HISTACK - One-Inch Modular Printhead

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Abstract

HISTACK (High Performance Interconnect & Stacking, ESPRIT Project Nr. 25345) is a research project, funded by the European Commission, with the goal to develop an interconnect technology for smart microsystems. The technology has been demonstrated for two applications: a silicon microphone for hearing instruments and an ink jet print head for post franking and ticket stamping. The project was started on November 1997 and finished on October 2000, and the partners involved were:

Microtronic (DK), Olivetti I-Jet (I), CSEM (CH), DELTA (DK), MIC (DK), CEA-LETI (F)

Olivetti I-Jet (that at the project start was named Balteadisk) was involved in the part of the work program related to the ink jet print head demonstrator; the objective was to develop a technology solution for the industrial fabrication of a one-inch ink jet device for industrial applications (post franking), realised by the self-alignment of an array of bubble ink jet printhead silicon chips. The main results of the project were an assembling process (by CEA-LETI), the design and realisation of a half-an-inch ink jet silicon chip actuator, the design of an assembly mother board for two chips, and the prototyping of one-inch ink jet printhead. Design and prototyping of the ink jet chips and printhead cartridges were made in the Olivetti I-Jet labs of Arnad, Italy; CEA-LETI Institute in Grenoble, France developed the assembly technology for the ink jet chips.

Background and Project Rationale

The two versions of drop-on-demand ink jet printing technology, thermal (also known as bubble) and piezoelectric, have been, and continue to be, in widespread use in home and office products such as printers, fax machines, word processors, multi-purpose products (i.e. able to write, read and transmit) and calculators etc.

Typically, these products have high printing quality, both black and white and colour. As far as colour printing is concerned, by using special paper the quality achieved can be so high as to be comparable with photography, which could obviously lead to interesting evolutions.

Today, notwithstanding the often misleading declarations made by manufacturers, we can realistically talk about a printing resolution of 600 x 600 dpi for black and white, and nearly 1200 x 1200 dpi for colour. These figures alone are sufficient to show the exceptionally high level of quality reached in ink jet products.

While it is true that excellent results have already been achieved in terms of printing quality, the same can certainly not be said in terms of printing speed, especially in colour printing. This constitutes an enormous barrier, which at present has confined ink jet products to the so-called consumer product range, excluding them from any high range or industrial application.

Applications in photography are, to coin a phrase, on the border in the sense that they require very high quality, but not necessarily high speed, at least in the traditional photograph format.

Below we list some of the applications, which could be addressed if ink jet systems with higher printing speed than at present were available:

- Franking (i.e. envelope printing for post office applications)
- Ticketing
- Bar coding
- POS (Point Of Sales)
- Labelling
- Textile printing
- Billboarding
- Plotting

These are only a few of the sectors in which it is known that studies on the use of ink jet technology are being carried out. The markets in question are clearly enormous, and therefore very attractive from the industrial point of view. The strategic aim of the project will thus be to develop technologies allowing higher printing speeds to be reached.

Drop-on-demand ink jet systems usually work in scanning mode, passing again and again to deposit the ink on the paper. Each time the printhead passes, the paper advances the same distance as the height of the swath. In order to increase printing speed, it is therefore obvious that, based on what has been said, two directions can be followed:

- To increase the scanning speed
- To increase the swath height.

In addition to this, especially in the case of colour printing, it is also useful to work with several printheads (e.g. three, each containing one of the three basic colours, cyan, magenta or yellow, instead of having all three colours on one printhead).

Having made this technical premise, it is then very simple to describe the state of the art today.

The scanning speed of the printhead on the paper is connected to the frequency of droplet emission. At present this is normally between 5000 and 10000 drops/sec for each ejector, with a maximum of 12000. It should be taken into account, however, that the scanning speed cannot be increased without a negative effect on the acceleration and braking dead times.

The swath height is usually 1/6th inch or 2/6ths inch, with some isolated peaks of 3/6ths inch.

This is clearly the road to follow to increase speed.

One or two printheads are normally present, with some exceptions having 4 printheads. The reciprocal positions are regulated by the user, which would obviously be a limitation in those applications (e.g. textile printing) which require many printheads (e.g. 8 or 10) working simultaneously.

The HISTACK project aim was to tackle some of these subjects and the techniques to be used to reach the targets are typical of MEMS: the objective was to develop an innovative assembling technology able to arrange on a proper board two or more printhead silicon chips and, at the same time, to solve all the electrical and hydraulic problems involved in a bubble ink jet system.

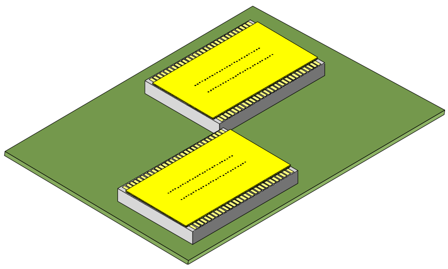

Figure 1. The HISTACK printhead principle

The HISTACK assembling process had the aim to ensure:

- The best reciprocal alignment
- The best driving electronic circuit
- The best packaging technology for ink/moisture proof durable product

Technology Development

The main objective of the project, as far as the role of Olivetti is concerned, was the development of a modular printhead and of an assembling technology capable to align two or more ink jet chips on the same mother board.

In order to experience all the critical aspects involved in this activity, the chosen prototype has been a one-inch ink jet printhead, made by the arrangement of two ink jet silicon chips having half-an-inch printing width.

The realisation of such a printhead has been addressed through the fabrication of the following different demonstrators, that were given during the development of the project:

1. Ink jet printhead chip: the base modular ink jet silicon chip
2. Printhead mother board: the board for the assembling of the ink jet printhead chips
3. One-inch printhead demonstrator: the integrated printhead prototype

The main technology aspects involved in the development of HISTACK project, as far as the IPH prototype is concerned, were:

a) Silicon chip development, in which the Olivetti background expertise in ink jet heads design was used to generate the architecture of an 156 nozzles, half an inch wide, chip
b) Printed circuit mother board design, that was the assembling board where to arrange two ink jet silicon chips in order to reach the printing width of one inch
c) Technology development of the assembling technique, able to assemble two chips with the requested tolerances, and able to be used for a printhead assembly with more than two chips for printing heads wider than one inch (two inches or more)
d) Realisation of a test bench, capable to handle and drive one-inch printing heads and to simulate the printing indicia usually adopted in the post franking applications

a) Silicon Chip Development

The silicon chip having the purpose to be used in the HISTACK printhead prototype is an ink jet actuator device with 156 nozzles addressed by an integrated power active matrix of NMOS transistors. The matrix is organised in 12 groups of 13 nozzles each, in order to minimise the number of the electrical contacts needed to drive the printhead.

The addressing of the nozzles is obtained by 13 address inputs that drive sequentially the internal NMOS of the matrix. The nozzles are arranged in two vertical parallel columns of 78 nozzles each.

The nozzles of a single column are vertically spaced of 1/150 of an inch, and the two columns are displaced vertically of 1/300 of an inch. The final results is a head chip that is able to print at 300×300 dpi in a single pass.

The realisation of the silicon chip has been carried out matching by integrating the electronic driving circuit below the actuators array, that was patterned with a multilayer thin film structure.

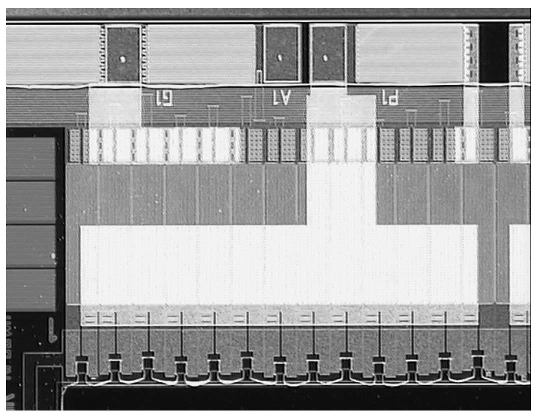

Figure 2. Printhead chip: view of a nozzle row

b) PC Mother Board Design

The motherboard designed for the HISTACK application is shown in the following picture. The electrical pattern and the materials used were chosen in order to ensure the perfect sealing of the silicon chips on the board and the highest chemical compatibility with the inks to be employed.

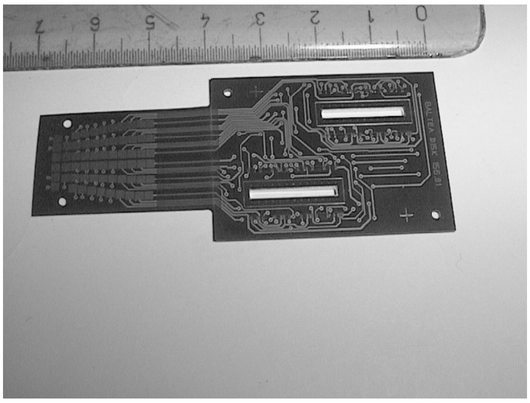

Figure 3. PC mother board

c) Assembling Process

The assembling process has been the most critical phase of the HISTACK printhead development, as it had to respect a number of leading factors, like the mechanical tolerance of the whole system that must be lower than ±10%, that includes the reciprocal positioning error of the two chips, the translation and the rotation errors.

At first, a solution with through silicon holes (feedthroughs) and flip chip bonding was proposed and investigated by LETI, but was evaluated too risky and expensive for an industrial realisation, as it introduces at least seven additional masks to the fabrication process (see next picture).

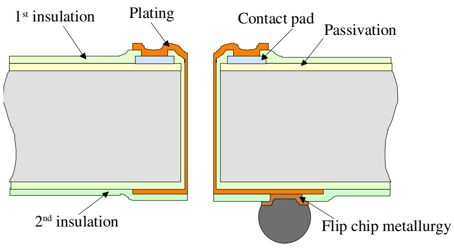

Figure 4. Feedthroughs solution (CEA/LETI - 1)

The technology process used for the demonstrator fabrication was a second solution in which only the flip chip auto-alignment was adopted and the electrical contact were realised by wire bonding, as shown in the next drawings.

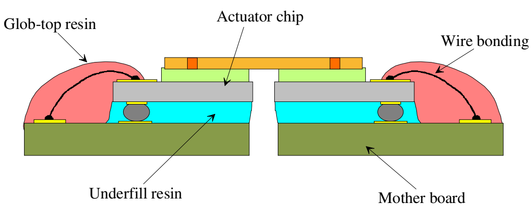

Figure 5. Wire bonding solution (CEA/LETI - 2)

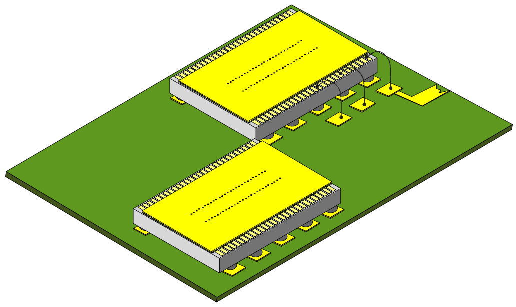

Figure 6. Wire bonding assembly

The above assembling sequence has reduced the number of additional masks from seven to just one: the mask for the bump metallurgy on the backside of the wafer.

The positioning accuracy of the assembly was tested by LETI using a CSO system, that is an optical testing machine specifically designed for the measurement of the flip-chip alignment precision. LETI and CSO Company developed the machine together.

The list of the technology process adopted for the fabrication of the HISTACK printhead prototype is reported in the next table.

Fabrication process of HISTACK printhead

Silicon wafer with ½ inch chips	Olivetti I-Jet
PCB con pattern per flip chip	Olivetti I-Jet
Backside lithography	LETI
Wafer back-end processing	Olivetti I-Jet
Bumping and reflow	LETI
Hybridisation (chip positioning and bonding)	LETI
Resin underfilling	LETI
Wire bonding	Olivetti I-Jet
Glob-top resin protection	Olivetti I-Jet

d) HISTACK Printhead Test

The test performed on the HISTACK printhead demonstrator is the standard stress test usually carried out on production printheads. The test consists in a thermal storage cycle with a step at -15°C for 12 hours, and a step at +55°C for other 12 hours. The cycle is repeated 5 times.

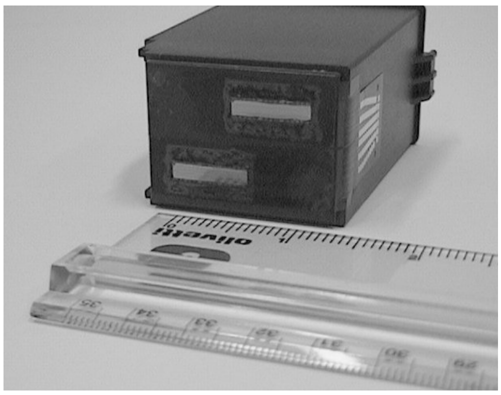

Figure 7. HISTACK prototype printhead

After the test (see next picture) the position of the nozzle plates respect to the alignment marks was not altered. Also the chip position was not modified.

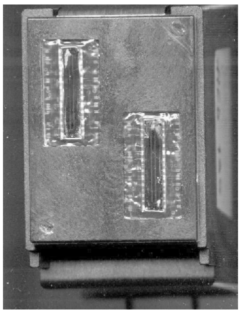

Figure 8. HISTACK printhead after stress test

The protective glue that encapsulates the electrical wires was a little bit softened by the thermal cycle, but with any consequence for the reliability of the system

Furthermore, the printhead has been evaluated on a proper test bench, to check the application capability. The picture below shows the prototype printing tool used to test the HISTACK printhead. The system consists in a test bench that can host printheads with different sizes and able to supply power separately to each nozzle varying the energy and the frequency of the ink ejection.

Figure 9. Printhead test bench

Biography

Alessandro Bellone received the Doctor degree in Physics from the University of Turin in 1985. He has worked at Marelli Autronica in the field of thick film sensors for automotive, and, in 1986, joined Olivetti central R&D Labs where has spent more than ten years as process engineer for thin films and semiconductor technology applied to printing head devices. Since 1995 he is responsible of the management of R&D projects funded by EC and National Authorities.