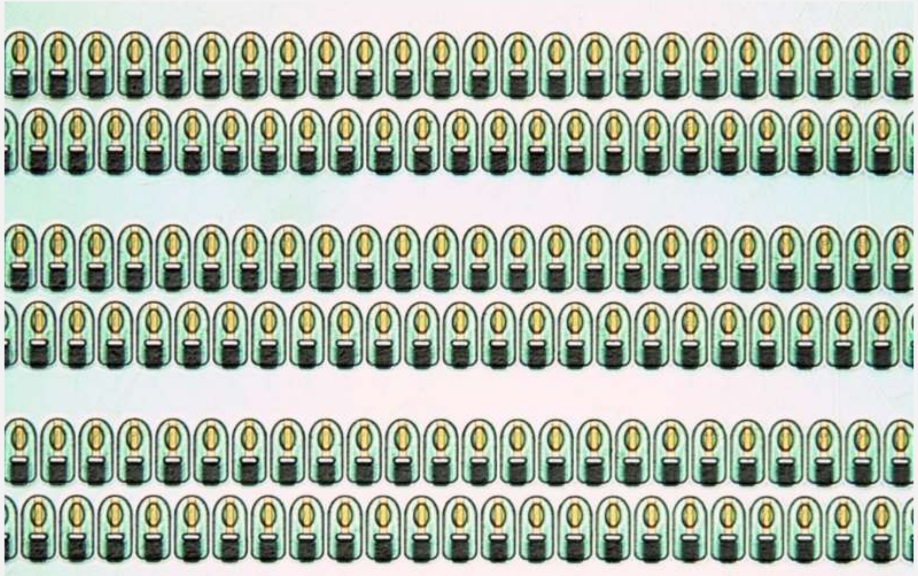
Memjet

Chip Technology Overview

Angus North

IOP Oct, 2023



Memjet, problem statement and value proposition

- In the year 2000, inkjet printers worked by scanning heads with a small number of ink nozzles back and forth across the width of the page, as the page was incremented
- This was SLOW
- Memjet (formerly Silverbrook Research) was formed to solve this problem, with a vision of page wide inkjet:
  - low cost, fast, full colour digital printing using scalable, page wide arrays of thermal inkjet nozzles
  - with the paper moving underneath a fixed array in a single pass.
- Memjet led the market in this segment, and forced other players, such as HP and Epson, to follow suit.

Speed evolution

Year 2000
Canon BJC-3000
4 pages/min
192 nozzles
Scanning sheet fed

Year 2010
Memjet K2
60 pages/min
70400 nozzles
Single pass sheet fed
Fastest home/office printer in 2010

Year 2023
Memjet Durabolt
137m/min
204800 nozzles
Single pass roll to roll

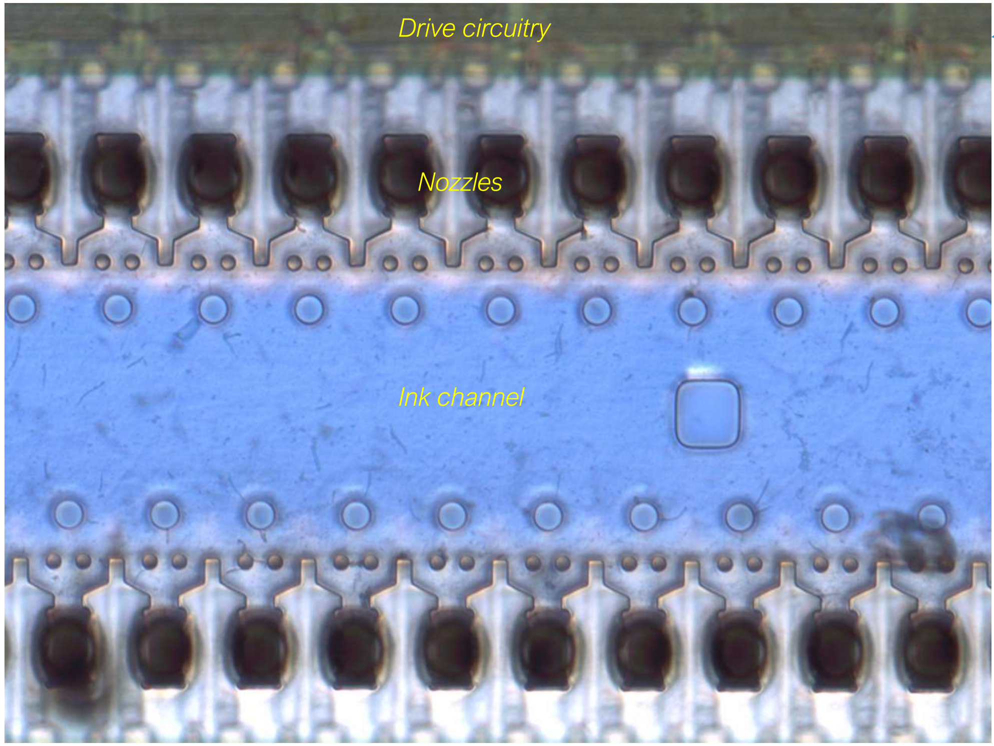
Nozzle packing density

Memjet's low cost page wide arrays are enabled by minimizing chip area, with a high nozzle packing density:

- 200X higher nozzle density than competing piezo (Fujifilm Dimatix Samba)
- 6X higher nozzle density than competing thermal inkjet (HP ProX).

Memjet has the highest nozzle packing density of any inkjet head on the market.

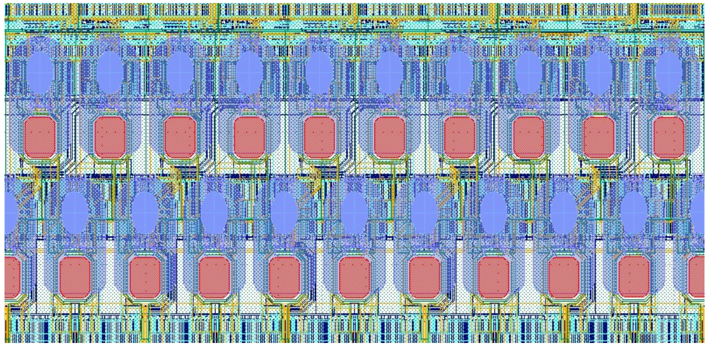
ProX vs Memjet layout comparison

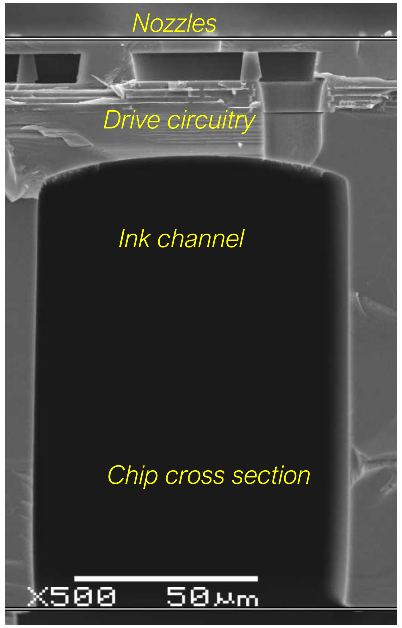


Images on same scale

HP ProX top view: Ink channel, MEMS and drive circuitry all separated in plane of chip, taking up a lot of silicon area

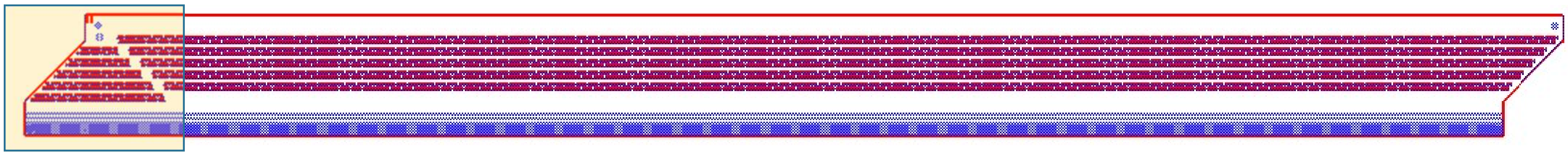
Memjet top view/layout showing drive circuity underneath nozzles

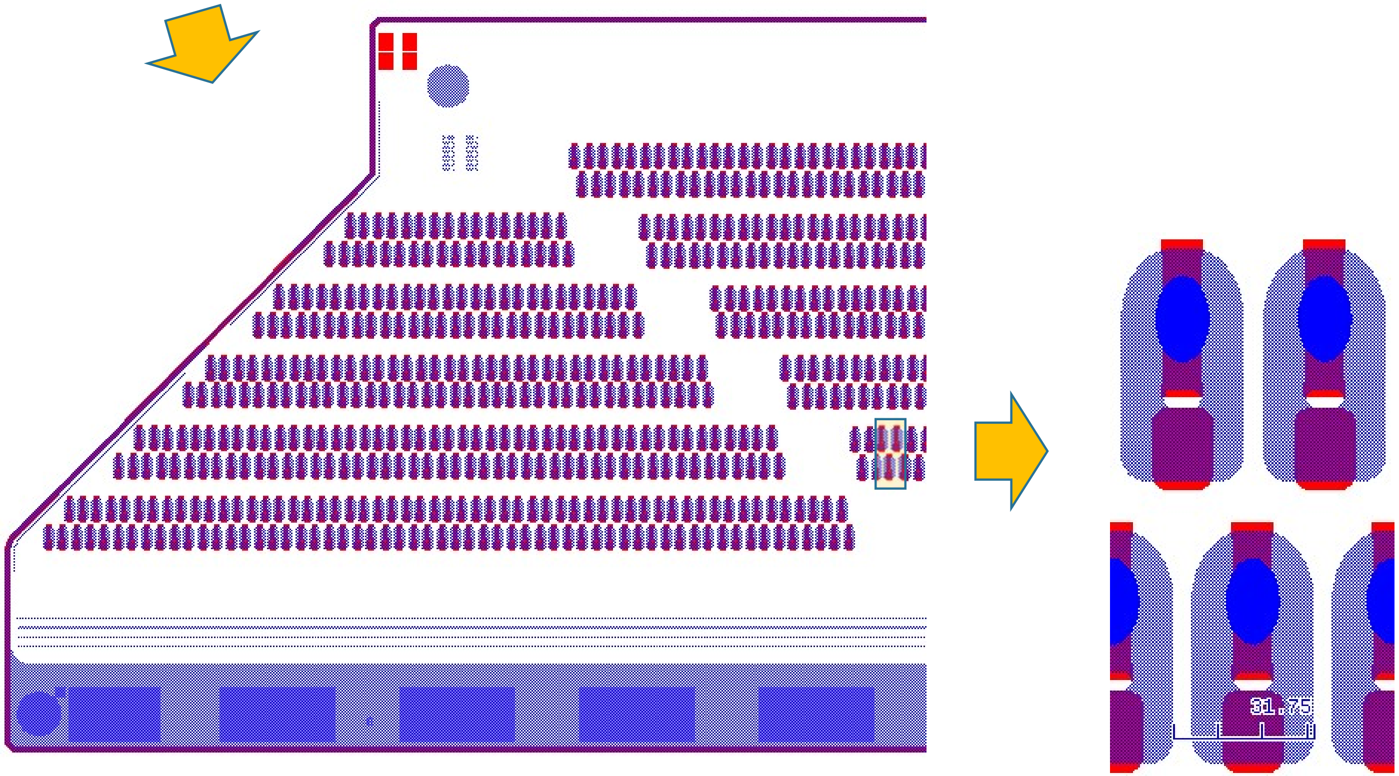




Memjet cross section: Ink channel, MEMS and drive circuitry vertically stacked to reduce silicon area

Memjet chip, front side

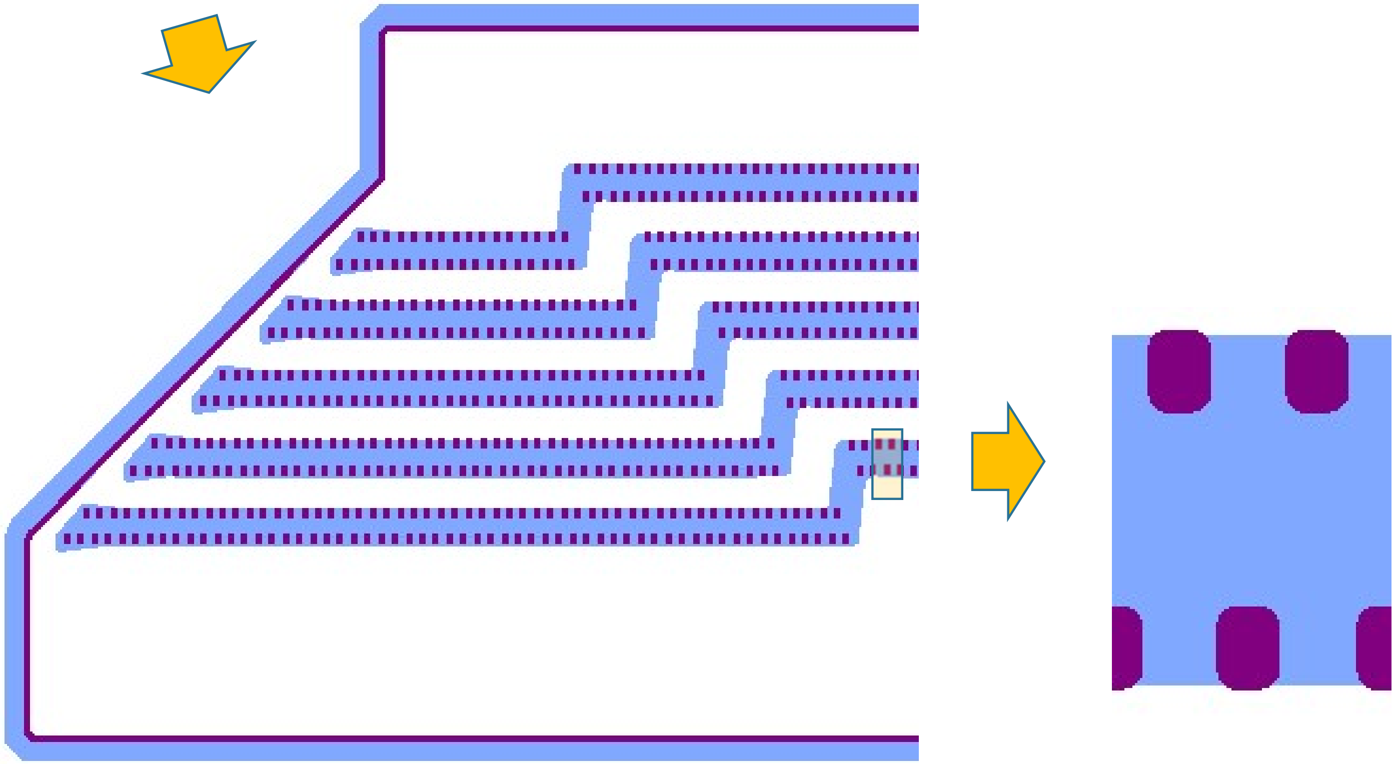




Design

- ~21 mm x ~1.6 mm
- 6400 nozzles/chip
- 10 rows of 640 nozzles each at 1/800 inch (~32µm) pitch
- Adjacent rows offset by 1/1600 inch giving 5 “colour planes” with 1600 dpi addressable horizontal resolution

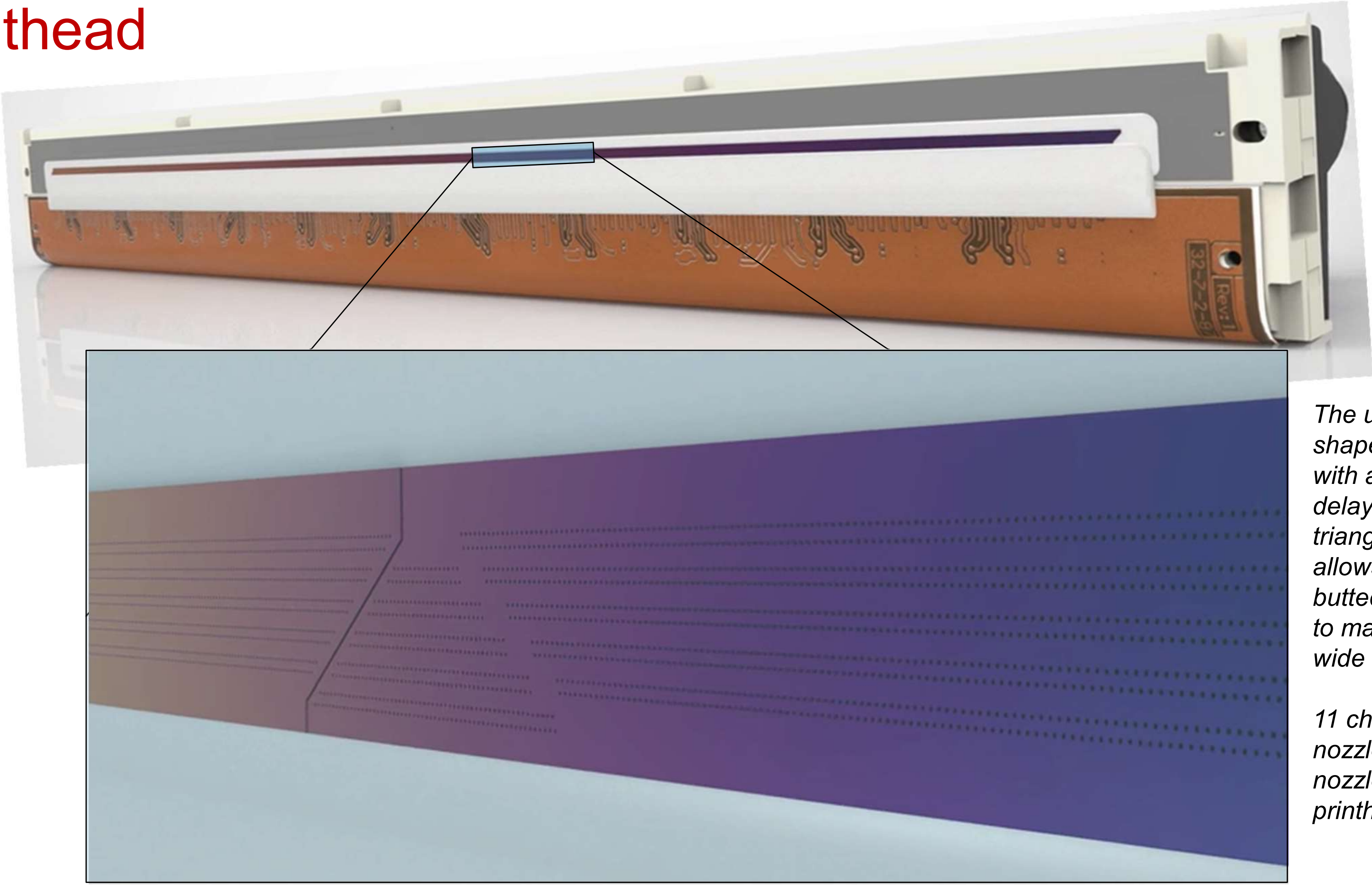
Memjet chip, back side



Design

- 5 ink channels etched in back of chip to connect to front side ink holes
- Back etch also singulates chips to avoid dicing, allowing more die/wafer

Printhead



The unusual shape of the chip with a set of time delayed "dropped triangle" nozzles allows chips to be butted end to end to make a page wide array.

*11 chips * 6400 nozzles = 70400 nozzles / printhead*

Key challenges in our printhead development

- Inkjet manufacture is a complex, multidisciplinary field, requiring expertise in:
  - semiconductor wafer processing
  - CMOS design and layout
  - MEMS device simulation, design and layout, fabrication and characterisation
  - materials science
  - chemistry, ink formulation
  - mechanical design and manufacture
  - part assembly, production and reliability testing
  - software
  - supply chain logistics
- In the MEMS space, the two key challenges were:
  - reducing ejection energy to enable page wide arrays, without compromising heater lifetime
  - developing foundry compatible processes for a high yielding printhead.

Very low ejection energy, excellent life without thick coatings

Thermal inkjet operates by heating water-based ink up above the 309 °C superheat limit of water, which causes a vapor bubble to form, which expands and pushes a jet of ink out the nozzle.

The ink and vapour bubble are very aggressive towards the heaters, which suffer from:

- oxidation
- corrosion
- cavitation (damage from the collapsing vapour bubble).

The traditional approach to protecting the heaters is to coat them with thick protective coatings.

These coatings must be heated beyond the 309°C superheat limit to heat the ink to the same temperature.

This requires a lot of energy: too much energy to dissipate in a dense, page wide array – heat build-up would rapidly cause uncontrolled boiling of the ink.

Top view of bubble formation in a Memjet chip

Very low ejection energy, excellent life without thick coatings

Memjet has resolved this difficulty through:

1. 15 years of materials research, optimizing our heater material to provide extreme oxidation resistance
2. coating the heaters with very thin anti-corrosion layers
3. venting the vapour bubble through the nozzle to avoid the cavitation damage

The result is “self cooling operation”, with:

- very low electrical energy of 225 nJ per ejection drop
- the majority of energy input removed as heat via ejected drops
- chip temperature rise of <= 25 °C above room temperature
- heater life >= 10 billion ejected drops of pigmented ink.

Side view of ejection from a Memjet chip

The foundry, fabless, “more than Moore” business models

- Foundries are very expensive to build and maintain
- They are a huge financial drain if they aren't kept at full utilization
- A company like Memjet with just one chip can't keep a fab at full utilization or afford to run one, so:
  - Memjet is fabless (working with 3 Asian foundries for CMOS, front side and back side MEMS)
- As a fabless company, the first thing you must do is find a foundry that's a good fit, considering the commercial prospects for the chip and the technology maturity
- Generally, you can't approach one of the large fabs with an immature MEMS technology unless the sales prospects are fantastic:
  - you would normally have to prototype in a smaller fab first, then transfer the process.
- Some higher volume fabs are keen for new MEMS business as a strategy to diversify away from CMOS, following a "more than Moore" strategy, to avoid the extreme cost of keeping up with the latest CMOS technology node, with a single ASML stepper costing more than 300 million USD.

Foundry compatible processes

- Having found willing foundries, there are unique challenges for the fabless MEMS customers:
  - The facility is shared among many customers, and the equipment and material selection is very limited, for cross-contamination reasons
  - The equipment and material constraints are different in every fab, making MEMS process transfers difficult and expensive
  - Each MEMS process is bespoke, requiring years to develop high yielding processes
  - The learning cycle is long, with design-layout-fabricate-test cycles taking 6 months to a year
  - During development Memjet mitigated these delays with:
    - staging of wafers at various points in the flow, ready to accept design or process changes
    - a 2 stage design process, with an experimental mask release, and a production mask release:
      - the experimental mask release aimed to cover the entire design space with a factorial experiment iterating critical dimensions
      - the production mask release contained a single design using interpolated experimental data.