

High Precision Laser Manufacturing and Plasma Cleaning of Apertures in TonerJet® Printheads

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Abstract

The TonerJet print process is based on toner transport through small apertures in flexible printed circuits, FPC:s. The transport is controlled by electrodes, that are etched into the flexible material. The print uniformity requirements have made it necessary to find a high precision manufacturing method for the apertures and the electrodes. Excimer laser aperture processing is the method used to achieve this.

One of the main challenges has been the registration between the apertures and the electrodes. This has led to the development of a special masking method.

Cleanliness of the FPC surface during the manufacturing process is of importance for uniformity and for the reliability of the insulating layers applied afterwards. Plasma cleaning was chosen due to its possibility to clean the inner walls of the apertures, and its lack of mechanical impact. A suitable cleaning cycle has been developed.

Through this, a manufacturing method that is competitive regarding yield, cost and quality has been formed.

Introduction

The TonerJet technology is a direct printing process where charged toner particles are deposited directly onto a print media[1)] (paper or belt) to form a visible image pattern. The print media passes at single pass four printheads, one for each colour, mounted in fix positions. The adressability is usually 600 dpi, and each printhead covers the full width of the print media. One big challenge for the manufacturing method is to meet the requirements of uniformity over the printhead width.

The printhead (see Fig. 1) consists of a flexible printed circuit, FPC, which contains and supports control electrodes, formed by an etched copper pattern. Each control electrode circumscribes an aperture. The area on the FPC that contains the electrodes and the apertures is from now on referred to as the print zone.

A toner supply sleeve transports toner to the print zone. The toner is transferred from the sleeve to the print media by electric fields, which are created by applying voltages to the electrodes.

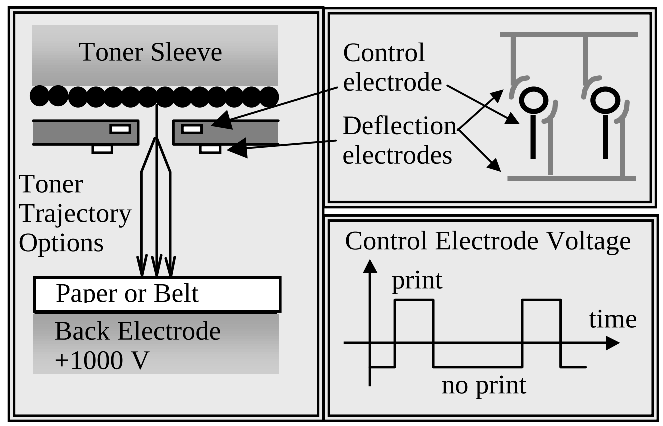

Figure 1. Cross-section of the print zone.

The FPC consists of a base material, polyimide, an etched copper pattern on each side of the base material, and an insulating layer, which may be polyimide or parylene, on top (see Fig. 2).

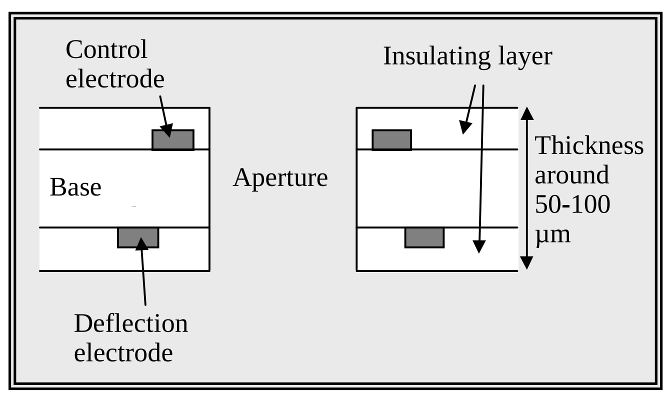

Figure 2. Cross-section of an aperture in the FPC.

Requirements

The manufacturing of TonerJet printheads is to some extent similar to inkjet printhead manufacturing, but there are significant differences that have led to the development of the methods shown in this paper.

The most important technical requirements in manufacturing the TonerJet printheads are tolerances and cleanliness. Of course the process used also has to be suitable for mass production.

Tolerances

Critical parameters are aperture size, position and the taper and smoothness of the walls. Due to the importance of uniformity in the print, aperture size must be constant within a few µm, and position must not deviate more than a few µm from the centre of the control electrode.

The requirement of centering the aperture in the control electrode adds an extra challenge. Polyimide is a flexible material, that shrinks and expands slightly with temperature and humidity. Even if the environment is kept constant, small deviations in its size may occur. This means that the absolute position of the control electrode has to be found, at least at certain intervals during the machining. This can be done with a vision system. The alternative, to find the first electrode, and then using constant step size, would mean a risk of ending up with an accumulated error in the other end of the print zone.

A certain degree of taper of the aperture walls is acceptable, which enables us to use laser as manufacturing method. Smoothness is important to facilitate the toner transport through the aperture.

Cleaning

Thorough cleaning of the FPC surface is important, since additional layers of material are applied on the FPC surface after the laser manufacturing. Any waste remaining from manufacturing will affect the adhesion of additional layers. Another aspect is that waste consisting of conducting material acts as a shield for the electric fields used in the print process, and will therefore influence the transfer of toner from sleeve to print media.

Manufacturing Methods

Background

When choosing manufacturing method, both a mass production situation, and prototype production must be considered. For the lab work and prototype production it is necessary to be able to manufacture small series of varying designs. Still, it is desirable to use similar methods for prototype manufacturing as for mass production, in order to avoid unpleasant surprises. Thus, flexibility and tolerances are important short term parameters, whilst cost, speed, yield etc. has to be fulfilled long term. In order to verify the latter, extensive tests and cost calculations have been made, using input from areas when these methods are used in mass production today.

Excimer Laser

Few manufacturing methods meet the high tolerance requirements, so therefore excimer laser was chosen, due to its high precision and flexibility in small series.

Since centering the aperture in the control electrode is a critical parameter, an exact and convenient solution is to use the control electrode itself as a mask for the laser beam. In order to do this, the area around the electrode has to be protected from the beam. The laser must also be adjusted in order not to damage the control electrode, which is around 5 µm thick and therefore possible to remove with laser. The methods described below are suitable ways to implement this. Method no. 1. and 2. have been developed in co-operation with Resonetics Inc., Nashua, NH, USA, and Method 3. by Fujikura Ltd, Chiba, Japan.

Method 1.

In mass production it is favourable to manufacture multiple apertures simultaneously, which is possible since the laser beam is uniform over an area containing up to 50-100 apertures. A mask with arrays of holes allows this (see Fig. 3). Since there is a risk of shrinkage in the flexible material, which means the distance between the apertures may be slightly altered from FPC to FPC, it might be necessary to manufacture a few masks for multiple apertures with different pitch.

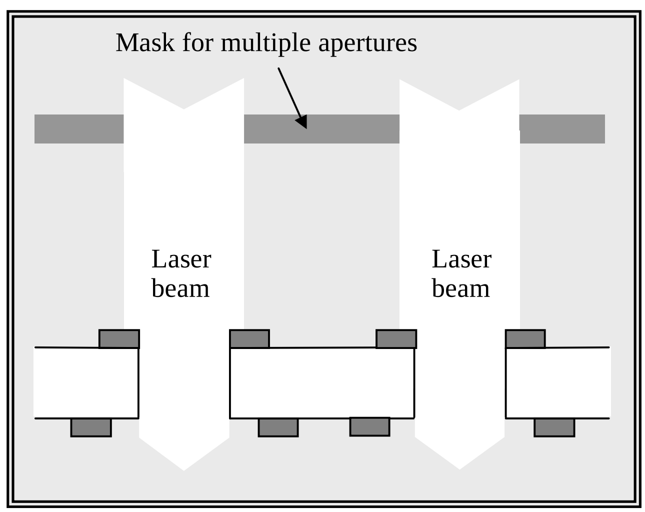

Figure 3. Cross-section of FPC during laser manufacturing of apertures, using both a separate mask as well as control electrodes to confine the beam.

Thus, sections containing 50-100 apertures are manufactured, followed by stepping of the worktable to the starting point of next section. A vision system can be used in order to find the control electrode that is starting point for every section of the print zone.

Since the laser beam is confined by the control electrode, it is not so critical exactly where the laser hits the FPC, as long as it is on the control electrode. Thus, this method does not require as high tolerances on the mask or the work table stepping, compared to the case when only the mask is used to confine the beam (see Fig. 4). Lowering the tolerance requirements is of course very important not only technically, but also for the manufacturing cost.

For prototype production, in small series, cost and speed of the process is less important, while flexibility and possibility to change design is the key issue. Therefore, the apertures are then made one at a time, which facilitates the mask production.

Method 2.

Apertures made by laser have a conical cross section, with a wall taper of a few degrees. The method above will therefore result in apertures with a smaller diameter on the deflection electrode side than on the control electrode side.

In the case that a smaller diameter on the control electrode side is required, or if the insulating layer is applied prior to the aperture manufacturing, the following method is advantageous.

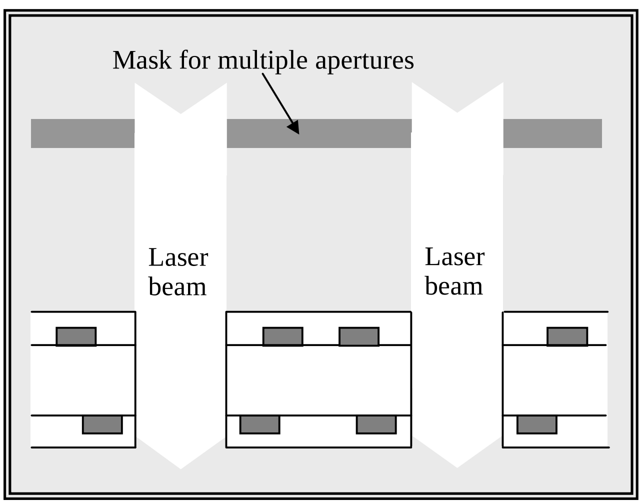

Figure 4. Cross-section of FPC during laser manufacturing of apertures, using a separate mask only to confine the beam.

Method 3.

Method 3. is, apart from some major differences, similar to Method 1. In this case a contact mask for multiple apertures is used (see Fig. 5).

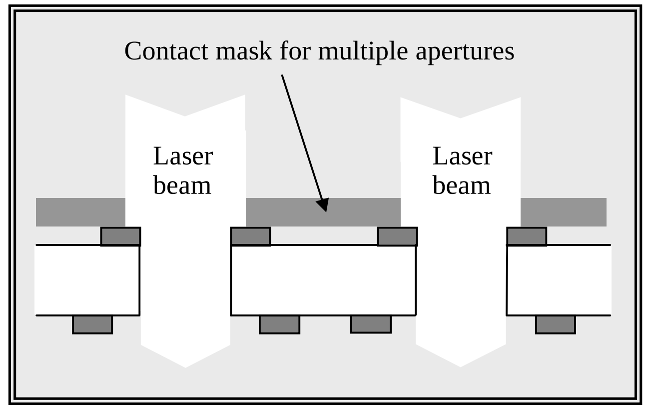

Figure 5. Cross-section of FPC during laser manufacturing, using a contact mask.

The mask is put in direct contact with the FPC surface, and the work table stepping is replaced by a continuously moving table, which means the laser beam is scanned along the mask. Thus, it is possible to use a mask covering the full print zone width, provided the mask can be manufactured with high enough accuracy.

The control electrode is used as a second mask, giving high aperture position accuracy, without as high requirements on the mask, just as in Method 1.

Plasma Cleaning

During the laser process, some of the polyimide material is not completely vaporised, and is deposited as a waste layer, mainly consisting of carbon. This contamination deteriorates the adhesion of the additional layers that are applied afterwards. Also the fact that the contamination consists of an electrically conducting material causes some difficulties. Conducting material acts as a shield for the electric fields that are used for the toner transfer, and may also cause short circuit between neighbouring control electrodes, in the case where the insulating layer is applied later.

It was therefore necessary to find a method to clean both the FPC surface, and the inner walls of the apertures, with smallest possible mechanical impact on the FPC. The alternative chosen is plasma cleaning, which is already used in industrial applications for cleaning of polymers, and fulfils the requirements above. A suitable process was developed in co-operation with Advanced Plasma Systems, Inc., St. Petersburg, USA.

The contaminating carbon is not only deposited on the surface, but also embedded into the aperture walls, in polyimide that is partly melted during the laser manufacturing. A cleaning cycle with only one gas mixture appeared not to be efficient enough. Therefore the following sequence of gas mixtures is used:

1. $Ar + O_2$
2. $CF_4 + O_2$
3. $Ar + O_2$

In the first step, the oxygen reacts with and binds to the carbon deposit, while the argon functions as an ion bombardment of the surface. This step removes the carbon deposit on the surface.

In the second step, the polyimide material is slowly etched away by the tetrafluoromethane (CF_4), in order to expose the embedded contamination. The oxygen has same function as in the first step.

The third step removes any possible remainders from the preceding step.

Samples from this cleaning sequence have been investigated using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS), and the result is satisfying.

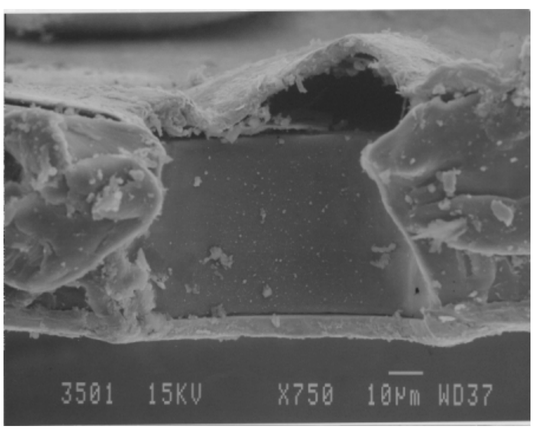

Figure 6. SEM picture: Cross-section of an aperture directly after manufacturing.

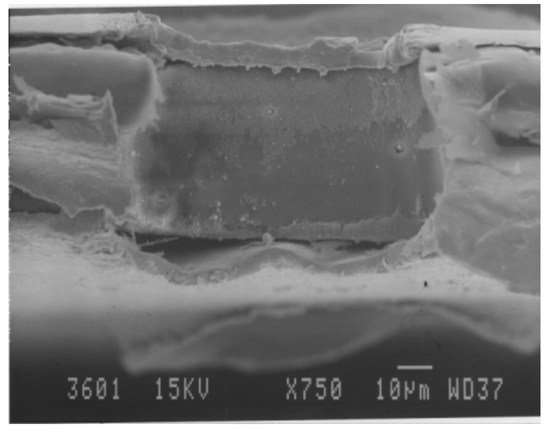

Figure 7. SEM picture: Cross-section of an aperture after plasma cleaning.

Summary

In order to find a high speed manufacturing method for TonerJet printheads, while still competitive regarding yield and cost, excimer laser aperture manufacturing and plasma cleaning have been investigated.

By using the control electrodes present in the printhead, as a secondary mask, the accuracy requirements on the excimer laser system can be lowered, while still maintaining high speed.

A plasma cleaning cycle, containing three steps with different gas mixtures, has been found to be an efficient and non-destructive cleaning method for both the FPC surface and the inside of the apertures.

Through these techniques discussed above, a manufacturing method that is competitive regarding yield, cost and quality has been formed.

References

1. Anders Berg-Palmqvist, *TonerJet - Colour, Speed and Simplicity*, ICPS, International Congress on Imaging Science, Antwerpen, 1998, pg. 81-85.
2. Agneta Sandberg, *TonerJet Tandem Color has Reached Prototype Stage,* IS&T's NIP 14, 1998, 180-183.

Biography

Karin Bergman has received her M.S. in Engineering Physics from Chalmers University of Technology in Göteborg, Sweden. She joined the R&D department of Array Printers AB in 1997, and worked mainly with printhead manufacturing, with focus on laser processing and materials. She is now mostly involved in the development of the TonerJet print process.