Renew, Retire, Replace

How the mask equipment industry
can transform its products
and become healthy again

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Problem statement

- The market for semiconductor chips is expanding rapidly as electronic devices and appliances become more pervasive in our lives.

- This expansion involves...
  - 300mm and 200mm fabs.
  - high-end (40 —> 7nm) and mature (180 —> 65nm) technologies.

Year	200mm Wafer Fabs
1995	70
2007	200
2016	188
2021	202

Source: SEMI

The semiconductor industry is structured to respond to 300mm (high-end) demand and is unprepared to cope with the 200mm (mature) resurgence.

What this talk is about

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- Over the past couple decades, the IC mask industry has...
  - Served the high end market with mostly captive and some merchant mfg.
  - Served the low end (standard / mature) market with merchant mfg.

- Mask equipment suppliers “chase” the high end and “retire” mature tools.

- So how should the mask industry respond to the legacy resurgence?

This talk will:
- Forecast the 2022 IC mask market and segment it by writing tool.
- Show how the mask writer toolkit must change to serve the market.

The topics

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- Show how the mask writer toolkit must change to serve the market

Methodology

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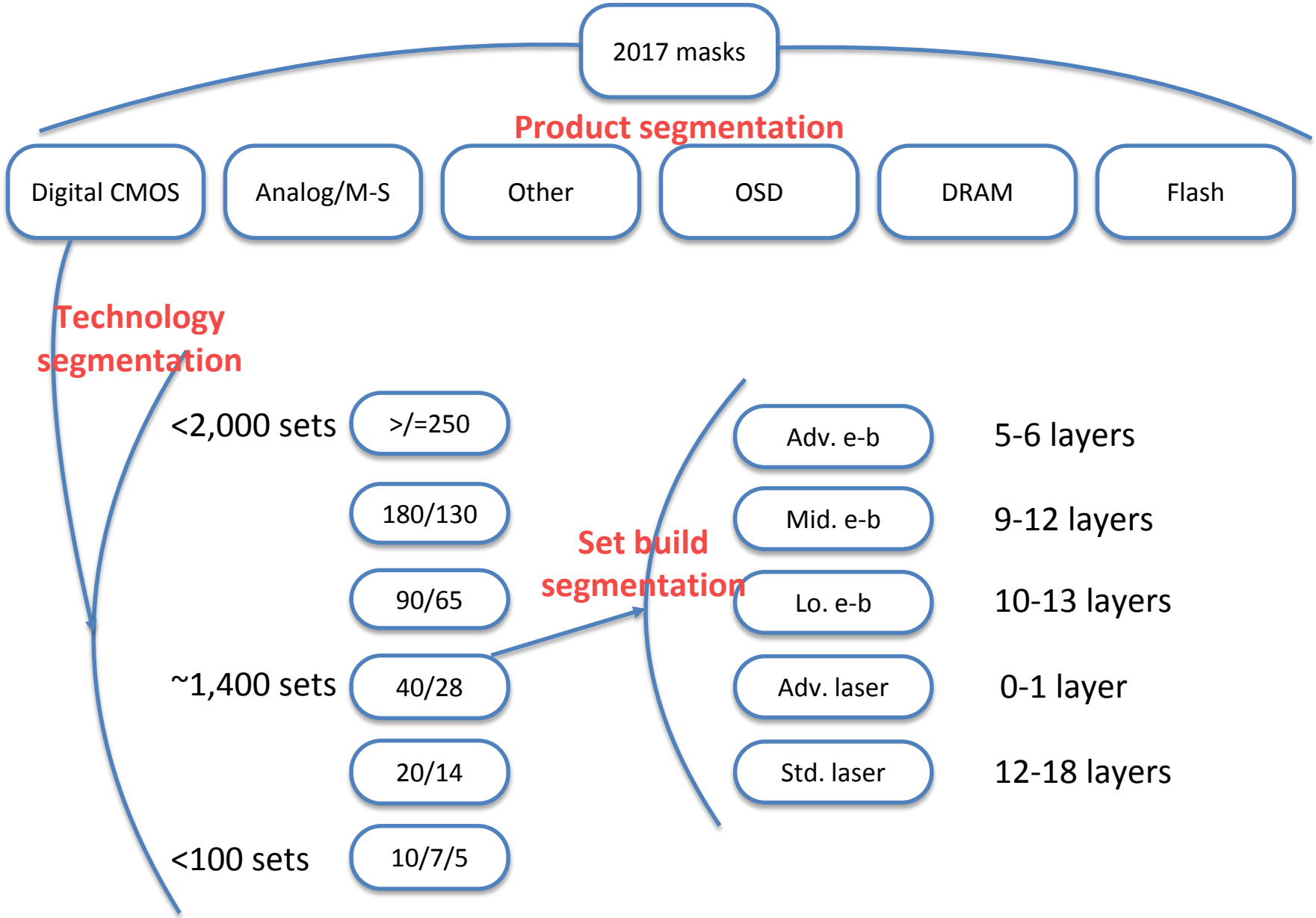
- What we already know:
  - Mask set build strategy (i.e., what tools are used to build any mask set).
  - 2017 tapeout volume, segmented by market and technology.
  - 2017 mask consumption, where:

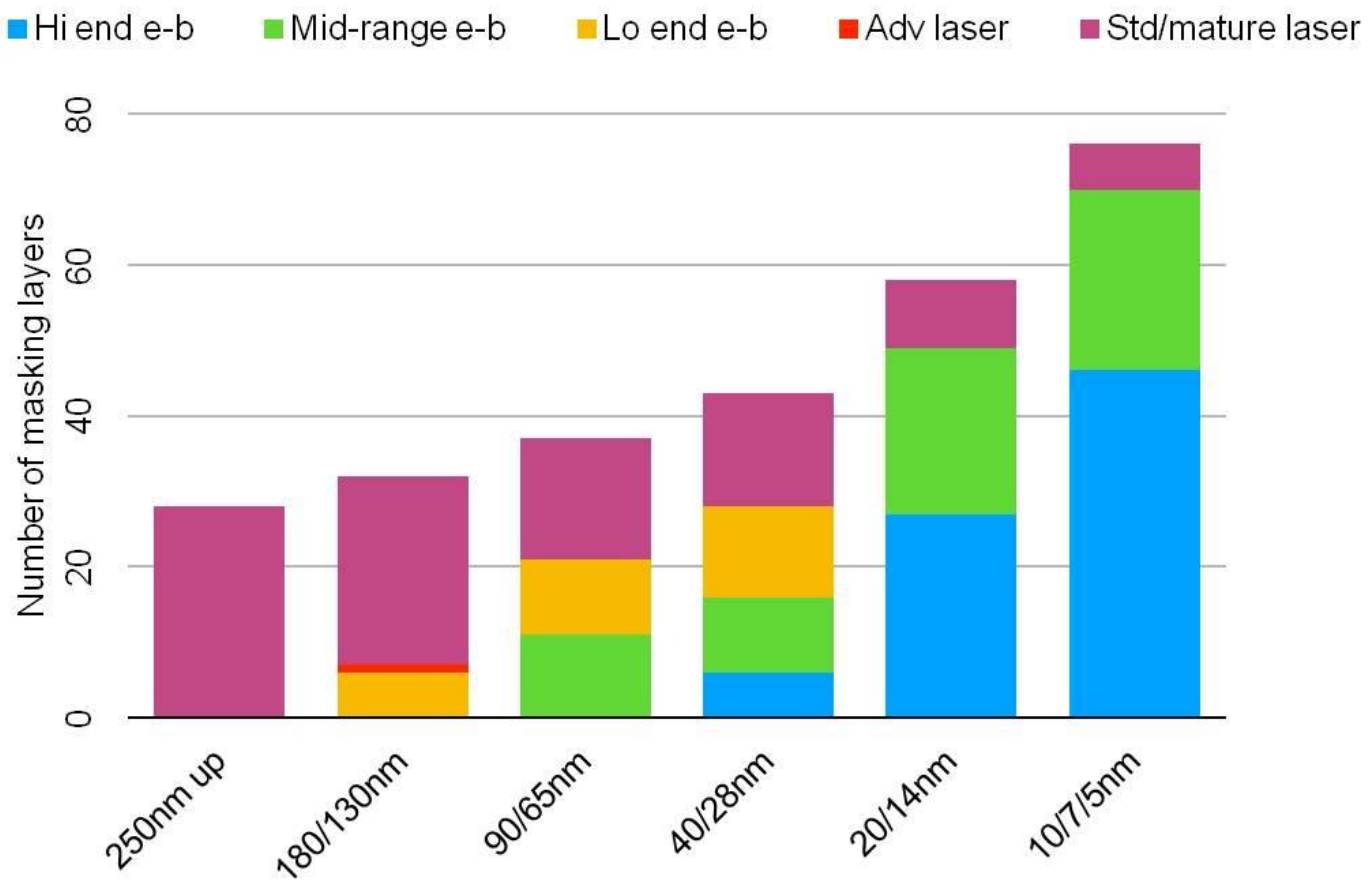
    [mask consumption] = [tapeout volume] x [masks per tapeout]
- Build a 2022 mask consumption model:
  - Using semiconductor market growth predictions, make (highly) educated guesses about tapeout / mask market growth.
  - From this, forecast the required 2022 toolkit.

Rather than showing data for the entire mask mfg toolkit, the focus here will be on mask writers, especially e-beams.

Methodology illustrated

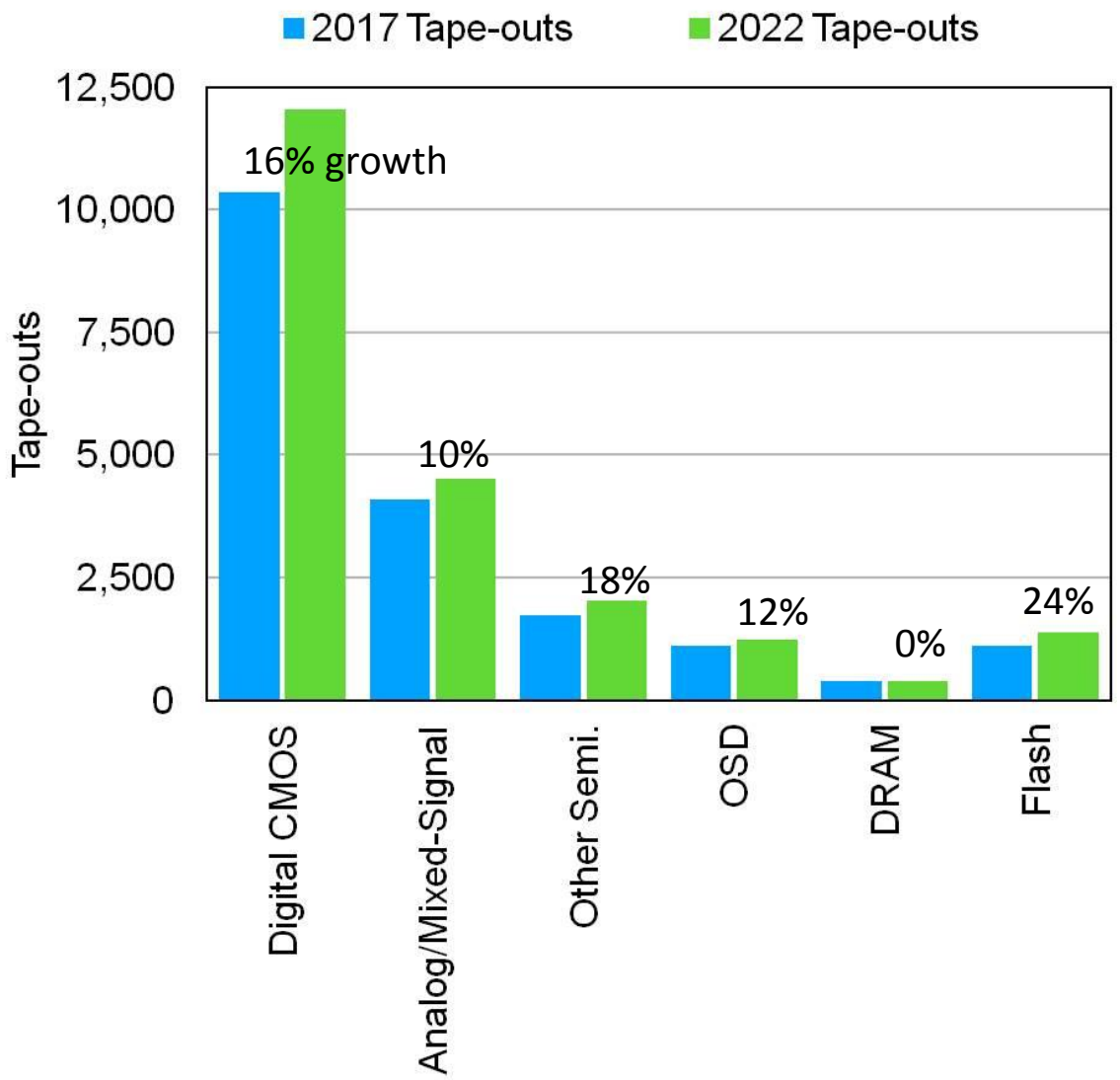


Logic set writing toolbase



All sets (except >/= 250nm) use multiple writing platforms.
Lasers are used at all nodes.
Low end e-beams phased out at 20nm.

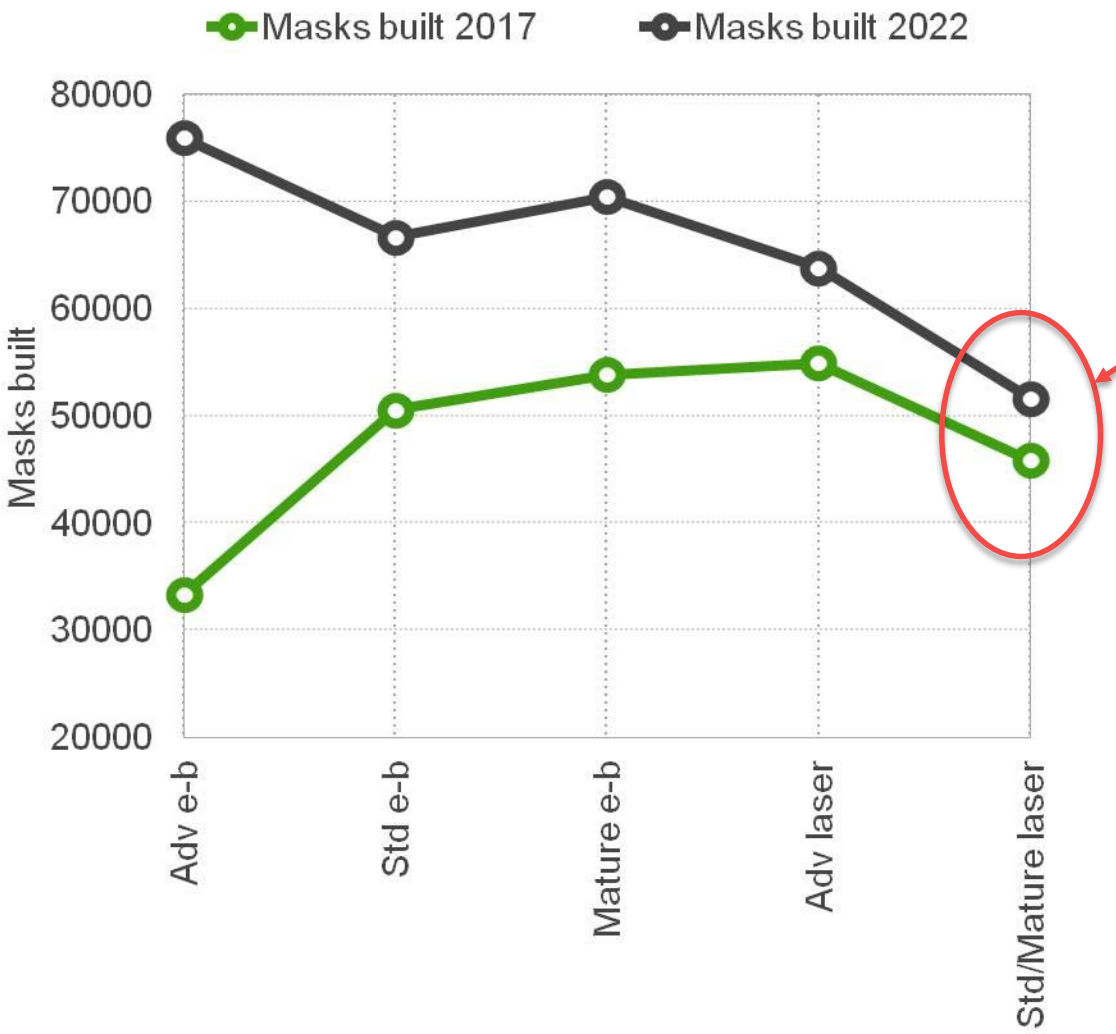
Tape-out forecast by product category



Subject each blue bar to the p. 6 analysis to get 2017 mask production by writing tool.

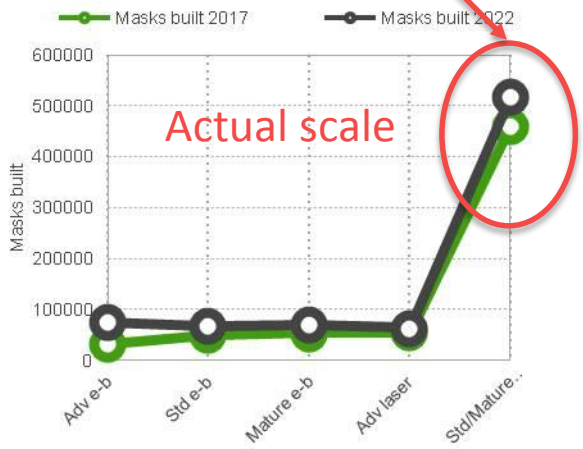
Apply the p.6 analysis to the green bars to get 2022 mask production by writing tool.

Worldwide mask demand

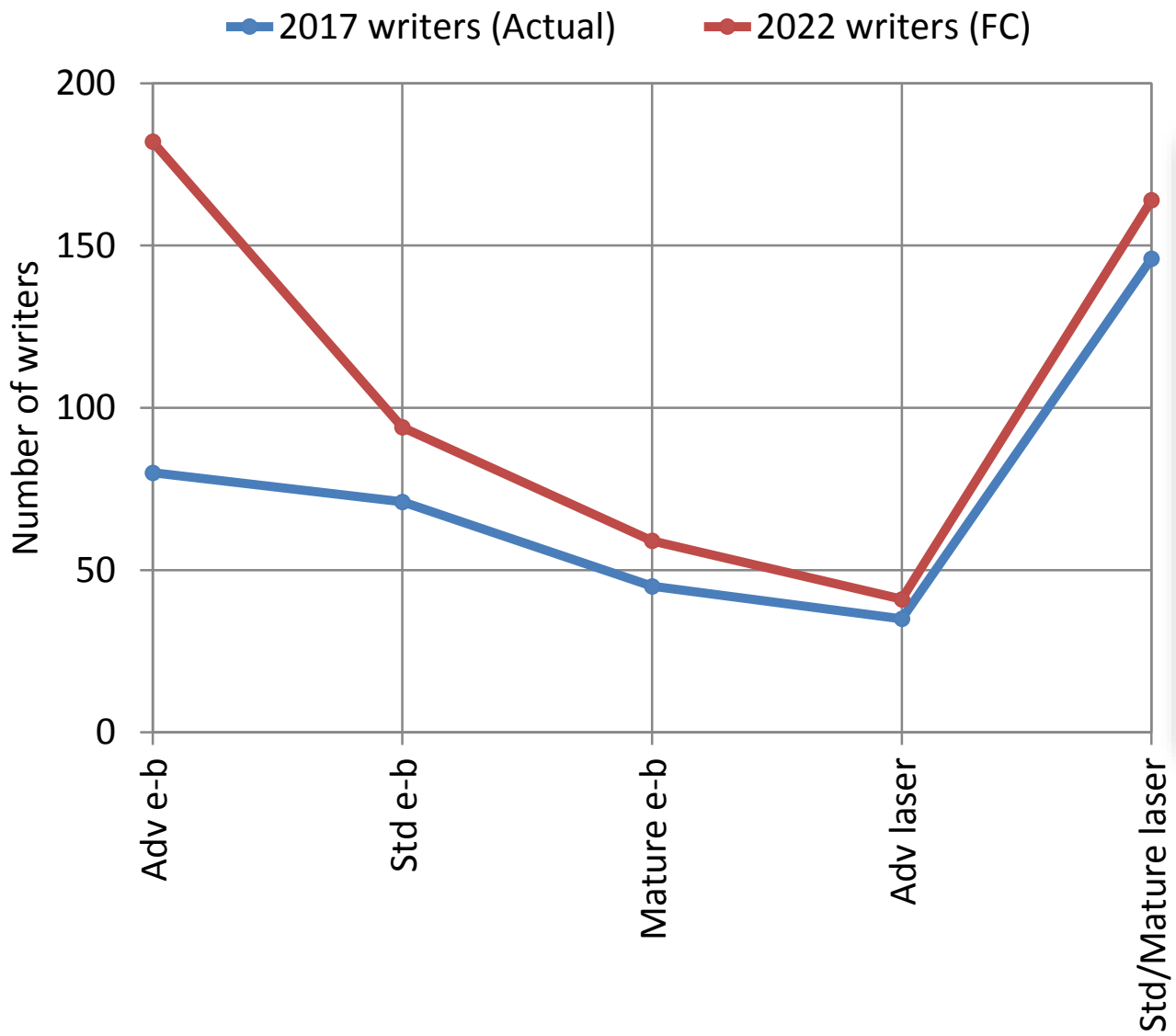


Assuming adv e-b tools are built, in 2022 the capacity gap is ~100,000 std/mature masks.

Std/mature laser tools build most masks, so their mask numbers are divided by 10 to fit on the same scale as other platforms.



Mask writer toolbase demand



There are >375 IC mask writers, split ~equally between e-b and laser.

Over the next five years, demand for all mask writing platforms, regardless of type or vintage, will grow.

GREAT NEWS, RIGHT??

Now for the sobering news...

"Svc" and "Parts" denote availability from OEMs.

Mask manufacturing toolkit health prognosis for 2020

Technology	Write		PEB/Develop		CD Metrology		Etch		Strip/Clean		Inspection		Repair		AIMS (TM)		Phase/Trans Metrology	
	Svc	Parts	Svc	Parts	Svc	Parts	Svc	Parts	Svc	Parts	Svc	Parts	Svc	Parts	Svc	Parts	Svc	Parts
</=20nm	Adv e-b				CD SEM		Dry				Adv DUV		e-b					
40/28nm	Std e-b				CD SEM		Dry				Std DUV		e-b					
90/65nm	Mature e-b				CD SEM		Dry				Adv UV		FIB/e-b					
180/130nm	Std laser				Optical		Dry				UV		FIB					
>/=250nm	Mature laser				Optical		Wet				Visible		Laser					

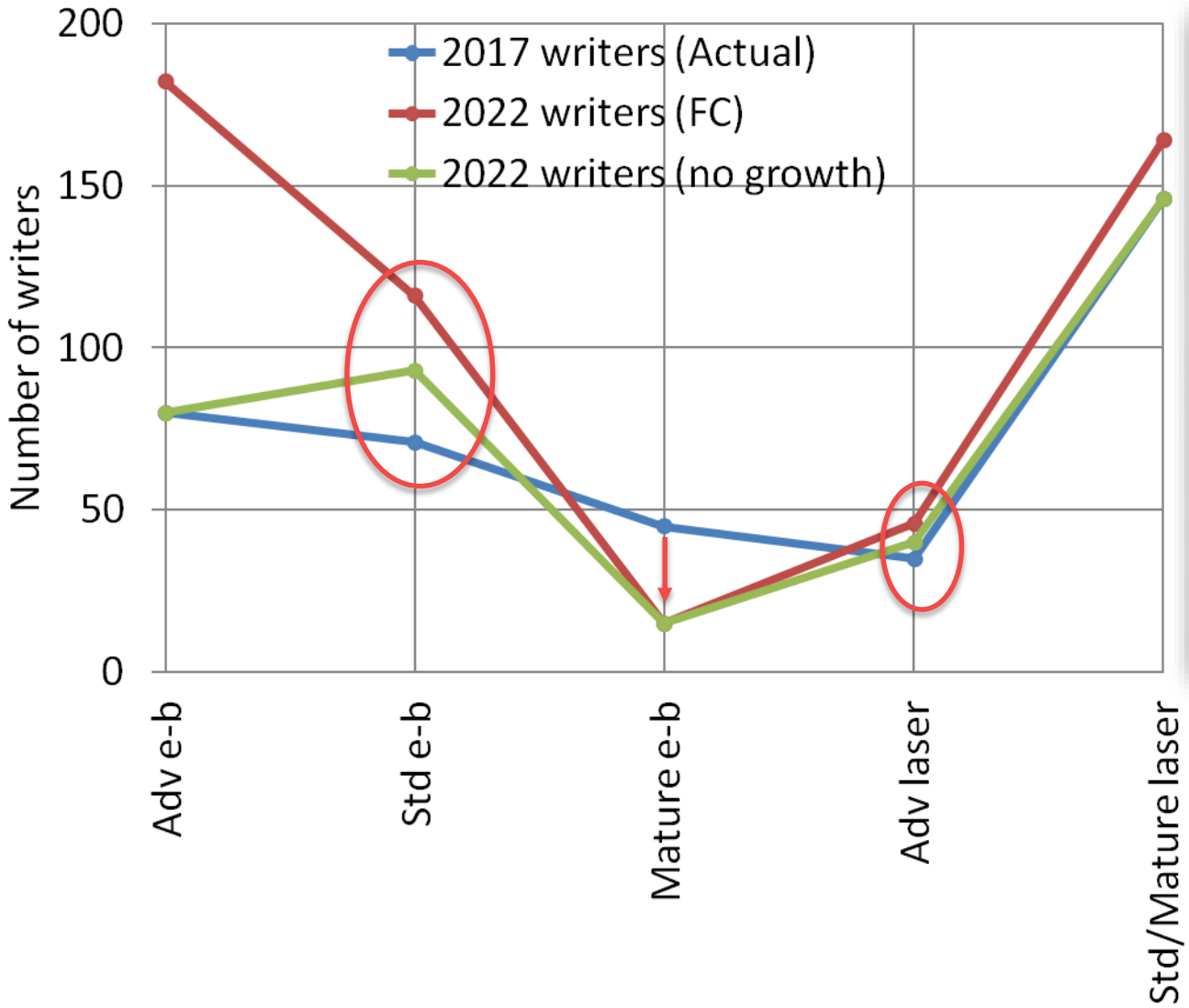
The 2022 demand statement is inconsistent with the mask toolkit's health.
Only advanced tools are being built.
Moreover, older tools (e.g., low-end e-b), will be de-supported in the next 5 yrs.

The topics

- Forecast the 2022 IC mask market and segment it by writing tool

- Show how the mask writer toolkit must change to serve the market

Mask writer landscape with mature e-b retirement



Even with no growth, mature e-b retirement creates a need for 22 mid-range e-b and 5 advanced laser tools.

With the forecast growth, new tools:

- ~100 adv e-beams
- 45 mid-range e-beams
- >10 adv lasers
- ~20 std/mature lasers

Prescription for mask tools lifetime extension

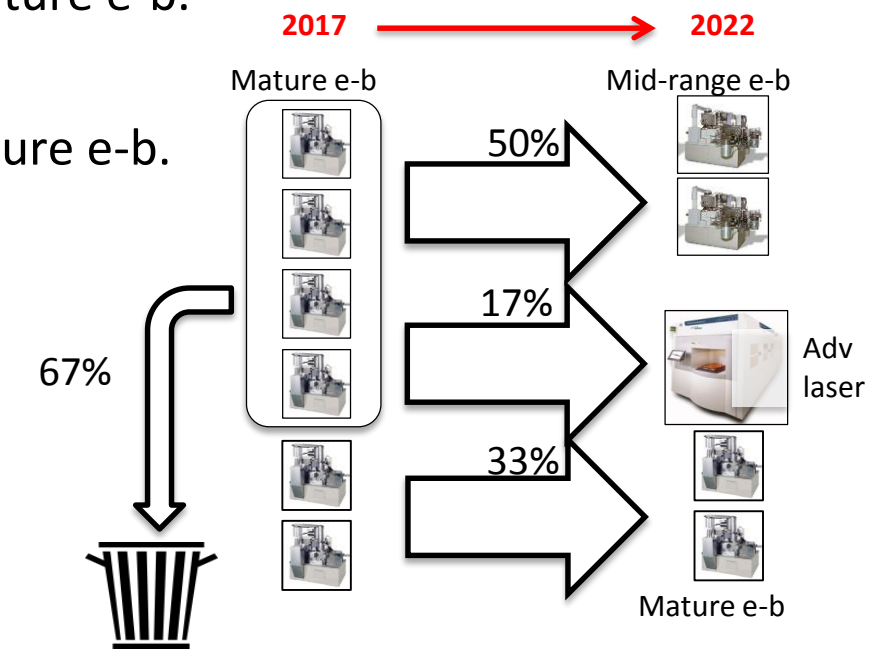
- **Strategy** for mask toolkit modernization:
  - ①Narrow the number of supported platforms; redesign / modernize them.
  - ②Provide modernization upgrades for existing supported tools.
  - ③Gradually retire unsupportable tools and replace them with modern ones.

  This strategy can be applied to most of the mask manufacturing toolkit.

- **Example**: retirement of low-end e-b writers.
  - Two year time horizon:
    - Redesign laser and mid-range e-b writer datapaths with modern, replaceable, scalable, generic data systems.
    - Provide data path upgrade package for existing mid-range e-b tools.
  - Five year time horizon:
    - Retire low-end e-beams over several years (say, five).
    - Fill the low-end gap with modern laser and mid-range e-b writers.

E-beam toolkit evolution

- Input assumptions:
  - Many mature e-b tools are “retired” by 2022 (let’s say 67% of them).
  - The retired tools’ work is moved to other tools.
    - 75% moves to mid-range e-b tools.
    - Mid-range e-b writes 1.5x as fast as mature e-b.
    - 25% moves to advanced laser tools.
    - Advanced laser writes 2x as fast as mature e-b.
  - Market growth is either…
    - As predicted earlier in this talk, or…
    - Zero.
- Output: additional tool demand by platform.



Tool suppliers' modernization challenge

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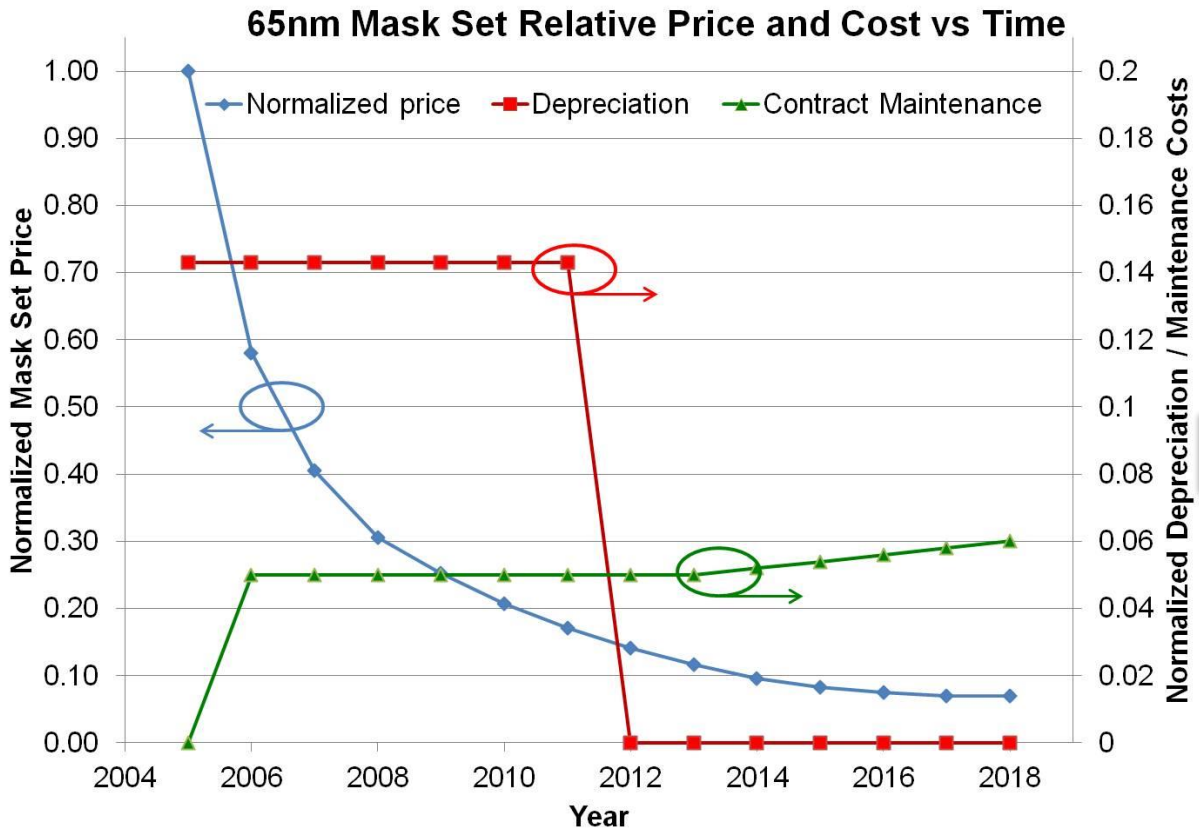
Build mid-range e-beam writers at a cost consistent with today's mask prices



Case Study: 65nm logic

Adv. e-b	5-6 layers
Mid. e-b	9-12 layers
Lo. e-b	10-13 layers
Adv. laser	0-1 layer
Std. laser	12-18 layers

- >50% of the masks are built with e-beams that must be modernized or replaced.
- Mask set prices have dropped >90% in 13 years.
- ∴ today's business model won't tolerate 2005 e-beam prices.

Writer summary

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- Advanced e-beam writers: healthy.
  - ~100 are required over the next 5 years.
  - Demand can be met by existing VSB and MBMW mfg capacity.

- Standard/mature e-beam writers: already described.
  - Renew standard / retire and replace mature.
  - Standard market will expand.

- Advanced laser writers: healthy.
  - Healthy mfg infrastructure with modernization strategy.
  - Capacity can meet the demand.

- Standard/mature laser writers: similar to std/mature e-b.
  - Renew standard / retire and replace mature.
  - Standard market will expand.

Summary

TOPPAN

- Explosive market growth in low-end electronics has created a manufacturing gap in a semiconductor industry geared toward chasing the high end.
- The IC mask industry faces a 70+ tool gap in low-to-mid-range manufacturing capacity as the mature toolkit is retired over the next 5 years.
- The gap can be closed by gradually retiring mature platforms and modernizing select existing platforms to replace them.
- This extension strategy is applicable to the entire mask toolkit.