutions of VGA, XGA, SXGA and HDTV. Finest features that have been imaged are at the 10μm level. Fig 4 shows an example of a section of a 42" HDTV PDP electrode pattern with 158μm (H) x 476μm (V) subpixel pitch and 22μm wide minimum electrode features.

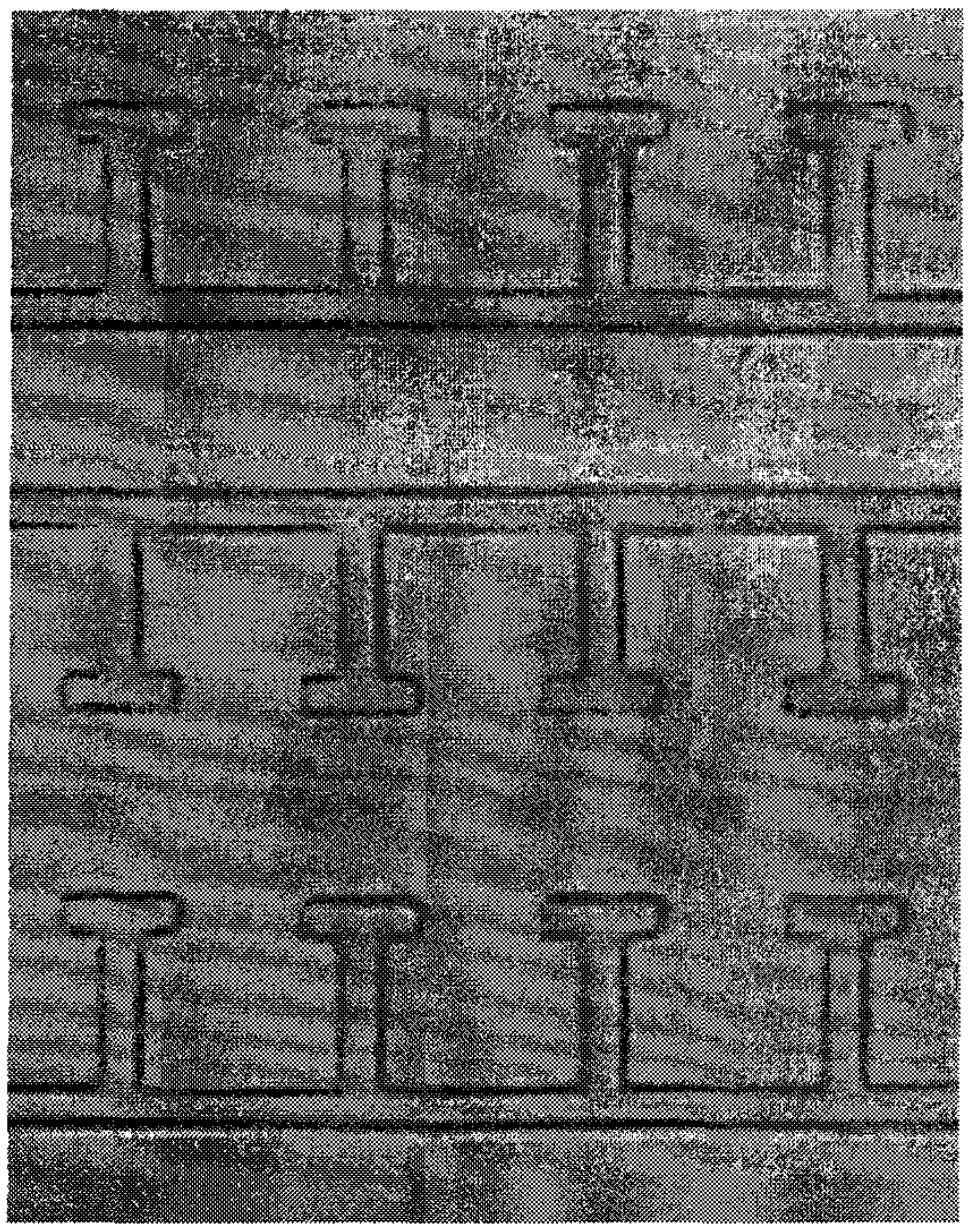

Figure 4. Section of 42" HDTV PDP electrode pattern. Finest feature is 22μm wide.

Alignment marks are automatically written into the ITO layer before subpixel patterning commences and border areas are deleted as required. Fan-out structures are also written if required.

Temperature stabilization of the machine structure and the optical systems together with automatic stage calibration routines have allowed achievements of positional accuracies better than +/-10μm over the whole 42" display area.

4. Production tools

The M9000 test tool has only 1 laser coupled to 1 scanner unit so TAKT times are relatively long. Production tools will use multiple heads to reduce TAKT time to values matched to the production line. The M9000 test tool processes sheets moving in 2 axes in the horizontal plane so its footprint is relatively large even though its maximum capacity is limited to a 1050 x 600mm sheet. This layout is not extendable to substantially larger sheets where tool footprint becomes a critical issue. To reduce the footprint of production tools to a sensible level, to minimize sheet sag issues and to interface simply to production line conveyors has meant the design of a novel tool architecture. Fig 5 shows an Exitech "PixAblater" production tool. Sheets are processed vertically and move through the tool via 2 parallel process regions. PDPs are oriented in portrait mode on the glass sheets so that multiple optics heads can address the long axis of each display. During processing the sheets are moved horizontally backwards and forwards within each process area as the optics heads scan the pattern. The bank of optics heads is mounted on a vertical stage and steps to allow coverage of the full sheet area. Sheets from the smallest (eg 1 up 42" PDP) to the largest (eg 6 up 42" or 4 up 50" PDP) size are transferred to the machine from the line conveyor by a loader/rotator unit. This unit rotates sheets to the vertical and moves them to one or other process area in the tool.

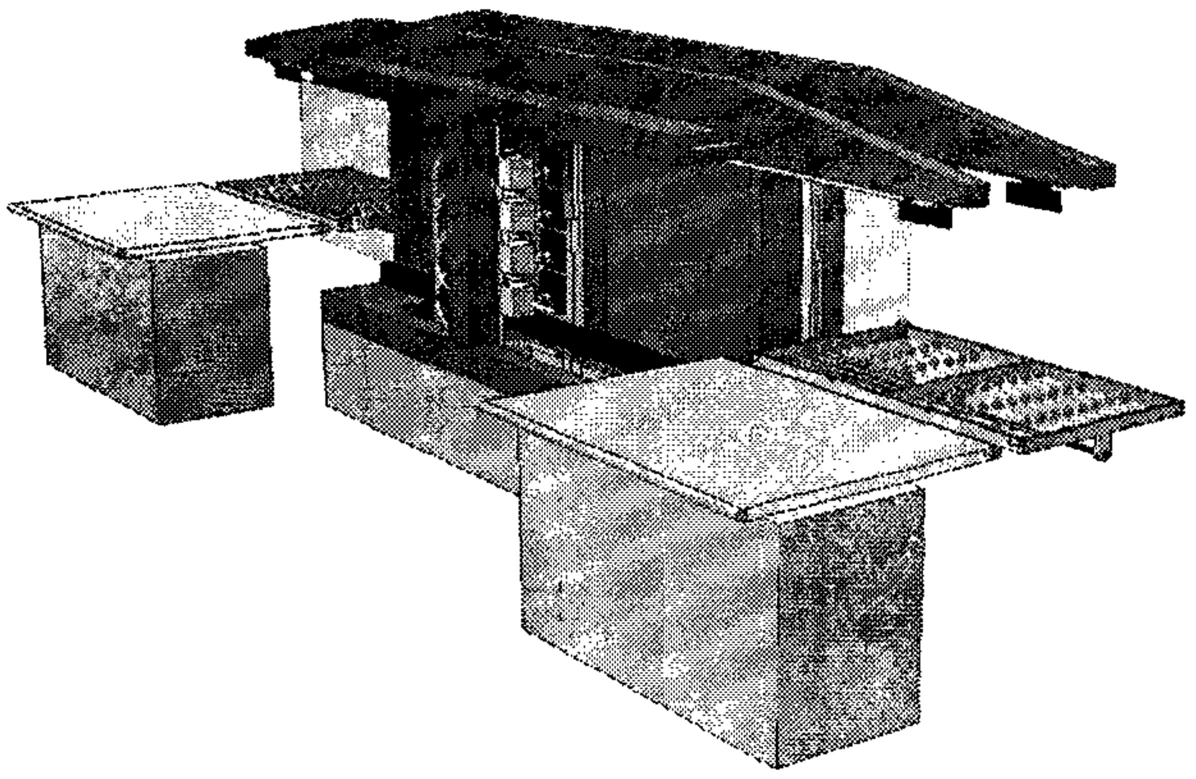

Figure 5. PixAblater-8 PDP production tool

After processing, sheets are unloaded from the tool via a 2nd rotator unit interfaced to the output conveyor. Using vertically oriented sheets has many process advantages including simplifying debris collection and eliminating 'sag' issues. Multiple 'FocaFloat' optics heads ensure consistency of sheet front surface position during processing. Special diagnostics and beam dump air pucks on the opposing side of the sheet keep it correctly positioned and ensure process reliability.

Each optics head is fibre fed by its own individual laser unit which is mounted remotely from the main tool in a separate service bay if required.

Depending on the sheet size, display size and number of PDPs per sheet the total number of optics heads on the tool can vary from 8 to a maximum of 16.

Table 1 shows sheet TAKT times for 3 different displays and 4 different PixAblater geometries. 42" displays are arranged 6 up on each sheet whereas 50" devices are arranged 4 up. From this data it can be seen that to achieve a production line sheet TAKT time of less than 100sec needs 2 PixAblater-10 units operating in parallel, whereas 2 PA-12s are needed to achieve less than 80 sec. Process times on PixAblater tools scale only with the display size and number of optics heads. To first order pattern resolution does not affect process rate.

	PA-8	PA-10	PA-12	PA-16
42" VGA	241	199	156	123
42" HDTV	241	201	157	124
50" XGA	227	187	151	112

Table 1. Sheet TAKT times for various PixAblater tools. Times in seconds per sheet. Format is 6 up 42" PDPs or 4 up 50" PDPs per sheet

The foot print of each PA-12 unit is a modest 2.7m x

8m including both rotator/loader units.

The use of robust and reliable fibre delivered DPSS lasers together with industrially proven subcomponents throughout the tool means that maintenance times are minimal. Typically less than 1% of operational time is required for regular maintenance due mainly to the long lifetime of subcomponents. For example the main laser consumable components, the pump diodes have lifetimes greatly exceeding 10,000 hours.

Process yield is also very high due to the nature of the pixel by pixel imaging process and the consistancy of the laser output. Diagnostics built into the tool record all pulses incident on the substrate and hence the location of any 'irregular' pulses can be inspected immediately after plate processing and repaired 'insitu' if needed.

So far over 50 42" PDP plates have been patterned on our M9000 test tool without a single laser misfire. PixAblater yields well over 99.5% are expected in production.

5. Cost of Ownership

Based on well established operating costs for the DPSS lasers we have calculated typical PixAblater tool running costs associated with 42" and 50" PDP processing. For all consumable parts, utilities and all other service items each 42" display costs about $0.70 whereas 50" displays cost about $1.00. These costs exclude labour costs associated with operation or maintenance. Running costs are dominated by the cost of laser pump diode replacement which are predicted to fall over the next few years as more manufacturers enter the DPSS market.

The capital costs of PixAblater tools are modest compared to the total costs associated with setting up full coater/developer/exposure/etcher/stripper facilities. Two PixAblater-8 systems (together capable of producing over 180 42" PDPs/hr) cost $7.5M to install whereas two PixAblater-12 systems (together capable of producing over 270 42" PDPs/hr) cost just over $10M.

6. Conclusion

We have developed a new industrial laser TCO etching process and built a demonstrator tool that consistently produces high quality, high resolution fully patterned 42" PDP front plates. This tool has shown that we now have a robust and reliable yet highly flexible process for dry, resist free patterning of ITO and SnO_2 for large display devices.

Based on this we have designed a production version of the tool that has highly attractive features in terms of its running costs, capital costs, yield and serviceability.

The main application for this tool is in the direct patterning of ITO and SnO_2 layers for PDPs but versions of the tool have already been designed for cathode cavity structuring for FEDs and for resist exposure by direct writing into the DFRs used for PDP barrier rib formation and other similar processes.

7. Acknowledgements

All the work reported here has been performed by the members of the Exitech Displays Tool Development Group under the leadership of Dr Ric Allott. I gratefully acknowledge their skill, enthusiasm and dedication.

8. References

[1] Yavas.O and Takai.M. High speed maskless laser patterning of ITO thin films. Appl Phys letters 73, 2558 (1998)

[2] Abbott.C et al and others. New techniques for laser micromachining MEMS devices. Proceedings of SPIE Conference on High Power Laser Ablation, TAOS, USA 4760 p281 (2002).