BUBBLE JET PRINTHEAD WITH INTEGRATED POLYIMIDE NOZZLE PLATE

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ABSTRACT

This paper reports for the first time on a new 1/3 inch thermal bubble jet printhead with integrated nozzle plate. The printhead is a combination of a standard printhead substrate with a new three-dimensional structured polyimide nozzle plate avoiding a three layer assembly known from other commercial printheads. The 50 µm thick nozzle plate contains the fluidic channels and 208 nozzles with minimum lateral dimensions of 10 µm. The misalignment of the two laser structured layers has proved to be less than 1 µm. The nozzle plate is assembled with the substrate using a 3 µm adhesive layer with an alignment accuracy of 3 µm. The integrated nozzle plate leads to a better control of the printhead geometry and saves one processing step in production. Fully three-dimensional Computational Fluid Dynamic (CFD) simulations have been performed to investigate the effect of misalignments, the thickness of the adhesive layer and heater geometry. The agreement between simulation and experiment is better than 5 %.

1. INTRODUCTION

The aim of inkjet printhead manufacturers and many research establishments is the optimization concerning maximum print frequency, active area of the printhead, resolution and quality of ejected droplets [1-5]. This requires a further miniaturization and optimization of the printhead geometry including fluid channels, heaters and nozzles to achieve an ideal printhead performance. Furthermore the number of nozzles and the printhead size should be increased to gain printing speed. An important tool for the optimization is the modelling of the complete device by computational fluid dynamics (CFD) simulations which is very cost- and time-effective compared to experimental hardware optimization. Also the use of integrated nozzle plates is beneficial for the optimisation of the printhead as will be shown in the following.

2. INTEGRATED NOZZLE PLATE

The integrated nozzle plate with two precisely aligned structural layers is made by an advanced laser ablation process considering an adequate design of the fluidic supply which is of outstanding importance to achieve high print frequencies [6]. This integrated nozzle plate avoids a generally used three layer design where the first layer includes the electronics and the heaters, the second layer contains the fluidic parts like channels or nozzle chambers and finally the nozzle plate with usually laser drilled nozzles [7]. Additional advantages are the reduction of processing steps and the necessity of only one alignment step. Due to this, smaller fluidic structures can be realized leading to a better control of the printhead geometry and to improved optimization opportunities for the ejection process.

After having validated the feasibility of such an integrated nozzle plate for a 1/3 inch printhead it is intended to fabricate a one inch prototype to meet the demands of high print speed and large format. This is very challenging because of the high requirements concerning the alignment of nozzle plate and substrate, the fabrication technology and assembly of the printhead.

Laser machining

An excimer laser (LPX 305 made by Lambda Physik AG) with a wavelength of 248 nm was used to structure different variations of integrated nozzle plates: A 1/3 inch nozzle plate and finally a one inch nozzle plate with different channel / nozzle dimensions and different foil thickness, respectively.

The 1/3 inch nozzle plate can be processed by using a commercial excimer laser system. But the structured area of a one inch nozzle plate exceeds the exposure area of typical commercial systems for excimer laser ablation. The whole structured area of a one inch nozzle plate must be firstly divided into several parts and then the laser has to step these parts sequentially. This can easily be realized for the nozzle layer. The channel layer however, is a whole area without any break. A stepping process would produce overlaps between the sub-areas. To avoid this, a full-scale scanning process was applied for lasering the channel layer. With this process the nozzle plate was structured by 2-dimensional scanning "on the fly".

The 50 µm and 75 µm thick polyimide foils (for the 1/3 inch and for the one inch nozzle plate respectively) were structured successfully in two precisely aligned structural layers by the 2-dimensional scanning process in combination with the sequential nozzle stepping. The two masks required contain the nozzle chamber with the ink channels and the

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nozzle, respectively. The misalignment of the both laser processes is less than 1 µm. A SEM picture of one nozzle chamber of the nozzle plate is depicted in figure 1 a) and the corresponding nozzle outlet is displayed in figure 1 b). An excellent sharpness of the edges and planar surfaces can be observed. In figure 2 a similar picture for the one inch nozzle plate is displayed.

To fulfill the specifications of different nozzle and chamber designs the draft angle of the lasered structures can be varied between 7° and 28° by varying the energy density of the laser pulse in a certain range and in addition by using other techniques such as a wobble plate in the laser optics.

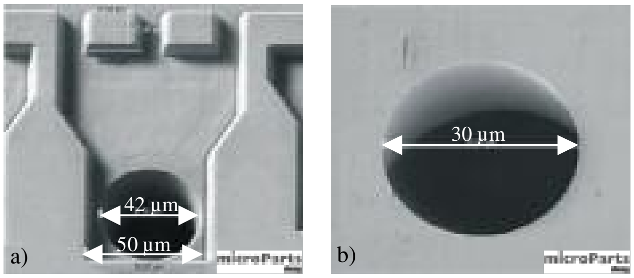

Figure 1: Full-scale lasered 1/3 inch nozzle plate consisting of two precise aligned structural layers. The nozzle chamber, ink channel and the nozzle. View from the inlet a) and outlet b), respectively.

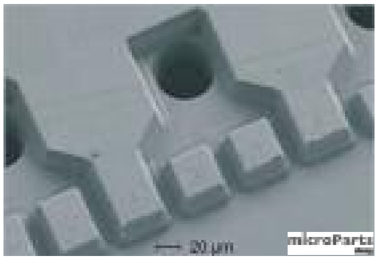

Figure 2: Full-scale lasered one inch nozzle plate consisting of the two precise aligned structural layers

Surface treatment

After the laser machining of the nozzle plates various treatments of the surfaces are required. On the one hand a cleaning of the laser entry side is necessary to remove the hangover of the laser process, not only for the performance but also for the liquid-tight assembly of the nozzle plate with the substrate. Therefore different kinds of cleaning processes such as cleaning with organic / inorganic solvent, ultrasonic cleaning and plasma cleaning using oxygen (O_2), oxygen-argon (O_2-Ar) or oxygen-tetrafluoromethane (O_2-CF_4) and combinations of those processes were tested to prove the best purification. Process optimization for the nozzle plate cleaning has been made successfully with a commercial system. The best result was obtained using the oxygen plasma in combination with a suitable pre-cleaning like it is depicted in figure 3 before a) and after the cleaning b), respectively.

On the other hand a surface treatment of the front side of the nozzle plate is necessary to provide an adequate hydrophobicity. Using a chemical treatment leads to an increase of the contact angel of up to 95° and shows a better long-term stability compared to conventional plasma treatments.

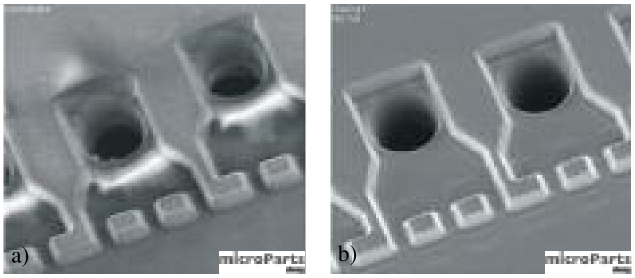

Figure 3: Laser structured nozzle plate before a) and after b) the cleaning in an oxygen plasma.

3. ASSEMBLING

The assembly of the structured nozzle plate is a major challenge for completing the printhead. Especially in view of handling a one inch nozzle plate - as foreseen for the final prototype - the integration process becomes critical. A further challenging requirement is the minimum height of the adhesive to guaranty the maximum printhead performance.

The assembly of the structured nozzle plate was achieved using a procedure derived from the transfer technique illustrated in figure 4. Cavities measuring few micrometers in depth were used to provide the adhesive in a predefined layer thickness. Epoxy was chosen because of the suitable media properties and good adhesion abilities. Using an especially adapted handling unit, the structured nozzle plate itself served as a stamp to pick up an approximately 3 µm thick adhesive layer from the silicon cavities.

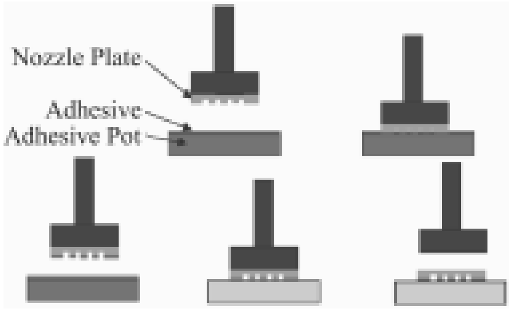

Figure 4: Schematic illustration of the adhesive transfer process.

The coated nozzle plate was then aligned onto the printhead substrate applying a FinePlacer of FineTech GmbH [8] to seal the individual channel structures against each other with a very good reproducibility without clogging of the fine structures (cf. figure 5). The adhesive Epotek 353ND by Polytec [9] showed adequate performance to create a layer thickness of approximately 3 µm. The achieved alignment accuracy was measured to be 3 µm. After an adequate curing process, satisfactory bond forces were obtained.

The assembling of a one inch nozzle plate is still in progress at the moment and will result in printheads with integrated nozzle plate of one inch size in the near future.

To prove the successful assembling of the integrated nozzle plate first the capillary filling of the printhead was studied using an optical observation like it is displayed in figure 5. Afterwards the functionality of the printhead was analyzed by operating single nozzles at different frequencies and taking stroboscopic pictures which are illustrated in figure 6. After operation and cleaning with acetone in an ultrasonic bath the printhead demonstrated a good and reproducible functionality which argues for the robustness of the assembling process.

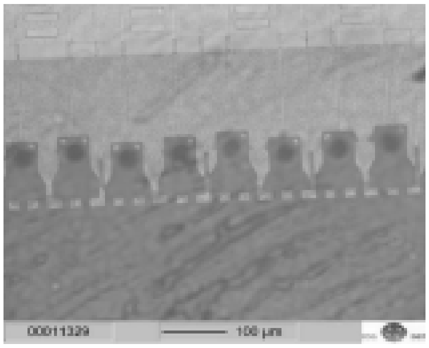

Figure 5: Assembled nozzle plate on printhead substrate. The dark areas are ink filled cavities, whereas the light areas represent leak-proof joined areas.

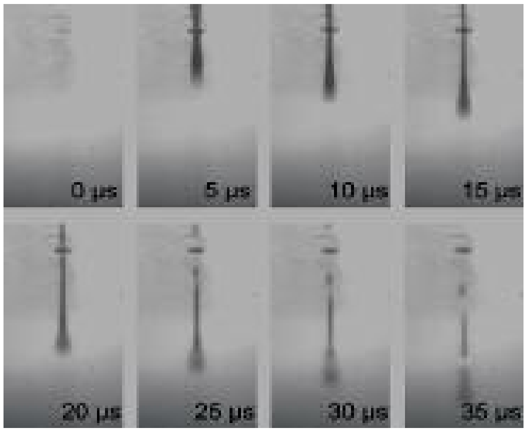

Figure 6: Ejection cycle of one of the first prototypes.

4. SIMULATION

In order to estimate the effect of the inevitable adjustment tolerances on the printhead performance simulations of the inkjet have been performed.

To simulate the entire ejection process of a thermal bubble jet printhead an appropriate pressure boundary condition [10-13] was used to set up a three-dimensional CFD simulation [14]. The modelling of the droplet ejection process was performed by the simulation package ACE+ from CFDRC [15]. A 3D model of an Olivetti I-Jet printhead, like it is displayed in figure 7 has been set up to simulate a complete dosage cycle including first priming, printing and refilling.

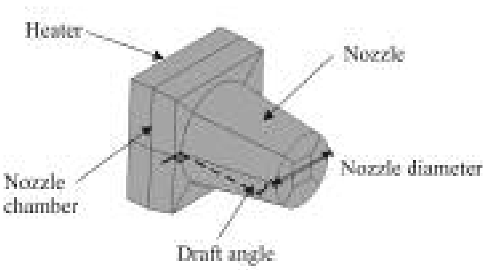

Figure 7: Simplified picture of the 3D model of one nozzle of the bubble jet printhead showing only the fluidic part (inlet channels not shown).

Comparing the simulations with experimental results like stroboscopic pictures as displayed in figure 8, good qualitative agreement has been obtained. The shape of the droplet and the tail look very similar. There is also a good quantitative agreement between experimental findings and simulations. The gravimetrically measured droplet volume of 26.0 pl agrees well to the simulated volume of 25.6 pl.

Thus the used pressure boundary condition, presented for the first time by Asai [10-13] for a 2D case, can also be applied successfully for the 3D case. The applicability of the simulation model is validated with tolerable deviations.

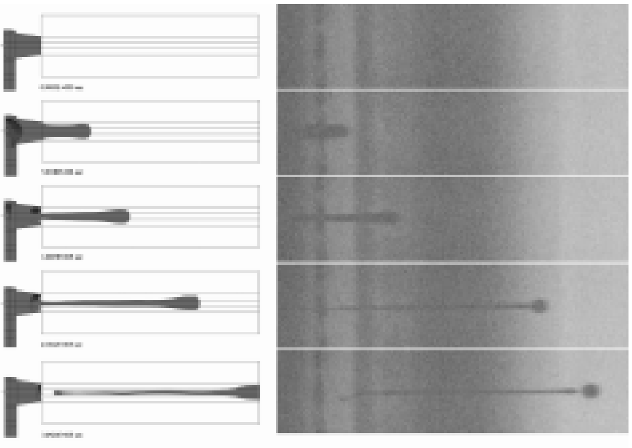

Figure 8: Comparison of the 3D simulations of the droplet ejection (only the fluidic part is shown) and the corresponding stroboscopic pictures from Olivetti I-Jet.

Simulation results

After having validated the simulation model further simulations have been performed to optimize the printhead by varying parameters like geometry dimensions, heating pulse or ink properties.

The knowledge of the allowable tolerances of lateral adjustment deviations or differences of chamber height are very important for the laser machining and the assembly and packaging of the printhead, particularly for the intended assembling of the one inch printhead. The effect of a variation of the draft angle which is affected by the laser machining process on the droplet volume and velocity is displayed in figure 9. In the same way the effect of other geometric parameters like nozzle diameter or nozzle length can easily be simulated.

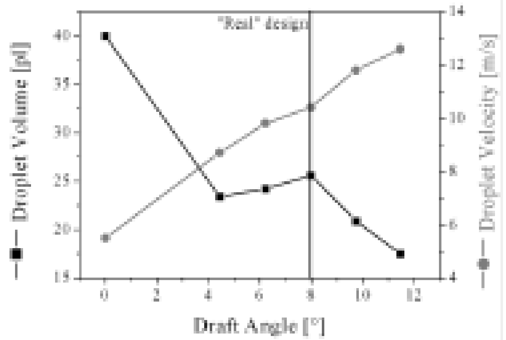

Figure 9: Simulated effect of varying the draft angle on the droplet volume and velocity.

The effect of other variations like an adjustment deviation or an additional height of an adhesive on the droplet volume and velocity is summarized in figure 10. Combining all this results with earlier simulation results considering the effect of ink properties [14] the optimum interaction between print head geometry and ink parameters can be found.

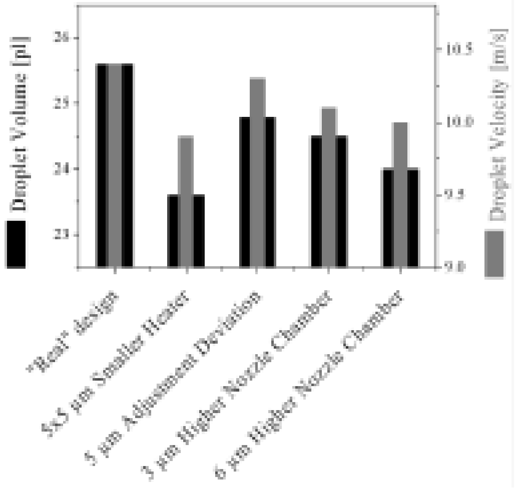

Figure 10: Comparison of simulated droplet volumes and velocities considering different geometrical tolerances.

5. CONCLUSION

The presented innovative laser micromachining of a polyimide integrated nozzle plate and the assembling procedure using an adhesive transfer technique provide an improved manufacturing method for bubble jet printheads in order to realize high speed and wide format inkjet printer. The integration of the channel layer and the nozzle layer in one material and one process step in contrast to standard manufacturing methods offers better accuracy and saving of one adjustment step. The presented three-dimensional simulation model of the thermal ink jet printhead verified by experimental results provides a valuable approach to understand and optimize thermal bubble jet printheads.

ACKNOWLEDGEMENT

This work was supported by Federal Ministry of Education and Research (BMBF), Germany (grant no. 16SV1607) within the EURIMUS program (IDEAL EM 42).

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