HP 60 INKJET CARTRIDGE

HP celebrated the 20th anniversary of their Deskjet printer this year, and it's a mark of the changes in technology in this field that the original 1988 model printed two pages/minute (ppm) and was priced at $995, whereas the latest versions print up to 36 ppm and cost as low as $29.

The HP 60 cartridge (*see Figure 1*) sells for $17.99, uses recycled plastic for the body, and has a new printhead design that ejects two sizes of ink droplets for finer detail than comparable low-cost cartridges.

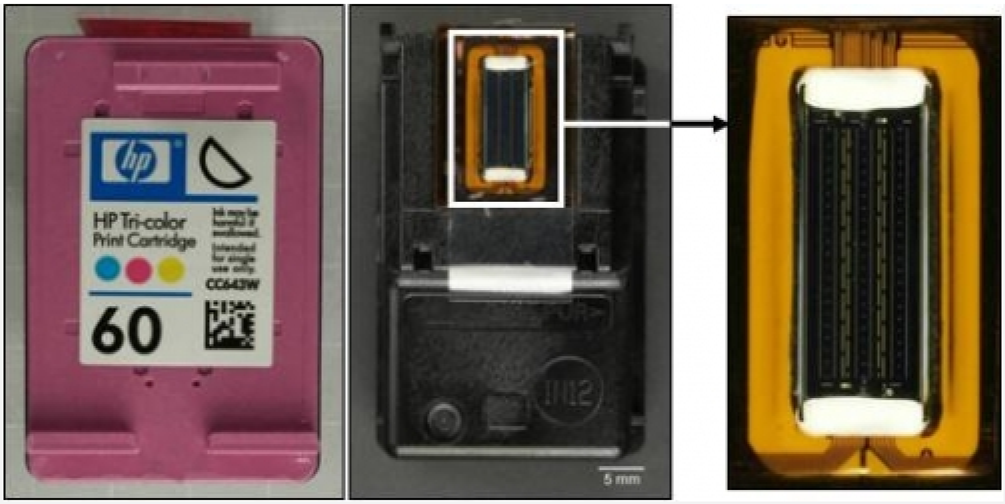

Fig. 1: HP 60 cartridge top & bottom showing printhead die.

Within the cartridge are three ink chambers filled with capillary foam for the cyan, magenta, and yellow inks. A TAB flex-circuit connects the contacts on the end of the cartridge to the bond pads at the top and bottom of the die, sealed here with white epoxy. We can see that the die is segmented into three sections for the three ink colors.

Figure 2a shows the top surface of the 4.2 × 11.5 mm die in more detail, illustrating the six rows of ink nozzles, two rows for each color. In *Fig. 2b* we have a closer tilted SEM view of one end of the device, showing that the nozzle plate is laid on top of the silicon die, and *Fig. 2c* is a higher magnification image of a group of nozzles, with the two different nozzle sizes (for the two droplet sizes) clearly visible. There is a recessed apron around each nozzle.

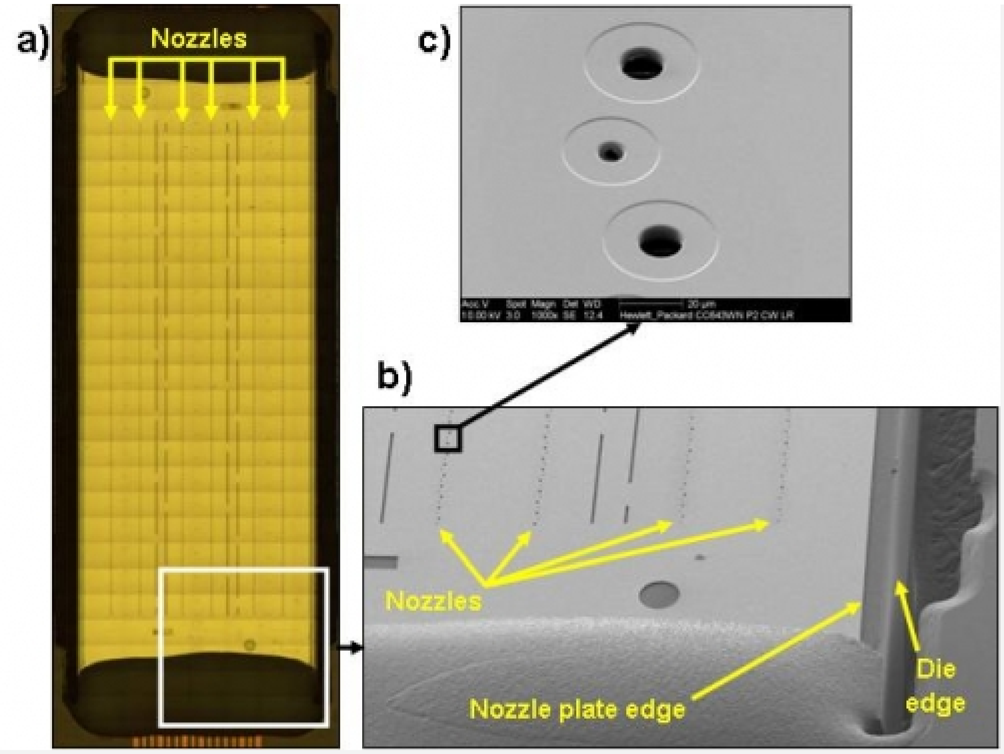

Fig. 2: Nozzle plate showing rows of nozzles and different nozzle sizes.

The HP specification for the cartridge states that there are 1248 nozzles in the printhead, ejecting droplets of 4.7 and 1.3 pico-litres from the two nozzle sizes. The larger is 14µm in diameter, and the smaller is 8.5µm.

When we cross-section the device, the details of the structure become visible (*see Fig. 3*). The die is fabbed from a full-thickness (670µm) wafer, with ink channels cut through the die, aligned to the openings on the cartridge body that connect to the ink chambers. The tops of the vertical channels open out to bevel-edged cavities in the die surface, and vias formed in a polyimide layer extend from these on both left and right to the two rows of individual nozzles. The nozzle plate is made of palladium-plated nickel with a flash of gold, and is glued to the polyimide layer, aligned to the ink channels.

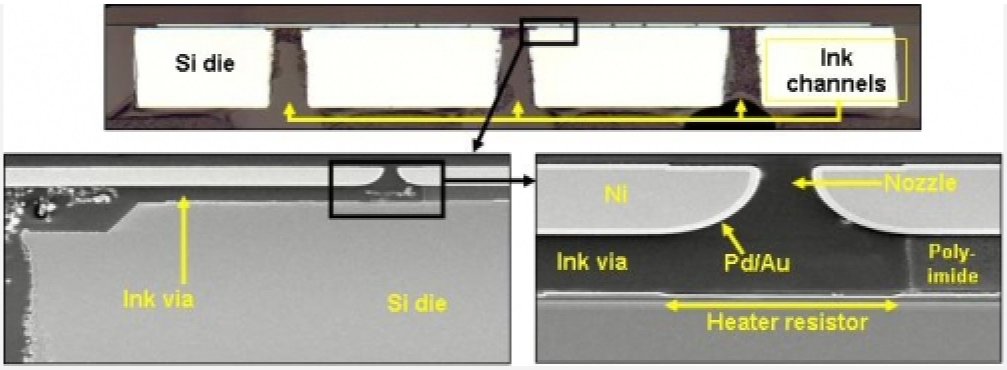

Fig. 3: Cross-section of die, nozzle plate and ink channels.

In *Figure 4* we go back to plan view, but this time with the nozzle plate removed. The three ink channels are clearly seen; the irregular shape and the rough sides shown in *Fig. 3* lead me to speculate that they are laser-cut, or possibly jet-abraded. The bevel angle of the upper portion of the channel is characteristic of a <111>-anisotropic etch such as potassium hydroxide, probably done in the fab before the main channels are drilled.

Figure 4c shows the two sizes of heating resistor that fire the two droplet sizes, and the corresponding driver transistors. It is interesting that even though the bigger droplet is over three times larger than the smaller one, the larger resistor is only ~10% bigger in area (30µm×15µm vs. 30µm×13.5µm) — either the current is really cranked up for the larger drops, or the smaller drops are ejected more forcibly, which may aid in finer resolution printing.

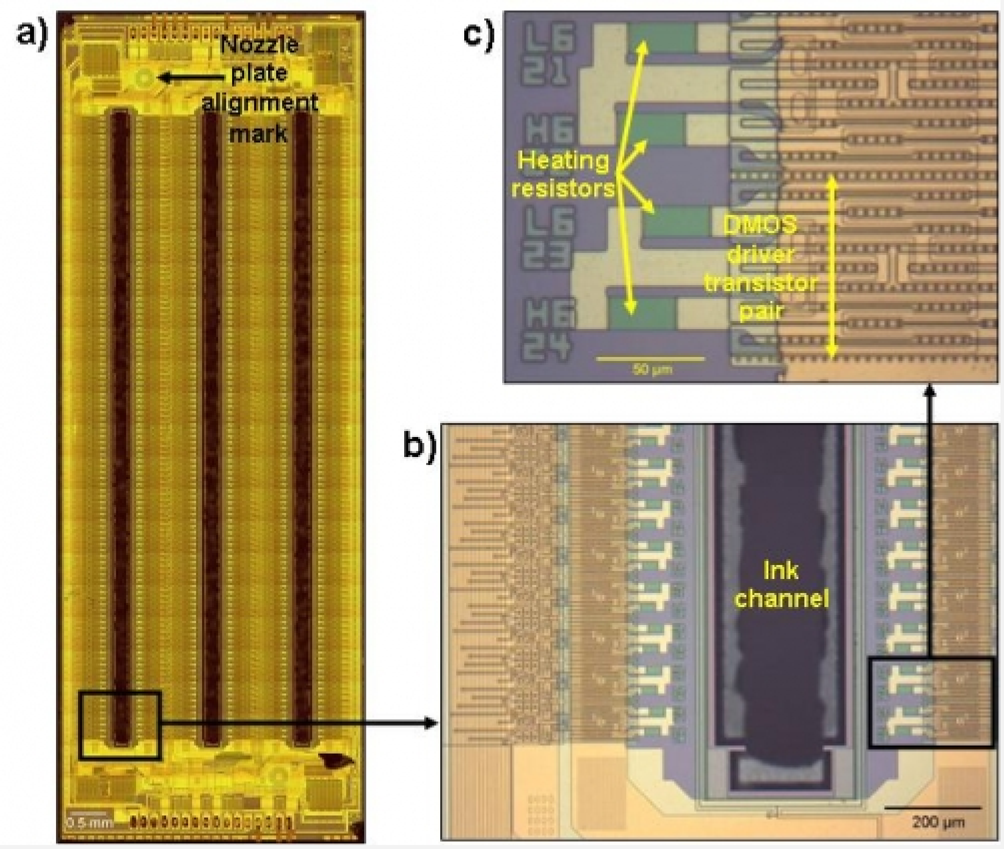

Fig. 4: Plan view of die, showing ink channels and heating resistors with driver transistors.

At this point we should discuss the actual operation of inkjet chips such as this one. We have seen that there are heating resistors under each nozzle — these are stressed with a 2.5µs, ~10V/250mA pulse to boil the ink and eject the drop [3]. This takes the resistor up to above the superheating point of water, the main solvent, and creates an almost explosive vapor bubble that ejects the ink droplet at about 50 km/h. The bubble then collapses, and the ink cavity refills with liquid. The firing signals are multiplexed to each resistor in sequence as the printhead is scanned across the paper.

One might think that the major challenge would be building a chip structure that could cope with repeated temperature excursions of this type, but that is only part of the story. When the bubble collapses, it creates a shock wave, and localised pressures up to 130atm can build up. This process is known as cavitation, and it is the principle behind the cleaning effect of ultrasonic cleaners. There is also chemical action, as ionisation occurs inside the collapsing bubble, giving activated ions and radicals which could can affect the ink and attack any adjacent surfaces. In addition, the ink contains mobile ionic contaminants such as sodium, potassium, and chlorine that could affect transistor performance.

Figure 5 shows the general structure of the chip. It uses an un-silicided, single-poly, two-metal NMOS process, with a minimum found gate length of 2.9µm. The process has been optimised for low-cost production; we estimate only eight masks have been used. The starting material is a 150mm, P-type wafer doped to ~3 × 10^{16} carriers/cm^3, a typical P-well concentration for a CMOS process.

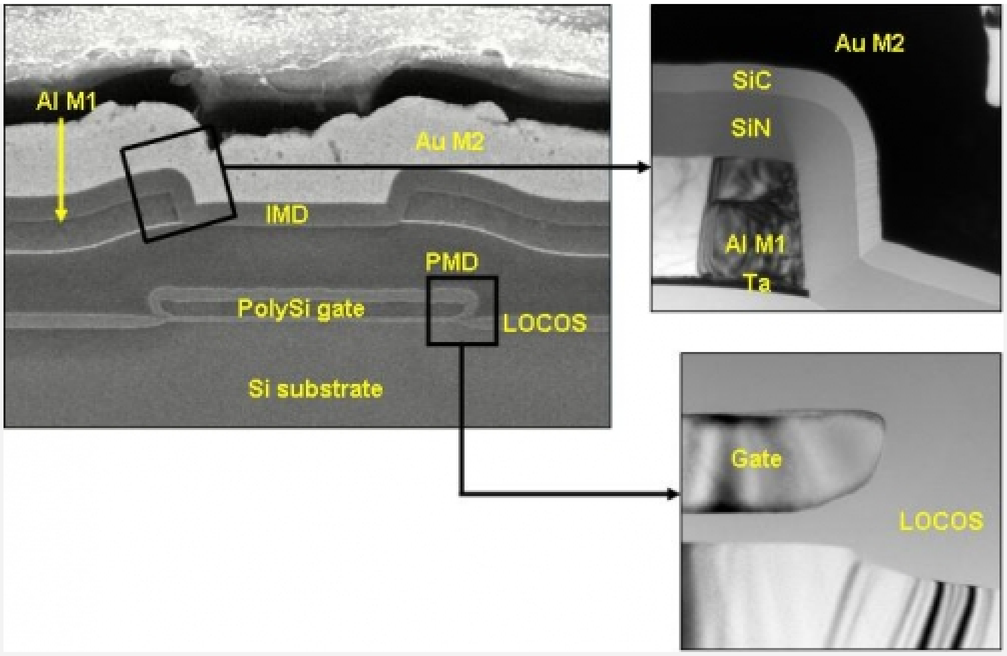

Fig. 5: Cross-sections of transistor showing device structure.

Since there is no need for wells, the first significant step is the nitride masking and growth of the LOCOS isolation (mask 1), then etch off the nitride and buffer oxide and grow the 1350Å gate oxide suitable for the 12V operation of the chip (I haven't seen that in decades!). Then the polysilicon deposition and gate definition (mask 2), source/drain formation, followed by an oxidation to give a form of LOCOS field oxide in the source/drain regions, with the gate acting as an oxidation mask.

The pre-metal dielectric (PMD) is 1.1µm of flowed phosphosilicate glass (PSG); mask 3 cuts the contacts for the Al/Ta metal 1 (M1), which is defined by mask 4. Mask 5 etches the aluminium off the Ta barrier layer to define the heater resistors. The intermetal dielectric (IMD) is a bilayer of silicon nitride (SiN) and silicon carbide (SiC), through which mask 6 defines the vias for the gold metal 2 (M2), which in turn is defined by mask 7. Mask 8 would be used to pattern the top etched portion of the ink channels.

There is no passivation over the gold metal 2, other than the polyimide ink-via layer, and of course the nozzle plate provides physical protection. It seems likely that the nozzle plates are applied using a wafer-scale operation, since there is an alignment mark on the die (see *Fig. 4*).

When it comes to the critical heater resistors, shown in *Fig. 3* and *Fig. 4c*, we can see more detail in *Figure 6*. The actual resistor layer is a mere 30nm of tantalum, which acts as a barrier layer for the aluminium M1 over most of the die. The heater sits on top of the 1.1µm PSG + 0.2µm LOCOS, which acts as a thermal isolation oxide as well as helping prevent parasitic transistor action from the 12V on metal 1.

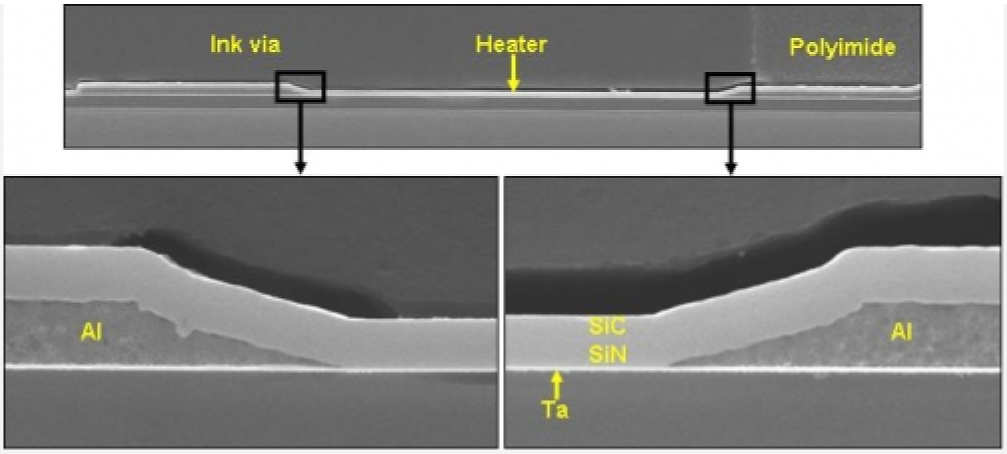

Fig. 6: Cross-sections of heater resistor.

The IMD, which is usually an oxide of some sort, is here the bilayer of SiN and SiC we noted above. This can evidently endure the inherent temperature swings of the firing process, as well as provide sufficient protection against cavitation for this disposable part. (Other printheads we have seen that reside in the printer have an extra tantalum layer on top of the IMD to give higher reliability.)