The Performance of High-Frequency and Picoliter-Droplet Inkjet Printhead by a Standard CMOS Processes

Jian-Chiun Liou, Chun-Jung Chen, Wen-Chien Liu, and Chi-Ming Huang
K200/OES/ITRI, Industrial Technology Research Institute
Chutung, Hsinchu, Taiwan, R. O. C.

Abstract

Enhance of the number and array density of nozzles within an inkjet head chip is the key to raise the printing speed and printing resolutions. The smart printhead has been designed by a 0.5 um CMOS processes. The physical design rules of 0.5um 2P2M 12V/12V, (Double Poly Double Metal Vds/Vgs) high voltage process and MIXED-MODE processes. This study develops the integrated multiplexer driver inkjet head (IMDH) by a standard CMOS processes to reduce the connecting addresses needed for controlling the nozzle orifices which ejection the small size of droplet. By using both the high-dose current (HDC) driver and high-dose current driver integrated (HDCI) process, it is able to control over 400 nozzles within an inkjet head chip and improve the chipset packaging density and alignment accuracy. The spec of IMDH printhead developed by OES/ITRI is 408nozzles/432heaters, 5 pL of ejected droplet volume and with the operating firing frequency of 18kHz. Combining both the HDCI process and high-density micro-fluidic channel design architecture, IMDH inkjet head is the supreme product developed by OES/ITRI in the present state and is the same or even higher level with famous factory's highest end of commercial products. This technology could be applied not only on the inkjet printhead products but also on many other applications.

Introduction

The integrated multiplexer driver inkjet head (IMDH) by a standard CMOS processes model. The physical design rules of 0.5um 2P2M 12V/12V, 12V/5V(Double Poly Double Metal, Vds/Vgs) high voltage process is included in this study. It is used as a basic layout guide for those who want to design and layout a high voltage circuit based on the 0.5um DPDM 12V/12V, 12V/5V MIXED-MODE process. This process was studied by what's different from the original 0.5um CMOS MIXED-MODE (DPDM, 5V) DESIGN RULES. That is NDD, PDD, HV OX rules and the high voltage device rules are particularly specified in this process. Others not mentioned are kept the same as 0.5um CMOS MIXED-MODE DESIGN RULES. Basically, the LV (Low Voltage) part is of 5V logic, and the layout rule is the same as tsmc's generic 0.6um DPDM (include PO1/PO2 capacitor option) ASIC design rule. For HV (High Voltage) part, The asymmetric HV device structure (HV only apply on the Drain side, not source side) is recommended for lower Ron and higher current drive purpose. Few customers may need symmetric device structure (Source structure same as Drain) for some reasons. However, both symmetric and asymmetric have the same design rule. This design rule (or layout rule) has been defined with the dimension on wafer. The differences of the feature sizes between mask pattern and wafer pattern should be adjusted by CAD (Computer-Aided Design) bias.

From an IC process engineer's point of view, the existing thermal inkjet process (Figure 1) can be thought of as a special double-level metal interconnect process with an unusual interlevel dielectric, namely the SiNx/SiCy thermal inkjet passivation, and an upper interconnect level consisting of a thick refractory glue layer and a thinner noble bonding layer. If the first-level thermal inkjet conductor could also serve as the IC contacting metallization, and if the IC interlevel dielectric could be part of the thermal inkjet oxide underlayer, an elegantly simple process could be achieved. The resulting merged MOS and thermal inkjet structure is shown in Figure 2.

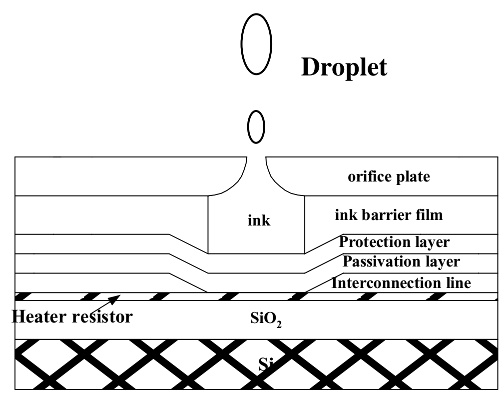

Figure 1. Thermal inkjet structure

Microheaters offer a large potential for industrial and scientific applications. The bubble ink jet is the most important commercial example. Furthermore, or micro-heaters can act as pressure sources in micropumps, or microdrop valves, or can be the key actuators in micro reaction chambers. The use of thermal microheaters in the bubble inkjet technology is illustrated in Figure 1.

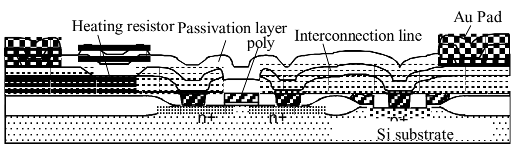

Figure 2. Merged MOS and thermal inkjet structure

Process Implementation

A thermal ink jet heater array with integrated power drivers and logic addressing circuit processes, the multiplexer inkjet printhead process block is shown in Figure 3. Beyond 400 heat-generating elements are at one end thereof connected to the power source via the common electrode, and are at the other end thereof connected to the driver elements respectively. The driver elements can be formed from; e.g., a MOS-FET or a transistor, and drive the heat-generating elements.[1] The ASIC circuit boosts a drive signal for the corresponding heat-generating element and enters the thus-boosted drive signal into the control electrode of the driver element,a gate electrode of a MOS-FET. The NAND circuit receives one split-block drive signal, an ENABLE signal, and a data signal from the 16-bit latch. The NAND circuit outputs the drive signal to gate of the corresponding heat-generating element is selected; while there is data to be printed; and while the NAND circuit has received the ENABLE signal.[2]

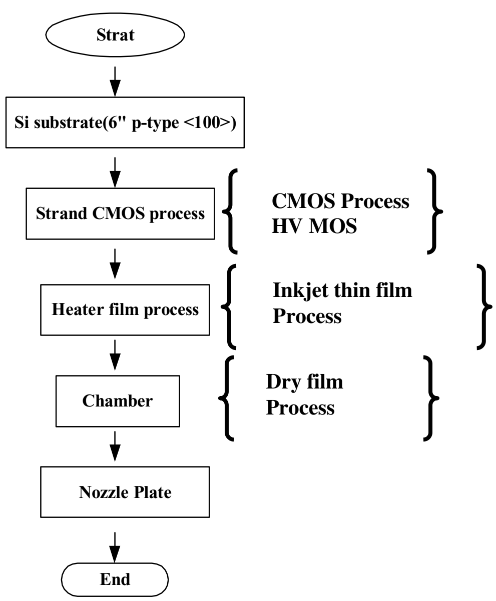

Figure 3. Process flow of the multiplexer inkjet printhead

Although many different CMOS and other processes can be used, this process description is combined with an example CMOS process to show where MEMS features are integrated in the CMOS masks, and show where the CMOS process may be simplified due to the low CMOS performance requirements. Process steps described below are part of the example 'generic' 1P3M 0.5 micron CMOS process. The CMOS structure is shown in Figure 4.

IMDH processing starts with a standard 6" p-type <100> wafer. Using the n-well mask and implant the n-well transistor portions. Grow a thin layer of SiO.sub.2 and deposit Si3N4 forming a field oxide hard mask. Etch the nitride and oxide using the active mask. The mask is oversized to allow for the LOCOS bird's beak. Implant the channel-stop using the n-well mask with a negative resist, or using a complement of the n-well mask. Perform any required channel stop implants as required by the CMOS process used. Grow 0.5 micron of field oxide using LOCOS. Perform any required nip transistor threshold voltage adjustments. Depending upon the characteristics of the CMOS process, it may be possible to omit the threshold adjustments. This is because the operating frequency is only 3.8 MHz, and the quality of the p-devices is not critical. The n-transistor threshold is more significant, as the on-resistance of the n-channel drive transistor has a significant effect on the efficiency and power consumption while printing. Grow the gate oxide. Deposit 0.3 microns of poly, and pattern using the poly mask so as to form poly portions. Perform the n+ implant using the n+ mask. The use of a drain engineering process such as LDD should not be required, as the performance of the transistors is not critical. Perform the p+ implant, using a complement of the n+ mask, or using the n+ mask with a negative resist. Deposit 0.6 microns of PECVD TEOS glass to form ILD 1. Etch the contact cuts using the contact mask. The nozzle region is treated as a single large contact region, and will not pass typical design rule checks. This region should therefore be excluded from the DRC. Deposit 0.6 microns of aluminum to form metal 1. Etch the aluminum using the metal 1 mask so as to form metal regions. Deposit 0.7 microns of PECVD TEOS glass to form ILD 2 regions. Etch the contact cuts using the via 1 mask. The CMOS parts of the integrated multiplexer driver inkjet head (IMDH) is finished.

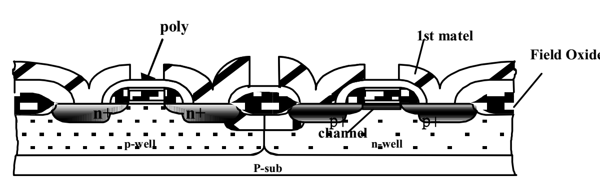

Figure 4. The CMOS structure

Next, integration of power MOSFETs and TIJ heater resistors allows individual jet firing to be controlled by a matrix addressing arrangement. Matrix addressing allows great reduction in lead count to the TIJ printhead. Many cost and system layout factors are improved by on chip. A layer of aluminum-silicon-copper (Al-SiCu) alloy conductor is conventionally magnetron sputter deposited to a thickness of approximately 5000.ANG. atop the tantalum aluminum layer areas and etched to provide discontinuous and independent electrical conductors and interconnect areas. To provide protection for the heater resistors and the connecting conductors, a composite layer of material is deposited over the upper surface of the conductor layer and resistor layer. A dual layer of passivating materials includes a first layer of silicon nitride (Si.sub.3 N.sub.4) in a range of 2350.ANG. to 2800.ANG. thick, which is covered by a second layer of inert silicon carbide (SiC) in a range of 1000.ANG. to 1550.ANG. thick. This passivation layer provides both good adherence to the underlying materials and good protection against ink corrosion. It also provides electrical insulation. An area over the heater resistor and its associated electrical connection is subsequently masked and a cavitation layer of tantalum in a range of 2500.ANG. to 3500.ANG. thick is conventionally sputter deposited. A gold layer may be selectively added to the cavitation layer in areas where electrical interconnection to the flexible conductive tape is desired.

Figure 5 illustrates the merging of integrated circuit and thermal inkjet technologies. Note how powerful the technology merging can be as chamber sizes continue to shrink in the future. Printhead Design and Fabrication Processes.[3] Today the ink-jet technologies most active in laboratories and in the market are the thermal and piezoelectric drop-on-demand ink-jet methods. In a basic configuration, a thermal ink-jet consists of an ink chamber having a heater with a nozzle nearby. A part of the multiplexer inkjet head chip is shown in Figure 6, there are three main blocks, heater region, MOS driver, and CMOS logic region.The multiplexer inkjet printhead different from tradition only MOS driver on printhead is logic circuit on printhead. Thus, the function is a serious in-parallel out signal for more and more jets.

Figure 7 shows a scanning electron microscope (SEM) photograph of channel integrated multiplexer driver inkjet head (IMDH). The dimensional stability, accuracy, and uniformity of this channel are known to have great effects on jet performance such as drop frequency, volume, and velocity. All of these drop performances ultimately determine the quality and throughput of a printed image. The trends in the industry are in jetting smaller droplets for image quality, faster drop frequency, and a higher number of nozzles for print speed, while the cost of manufacture is reduced. These trends force further miniaturization of the ink-jet design. Consequently, the reliability issue becomes critical.the company introduced a new beyond 400 nozzles tricolor printhead that can jet much smaller ink droplets (5 pl).[4]

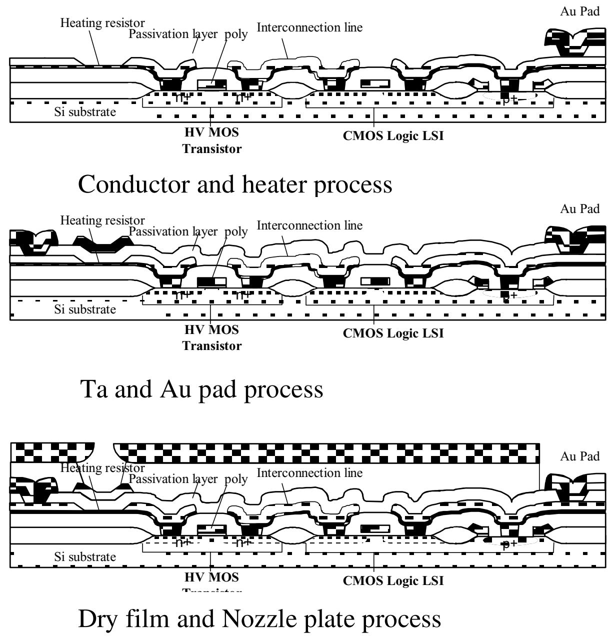

Figure 5. The merging of integrated circuit and thermal inkjet technologies.

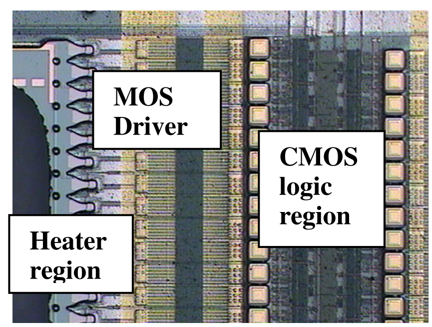

Figure 6. The part of the integrated multiplexer driver inkjet head (IMDH)

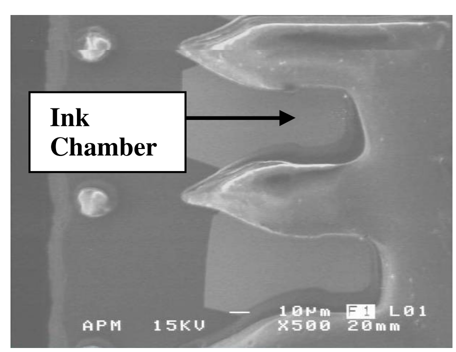

Figure 7. A SEM photograph of a channel

Results and Discussion

The equipment of droplet observation was setup consist of CCD camera, control board, control program and PC. Figure 8 show the equipment.

Figure 9 shows the image captured by the experiment equipment. The figure shows the ink ejected out of the nozzle, and its direction is down. The image postprocessor program was developed by our group to measure the droplet length from the image. The program can measure droplet length on-line and off-line. The program can continually measure the droplet length and output the data to an ASCI text file.

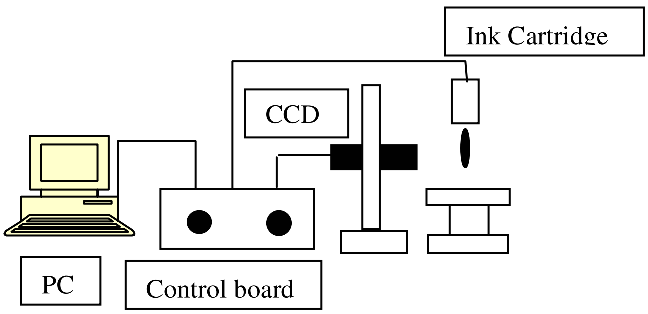

Figure 8. A sketch map of equipment

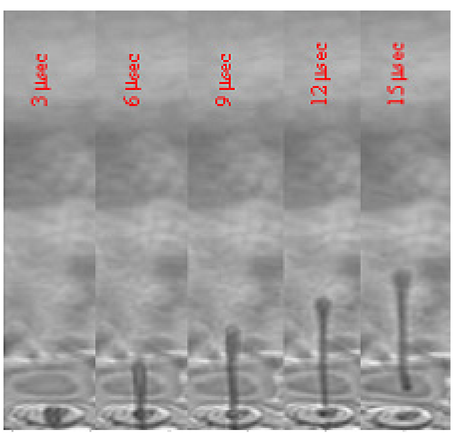

Figure 9. Experiment image

The channel heater is measured about one mil square. Ink feeds from both sides of the heater chamber. This fluid architecture would significantly decrease the possibility of nozzle clogging that may result from particulates trapped in the printhead fabrication processes as well as in the process of making inks. A row of small openings between the ink manifold and the heater chamber was also introduced in the new design, in order to improve the reliability of the new printhead.

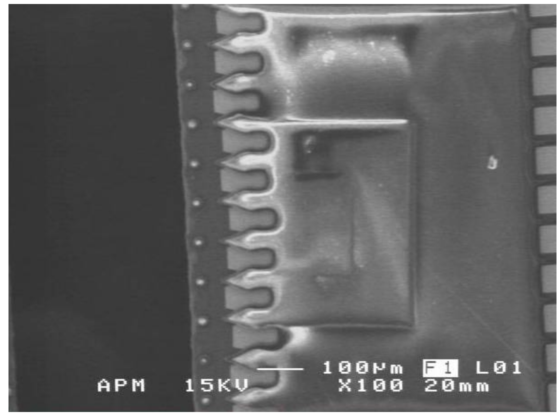

Figure 10. A light microscopic photograph of a channel in the IMDH printhead.

Figure 10 is shown a light microscopic photograph of a channel in the IMDH printhead, the channel and chamber designed is the best tape for integrated multiplexer driver inkjet head (IMDH).

Another trend in the industry is market demand for lower cost per print. Printhead producers could pack in greater ink volume per cartridge to increase the print count or install a permanent or semipermanent thermal printhead to reduce the cost of new ink cartridges. Again, this trend will demand even higher reliability for thermal ink-jet printheads.

Another important consequence concerns the early stage of bubble growing. Since the critical nuclei near the spinodal are spatially extended the initial bubble nuclei must be considered as spatial extended, too. The visualization has been performed with the stroboscopic technique described in detail in Ref. [5]. In contrast to classical boiling the vapor bubbles grow from extended nuclei. The rapid phase change process looks like common film boiling but, in fact, the underlying mechanisms are quite different as mentioned in the previous subsections.

The performance of high-frequency and picoliter-droplet inkjet printhead is demonstrate the droplet frequency, print resolution, drop size, nozzle amount, and the lower input signal interconnect line to addressing beyond 400 jets, even more. The multiplexer inkjet printhead different from tradition only MOS driver on printhead is logic circuit on printhead. Thus, the function is a serious in-parallel out signal for more and more jets.

Summary

The microelectronic integration of the intimate electronics needed to operate a large array of TIJ jets has allowed thermal ink jet to capture the market for desktop printers by offering users superior cost and performance. Further integration of logic for powerful function is enabling thermal ink jet-based products to move ever further up-market. The depicted integrated circuit thermal ink jet transducer array serves beyond 400 jets and includes data interfacing, jet addressing, drop generation power pulsing, and bidirectional operation. The chip also includes output features that facilitate the electronic management of assembly of multiple chips into larger arrays. The illustrated thermal ink jet chip design allows beyond 400 jets to be operated with less than ten input control lines.

References

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Biographies

Jian-Chiun Liou joined the Printing technology Development and Manufacturing Section of OES/ITRI in 1999. He received his M.S. degree from Institute of Electronic of National Taiwan Ocean University, Taiwan. He interest lies in the ASIC design, MEMS technology and integration of inkjet printhead processes.

Chi-Ming Huang joined the Printing technology Development and Manufacturing Section of OES/ITRI in 2002. He received his M.S. degree from Institute of Applied Mechanics of National Taiwan University, Taiwan. His current research includes MEMS technology and integration of inkjet print head process.

Chung-Jung Chen joined the Printing technology Development and Manufacturing Section of OES/ITRI in 1990. He received his M.S. degree from Department of Power Mechanical Engineering of National Tsing Hua University, Taiwan. He interest lies in electro-photography, media handling of printer and magnetic damper. He is the department manager of printing Device Department in OES/ITRI.

Wen-Chien Liu joined the Printing technology Development and Manufacturing Section of OES/ITRI in 1989. He received his P.H.D. degree from Department of Photonics Engineering of National ChiaoTung University, Taiwan. He interest lies in the Photonics in OES/ITRI.