Small Dot Ion Print-Head

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Abstract

A novel Ion head architecture is presented for high resolution Ionographic printing, with a spot size capability of ~50 µm. This ion head is manufactured using electroforming technology to provide a unique discharge geometry including a controlled gap which may be tailored to the discharge. Experimental measurements confirm the advantage of this geometry in producing high current densities. An electroformed screen electrode is also provided to focus the ion beam on a small spot. Experiments using a novel knife edge technique validate the achievable spot size. A simplified numerical and analytical model based on Paschen's curve shows the effect of nozzle scaling on the charge that may be extracted a nozzle. The model also allows testing the effect of an optimized nozzle profile demonstrating its advantages for a small nozzle implementation. The knife edge tool is used to experiment with different discharge electrode nozzle sizes for a fixed screen electrode allowing selection of the most efficient combination.

Ion head Background

Ionography is a direct imaging printing process employing direct charge deposition on a dielectric imaging substrate to create a latent image which may be then developed with toner. Several different Ion sources have been employed for Ionography, with the DBD (Dielectric barrier Discharge) based Ion Print-Head being the most successful one and still being used by Delphax Systems[6]. The reader is referred to [1] for a comprehensive summary of the history of the Ion Print-Head (afterwards renamed electron beam imaging, a name more representative to the true operation of the device as s discussed on [3]). Figure 1 shows an image of a typical Ion Print-Head from a Delphax patent.

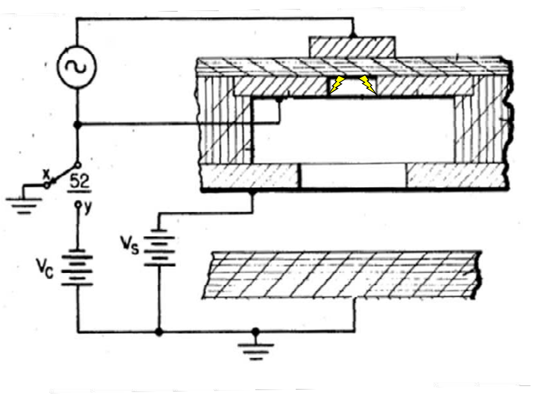

***Figure 1**. Ion Print Head drawing from US Patent 4,160,257 granted on 1979*

The Ion Print-Head consist of an AC driven electrode pair with a dielectric layer in between forming a DBD. One electrode (discharge) has an opening (nozzle) where the plasma is generated while the other is fully enclosed (embedded electrode) to prevent discharges on its surface as depicted in figure 3. A second dielectric and a third electrode(screen) are placed on top of the generator, this one serves the purpose of gating current being extracted from the plasma. A key metric for an Ion head is the amount of charge extracted per nozzle per AC cycle, this charge which is of the order of ~1-2 pC will be denoted as Charge Factor. Typical AC excitations are on the order of 3000 Vpk-pk at 2.5 MHz.

Key challenges for an Ion Print-Head based print engine are:

- Resolution requirements [2] limited both by the Print-head charge beam size and blooming on the dielectric imaging surface,
- Current requirements for high speed operation [3]
- Lifetime.

Additionally there several manufacturing challenges related to an Ion Print-head including coating of the dielectric layer serving as barrier for the DBD which needs to sustain AC potentials of 3000 Vpk-pk while at the same time provide uniform discharge across the width of a print head, alignment of several nozzle layers and elimination of parasitic discharges due to unfilled air gaps within the structure.

Small Dot Ion head challenges

Scaling an Ion Print-head for high resolution printing (>1200 dpi) is challenging if the basic building block (nozzle) is of the order of 150 µm in diameter. A drive towards smaller nozzles (<50 µm) requires different manufacturing methods and also attention to the nozzle geometry in order for the head to deliver the required amount of current.

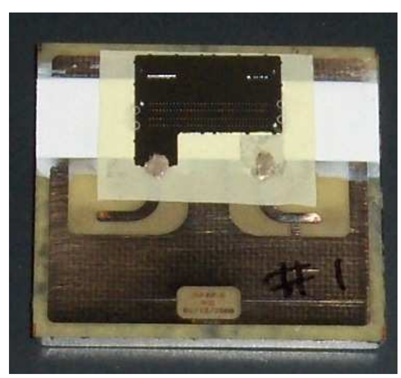

***Figure 2**. HP Ion Head Print Head*

Figure 2 shows an image of a prototype for a narrow (25 mm wide) Ion Beam Print-head, the print-head includes a PCB containing the embedded electrodes, a dielectric layer, a discharge electrode, a second dielectric layer and a screen electrode. Both, discharge and screen electrodes are manufactured using electroforming. Electroforming allows unprecedented control of the discharge geometry as compared to prior methods use to manufacture these electrodes (i.e. metal etching).

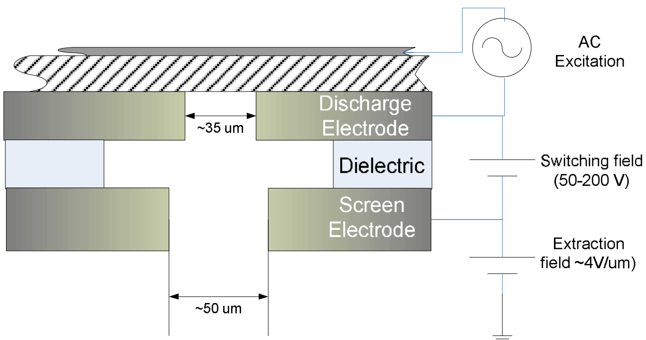

***Figure 3**. HP Ion Head Print Head Nozzle cross section*

Figure 3 shows a typical cross section of one nozzle for a prototype Ion Print-Head, the discharge electrode geometry is shown cylindrical for illustration purposes but other shapes are possible and may have significant effects on how the plasma is generated. A high frequency (2.5 MHz) excitation is placed between the discharge electrode and the embedded electrode to generate plasma in the discharge electrode cavity. A relative switching field is applied at the screen electrode in order to gate the extraction of charges from the plasma.

Ion Head characterization: Average Current measurements and Knife edge

Several characterization methods are used to evaluate the performance of our Ion Print-Heads. The most basic one is measuring the average current over a known amount of AC excitation cycles across several nozzles to obtain the average Charge Factor of a Print-head for some specific driving conditions[4]. Figure 4 shows a typical charge vs. AC excitation for an HP Ion Print head at atmospheric air conditions.

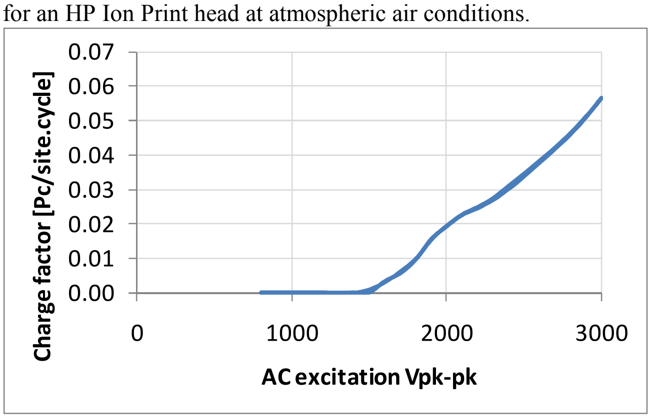

***Figure 4**. HP Ion Head Print Head Charge factor transfer curve in Nitrogen at 1.9 V/µm extraction field. The Print-Head had a 35 µm discharge electrode and a 50 µm screen electrode*

The Print-Head was biased with an extraction field of 1.9 V/µm against a grounded electrode into which the current was collected and measured. The environment used for the discharge was Nitrogen. This specific printhead had a 35 µm diameter discharge electrode and a 50 µm screen. Average nozzle current measurements provide insight into the threshold potential required to start the discharge and the achievable Charge factor. This measurement however does not provide information on the beam profile for any given nozzle or on the uniformity of the nozzle output across a Print-Head.

In order to gain more insight on the behavior of our print head we have developed the knife edge characterization system shown in figure 5. This system enables profiling the Ion Print-Head beams experimentally. It includes a silicon wafer with two isolated electrodes, the top electrode is floating above the other with a thin (< 1 µm) polymer dielectric in between.

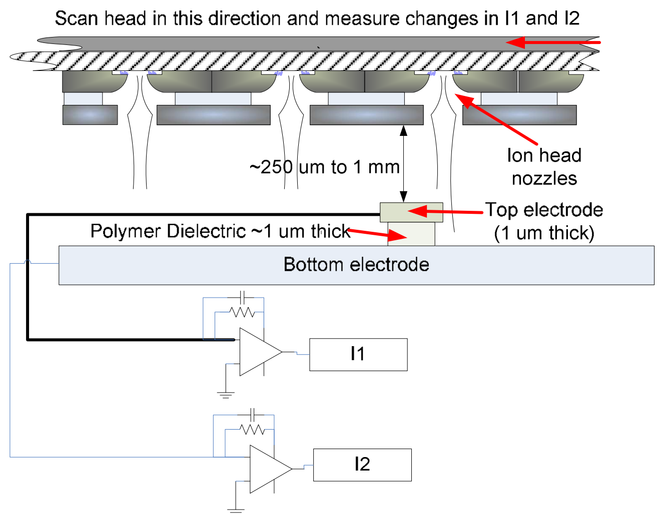

***Figure 5**. Knife Edge system*

Currents from both electrodes are measured. The top electrode can be made narrower than the Ion Head nozzle. The knife edge system allows obtaining data as shown in figure 6, note that the beam width may be extracted from this raw data through deconvolution as the width of the current scanning probe (top electrode) is known. (~10 µm). Also the net current from the beam can be integrated and from it we can extract the Charge Factor and its variation along groups of nozzles. Both bottom and top electrodes are kept at virtual ground thru the current measurement op-amps, thus the Print-Head effectively senses one uninterrupted ground plane.

This system allows verifying manufacturing variations and defects as well as basic behavior, note from figure 6 that there is noticeable non-uniformity of the beam currents across the width of the print head. Process optimization and improved control of the coating and lamination steps required to make the head yielded significantly improved results as shown in figure 7.

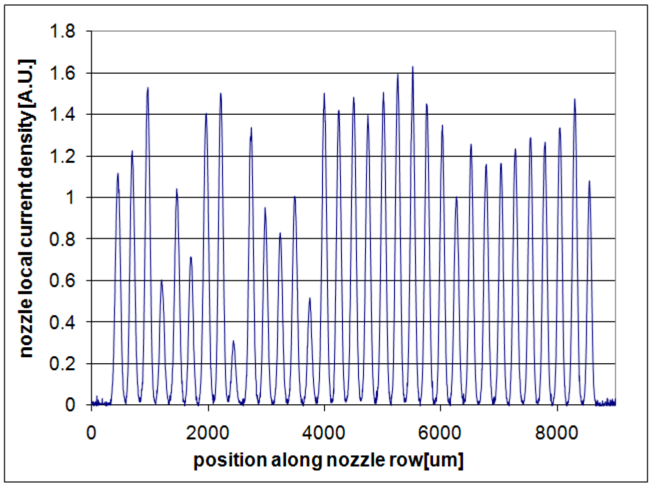

Figure 6. Beam profile for an early Ion Print-head, the local current density is shown in arbitrary units for comparison purpose only

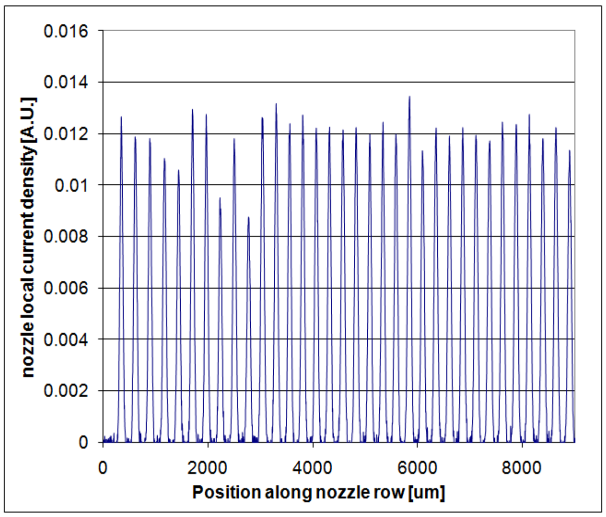

Figure 7. Beam Profile for an Ion Print-Head after manufacturing process was optimized, the local current density is shown in arbitrary units for comparison purpose only

Discharge electrode design

Although the plasma initiation within the Ion head gap cannot be fully explained using Paschen's curve[5], this simple tool still brings some insight as to what happens when the nozzle is miniaturized[7]. Combining Paschen's curve with a simple electrostatic simulation of the discharge electrode, dielectric and embedded electrode system allows computing the area of the dielectric which will be involved in a discharge as well as the potential Charge Factor, assumed to be the charge that may accumulate on the dielectric limited only by Paschen's minimum potential for breakdown. Figure 6 shows the results of this simplified calculation which reveals how the potential Charge factor from an Ion Print-head Nozzle would scale with diameter, note that the scaling drops faster than the nozzle area. In contrast the optimized nozzle geometry shown also in figure 8 shows improved performance when scaling down to small 35 µm nozzle diameters.

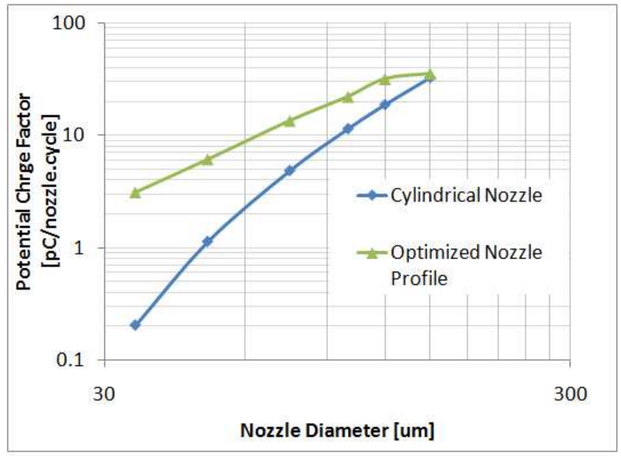

Figure 8. Nozzle Potential Charge factor scaling with diameter from electrostatic numerical simulation and application of Paschen's curve

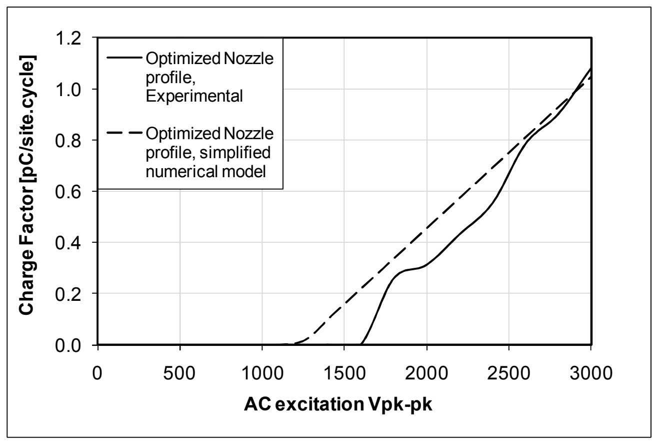

Figure 9. Comparison of small dot Ion Print-Head experimental charge factor results with simplified Numerical model. Extraction field1.8 V/µm. The Print-Head had a 35 µm discharge electrode and no screen electrode.

This optimized geometry was implemented and results from an operational head are shown figure 9, note that the simple model predictions provide an upper bound for the Ion Print-Head charge factor as expected. The threshold for turn on is not predicted accurately, which is not surprising given the simplicity of the model. This Print-Head only had a discharge electrode and no screen electrode, the experiments were run under a Nitrogen atmosphere[3] with a negative bias so that ion mobility limitations would not dominate the results.

Screen Geometry Optimization

The ability to profile independent nozzles allows making large amount of experiments quickly across multiple geometries. Discharge electrode plates with varying apertures (40 µm thru 120 µm) were made and assembled with screen electrodes with a single aperture diameter (50 µm) as shown pictorially in figure 10. Individual beams were scanned using the knife edge generating the data shown in figure 10. Results are shown for both the full width half maximum (FWHM) beam diameter and the nozzle Charge factor. Data represents results over tens of nozzles.

From figure 10 we can observe that the screen aperture almost solely dictates the size of the beam, it being fixed at about 48µm to 50 µm. Also we observe that the achieved charge factor has a local maximum at about 60 µm discharge electrode diameter, the increased current obtained from doubling the nozzle diameter is only about 20%. This result shows that it is not efficient to use a large generator electrode with a small screen as most of the current is lost to the screen electrode simply resulting in extra heat dissipation from the Ion Head.

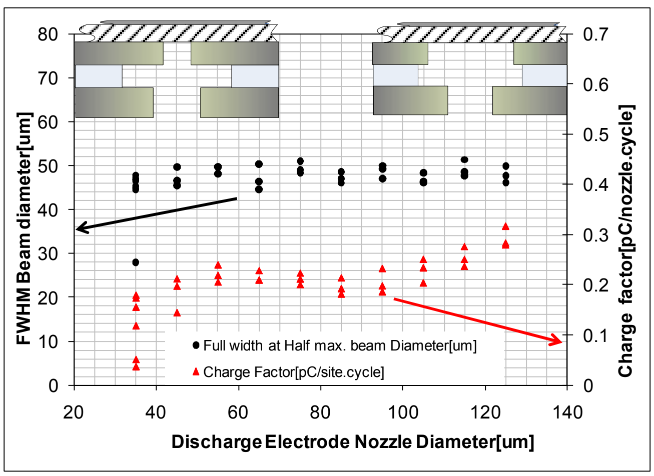

***Figure 10**. Effect of varying discharge electrode diameter for fixed screen diameter on Charge factor and Beam width*

Concluding Remarks

Experimental results for a small dot Ion Print Head being built at HP laboratories is shown. In spite of the manufacturing challenges related to constructing such a device we have overcome them and shown data for operational print heads with the capability of producing charge beams narrower than 50 µm. We have also shown a set of analytical tools that allow detailed measurements on the print head performance. Through the use of these tools we have been able to find optimal geometrical configurations for our print head.

References

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Author Biography

Napoleon Leoni is a Mechanical Engineer in the Commercial Print Engine Lab of Hewlett Packard Laboratories. He received his B.Sc. in Mechanical Eng. from Universidad Simon Bolivar in 1994 and his Ph.D. from Carnegie Mellon University in 1999. Prior to joining HP he worked on nano-positioning systems for Disk Drive head testers. He joined HP in 2003 and has worked on novel charging systems for digital presses.

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Richard Fotland is a consultant with over 50 years experience in product and process development. His professional achievements have been recognized thru many awards including the Society for Information Display Johann Gutenberg Award and the IS&T Kosar Memorial Award for the development of Ion Printing. He holds a B.S. Physics(1954), and a M.S. E.E(1958) from Case Western Reserve.