3D NAND Status and Roadmap
2017

Mark Webb
MKW Ventures Consulting, LLC
What We Know

- TLC is primary focus for all 3D NAND. MLC is a derivative if needed.
- Building the highest possible capacity part is not always optimal.
  - 256G is “Sweet Spot” today, 512+ is useful for high capacity SSDs
- Micron has 256Gb 64L product at 59mm2. CUA is die size advantage
- Toshiba has 512Gb at ~132mm2
- Hynix has 72L (“64L Class”) 512Gb
- Samsung has 512Gb at ~129mm2
- Controller companies/end customers have be qualifying these or similar parts or 6+ months.
  - These are available today for use in SSDs, Memory cards.
- As Samsung and Micron have converted majority of bits to 3D, their costs have declined significantly. 3D NAND is lowering costs.
What is Announced/Claimed

- 64L is a done deal. It will ship in high volume at low cost
- Toshiba/WDC announced 96L/QLC
  - Sampling in Fall, shipping in 2018. Not seen in the wild
- Micron is planning Gen 3, will ship in 2018
- Samsung/Hynix planning 96+ layers
- None of these are close to qualification and subject to change as they are evaluated
  - Claiming any of these announcements as a first or leadership is debatable
- Key Takeaway: There is no “brick wall”, we have plans for 3-5 years
Future Model and Estimates

- At full production, 3D wafer cost is significantly more expensive than 2D NAND for both Greenfield and Conversion
  - Fab output/ft$^2$ drops and new equipment needed.
  - There are still multiple critical lithography layers and advanced tools
  - Some layers are pitch doubled.
- String Stacking adds to cost. Doesn’t double the cost of the array but could add 10% to cost. All NAND vendors will need some type of string stacking eventually
- BUT Improvement in bits/mm$^2$ is dramatic and overcomes the wafer cost increase
- Yields are lower for 3D NAND initially. Multiple vendors have achieved mature yields. Adding layers doesn’t automatically limit yields (redundancy)
- Yields will approach HVM Goals after 6-12 months in production for all companies
- For new technologies, wafer cost and die cost start very high and reduce over lifetime with efficiency and high yields
- All of these inputs go in to our very detailed cost model for all companies
From FMS 2013: ROI on NAND Scaling

Unit cost is very high to start

- High wafer cost
- Low output
- Low yield

3D NAND is NO different

N Generation announced for samples

N +1 Generation announced for samples 6Q Later

N +1 Cost is cheaper than N

Quarter after N Generation Samples

Unit cost (normalized)
Process/Product Technologies

- REPEAT: Geometry terms like 40nm or 20nm are not useful. Architecture is too complex for analysis like this.
  - All companies have channel holes at 60nm+ and contacts at 20nm
  - Vertical gate spaces and features can be <20nm
- Micron/Intel floating gate is significantly different from charge trap
  - Opinions vary on which will scale better
  - CUA gives die size advantage at equivalent number of layers
- Density (Not Capacity) and Die Size are the key cost metrics and both are available after sampling. Some numbers are published.
- QLC is coming. Acceptance depends on performance and actual cost savings (25% lower in theory).
  - Yields, test cost, overprovisioning, etc combine to determine true cost.
Cost summary

- Planar yields gave them a cost advantage up to 32L/Mid 2016.
  - Ramp decisions were based on each companies Planar vs 3D Costs
- 48L+TLC+HVM yields gave 3D a cost advantage even with mediocre yields
- 64L Gives all companies a large cost advantage.
  - This drives aggressive capital spending and conversion
- 96L+ and QLC allow significant cost reduction for next 5 years
August 2017 Cost Summary ($/GB)
Announces or Reported Technologies

2017/2018/2019 NAND Costs
(2017 Average Cost)

- 2017 HDD
- 2017 Planar TLC
- 128L not mature until 2020

Flash Memory Summit 2017
Santa Clara, CA
Impact of Cost on 3D Ramp

- 3D NAND will be ~50% of all bits for 2017 overall. This will be confirmed in earnings announcements.

- 3D Industry conversion prediction
  - 50% of Industry Bits in 2017
  - <75% of Industry Bits in 2018
  - Market/capital spending decisions 2019+
    - Can we afford to convert
    - Is it cost effective for <128Gbit
    - Is NAND Price stagnating market growth
    - Phones market is the tipping point
What about price???

- In June 2016, NAND (and DRAM) shortages started to appear and have continued since
- Prices increased. Market reports showed increased of 50-100%.
  - NAND vendors actual reported increases of 15-30%
- During shortage, Price is not related to cost. Costs went down, prices increased.
- When the shortage is eliminated, prices will fall quickly based on costs and acceptable margins
- 64L conversion and ramp SHOULD address the shortage in 2018
Summary

- 3D NAND at 64L provides significant bit cost reduction compared to Planar.
- 64L is working at all companies and will ramp aggressively in 2017
  - This will provide relief to shortages by early 2018.
- Yields will struggle initially, then reach maturity over time. Not new
- 96L+ and QLC provide significant bit cost reduction over the next 5 years.
  - 25% cost reduction per year