[Gu]estimating the NAND Future: 2D, 3D, Post NAND

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Introduction

- Many future Non-Volatile memory options exist today, which ones succeed will depend on cost.
  - Low cost options will win
  - Higher cost options will occupy niches. Some “good” niches
- Increased density on single die is nice but is not the biggest challenge or greatest need.
  - I can easily build a 1Tbit single package at multiple vendors today.
- So the challenge for 3D NAND or future memory options is to deliver cost reductions beyond those possible for 2D NAND
  - Predicting costs over time allows us to determine when the technology ramps

2D NAND Status

- In line with our predictions last year…
  - 15-16nm has been introduced. Based on various scenarios, cost reduction will be ~20% vs 40% historical
  - Scaling beyond this is physically possible but doesn't lead to return on investment.
- TLC offers 25% cost reduction options over MLC.
  - SSDs are next major application with large ramp in 2015
- Manufacturing continuous improvement offers 10-15% cost reduction per year
- Summary: 2D costs will continue to drop even without new nodes. TLC is the biggest opportunity

3D NAND

- 3D NAND (Vertical channel) allows us to get back to 40% cost scaling per generation
- Our Model for 3D NAND costs is:
  - 32 Layer process for now
  - 40nm lateral half pitch (“F”) .
  - $6F^2$ Cell
  - Assume some increased die size for routing 3D
  - 70% higher wafer cost for 32 layers than 2D
  - Yield learning is half as fast as current 2D NAND
    - Program/Erase schemes, defect isolation, test development
    - Will improve to normal by 3rd generation

What Do the Cost Models Show?

- 32L 3D NAND, even with slow yield learning and increased wafer cost, has opportunity to reduce unit cost significantly.

- Samsung has announced real products (“VNAND”).
  - However, Samsung die sizes shown in papers and by analysts lead to a large cell size assumption
  - ~4X larger cell than any reasonable prediction based on layers, geometry.
  - Clearly not a 40nm, 6F2 Cell as modeled and expected historically

- We modeled the exact costs over time for 2D NAND, 3D NAND (Model 32L/6F), and Samsung VNAND
  - We assume Samsung yield learning is faster than model

The Results

Relative Cost Per Bit, 16nm MLC baseline

	16nm MLC	16nm TLC	3D-NAND (32L 6F)	32L VNAND (Not 6F)	96L VNAND (Not 6F)
Cost Today 16nm MLC Baseline	100%	76%	NA	232%	NA
Cost Q4 2015	88%	68%	79%	150%	72%

- 2D has significant cost reduction to come
- 40nm 6F cell allows cost reduction beyond 2D
- Cell size limits cost reduction for VNAND unless 96L used
- This matches reported plans for multiple NAND vendors

Post NAND Technologies

- NAND issues with cycling, ECC, etc are not ideal but are controllable so replacement technology must still meet cost goals to be “non-niche”

- **MRAM:** Shipping in low density in relatively low volume. Great opportunity for Cache/DRAM. 10x cost reduction needed for NAND applications

- **RRAM:** Latest announcements/papers show opportunity to create scalable low cost, cross-point array (near $4F^2$). Need samples ASAP, demonstrated high density product

- **PCM:** This technology is so mature, it is boring people.
  - Samsung, Micron and others have demonstrated volume production in past.
  - Well understood technology with potential for high density, but not NAND replacement

Summary/Predictions

- 2D NAND will continue to have modest cost/ASP reductions and significantly increased bit shipments.
  - TLC will fill need for cost reduction as it is highest confidence option. TLC SSD volumes will grow dramatically
- 3D NAND will be relatively low volume for 2 years at least
  - **3D NAND: <15% of industry bits in 2015, <25% of bits in 2016**
- New PCM chips/products will be announced (2015) and ship (2016).
  - High Cost, High performance applications. No NAND replacement
- New MRAM products/applications will be announced (2015) and ship (2016).
  - Low density Cache/embedded. No NAND replacement
- RRAM low density (Mb) announcements/samples will increase interest and add confidence to cost roadmaps
  - High density NAND replacement (64Gb) could start as early as 2017