INTERMOLECULAR

NCCAVS Talk

Material Innovation for Non-Volatile Memory Selectors

Larry Chen, Mark Clark, Charlene Chen, Milind Weling

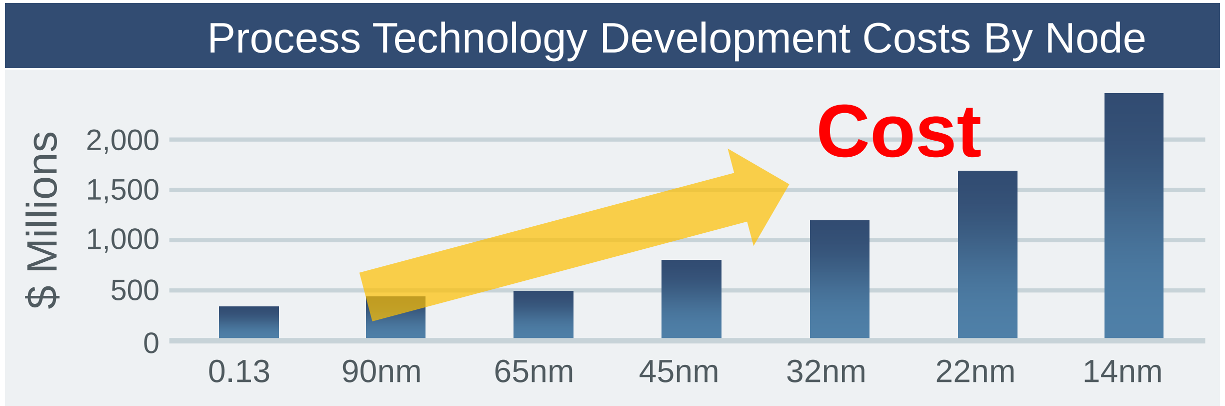
Feb 23rd, 2017

Outline

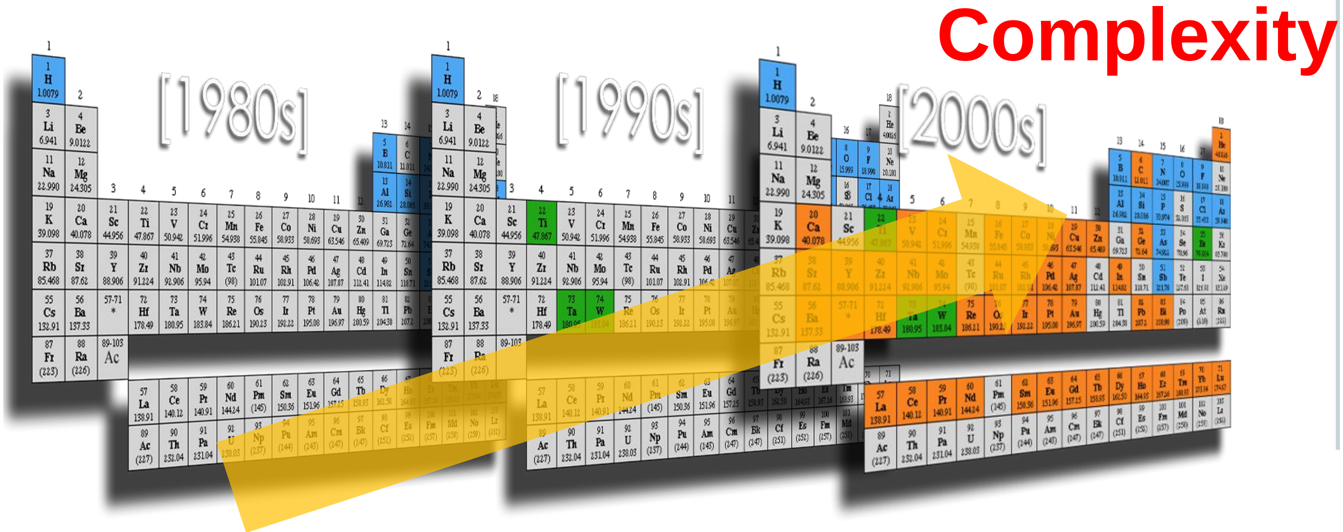
- IMI: Technical Value Proposition
- NVM Selector Key Performance Indicators
- IMI selector screening methodology
- Case study
- Summary

IMI: Technical Value Proposition

Growing Complexity & Cost of Material Development



Source: Common Platform & All Partners Analysis



Source: Intel

- Advanced materials are key to Semiconductor roadmap and leadership
- Critical attributes for material discovery process
  - Enables fast screening
  - Handles complex and toxic material system
  - Minimizes fab exposure to contamination

IMI Offers Unique Development Platform

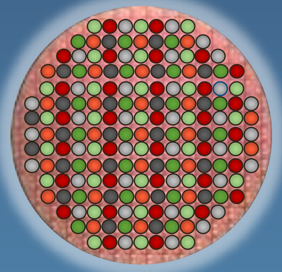
INTERMOLECULAR

High Throughput Experimentation accelerates and de-risks materials innovation

Accelerated Experimentation

IMI Processing Systems
- Wet: Clean, Etch, Deposition
- Dry: (PE)ALD, (PE)CVD, PVD

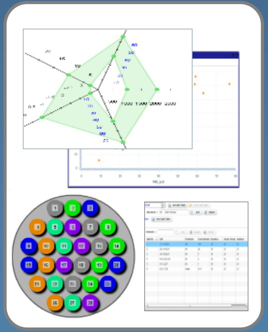
PVD

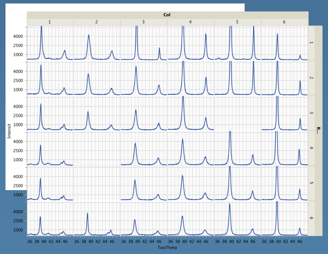


High throughput experimentation

Analytics Excellence

Metrology
- XRF, XRR, XRD
- ellipsometry,, UV-Vis, FTIR
- Optical microscopy
- SEM, AFM, contact angle,
- Particles (SP1)
- TEM, XPS, Auger, SIMS, TXRF, ICPMS (External Vendors)

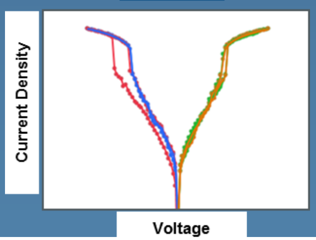




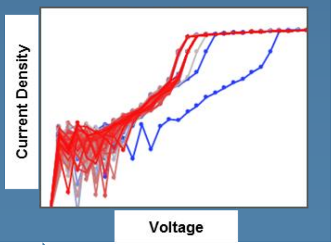
Electrical Characterizations

Electrical Characterization & E-test
- Fully automated probers with heated and/or cooled chucks
- Device: C-V, I-V & parameter extraction (EOT, EWF)
- Parametric: Leakage, line resistance, contact resistance, capacitance
- Reliability: V_{bd}, TDDB
- Pulsed switching: I_{on}, I_{off}, data retention (eg. Non-volatile memory)

DC-V Bip



P-Cyc



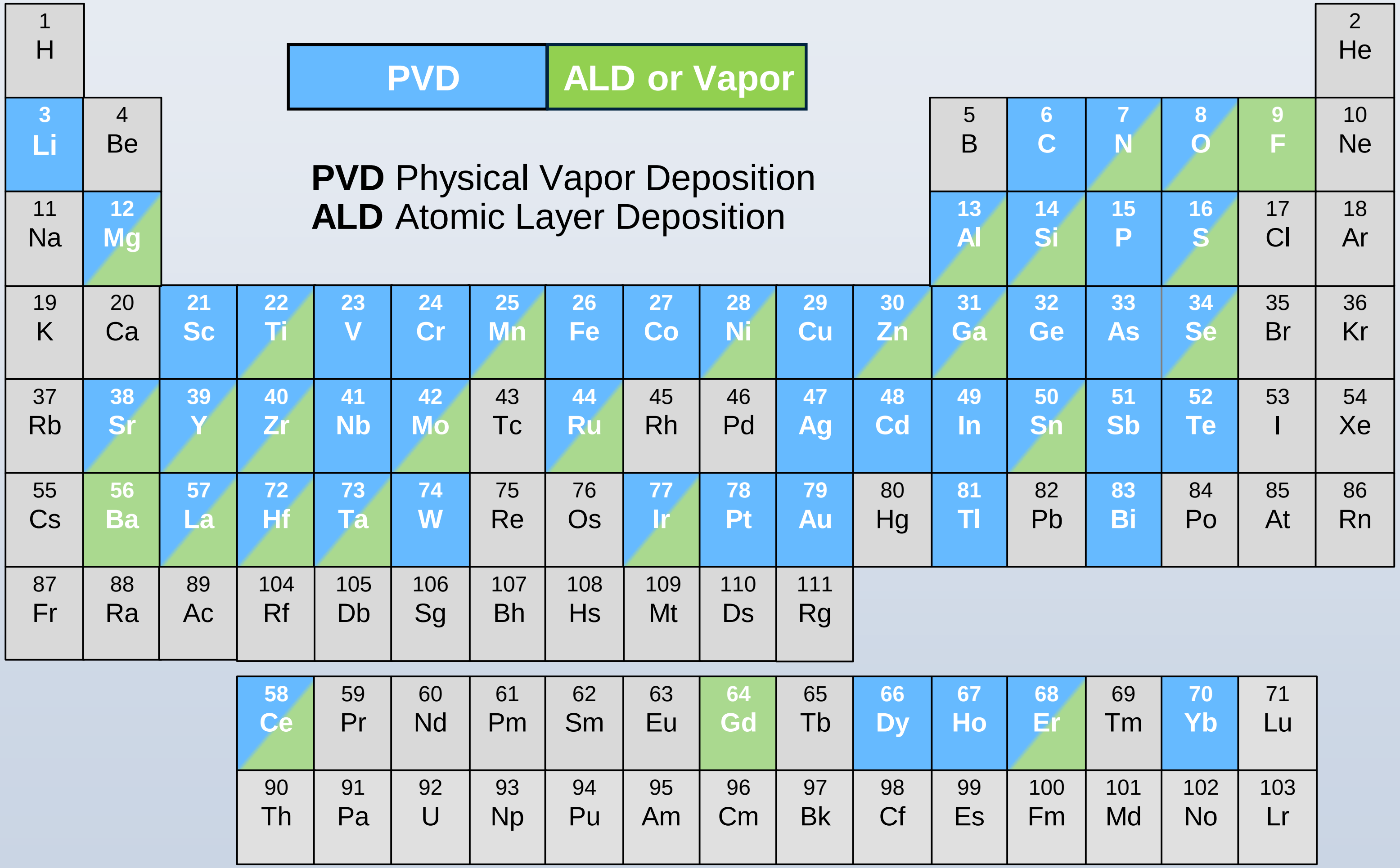
Deep Material and Device Innovation

Application knowledge + Understanding of integration issues

Extensive Materials Capability

Deposition and characterization of multinary materials:

- Metal Oxides
- Metal Nitrides
- Metals
- Alloys
- Chalcogenides

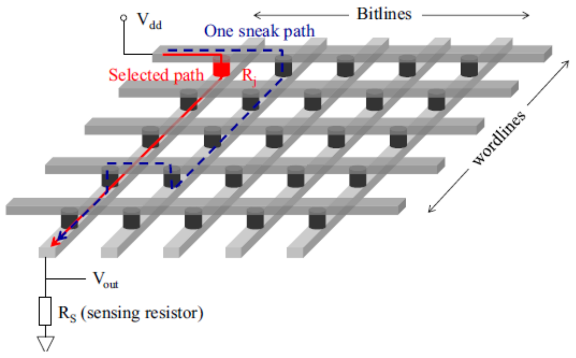


Screening of Non-Volatile Memory Selectors

Non-volatile Memory Selector
- Key Performance Indicators

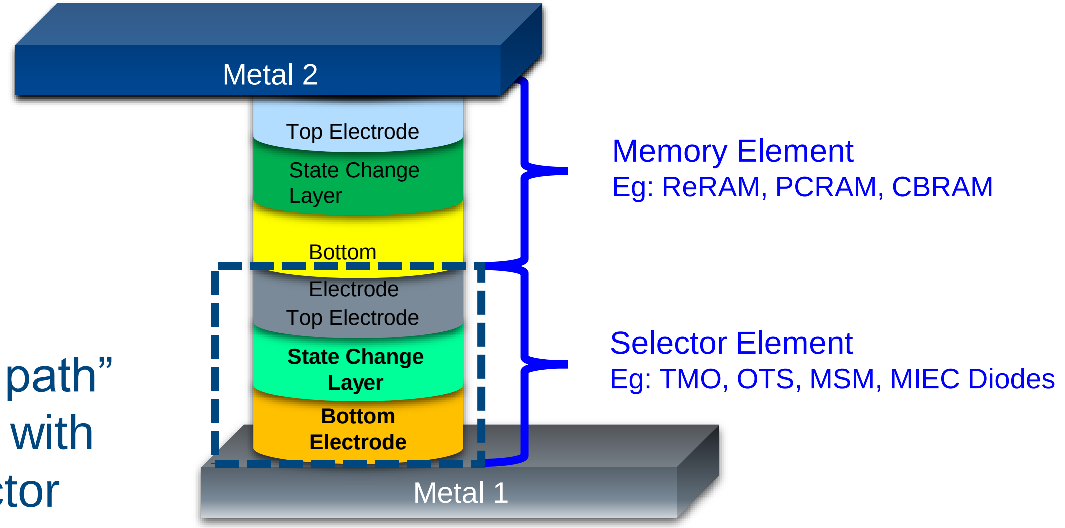
New Selector required to eliminate sneak current for cross-point memory

Sneak current paths



* Ref: An Chen 2014 AVS TFUG Seminar

"Sneak path" solved with selector device



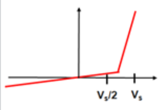
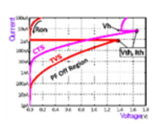
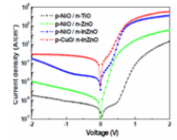
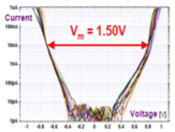
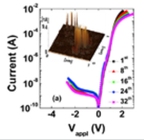
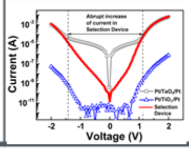
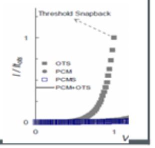
Generic Cross-point Memory Cell

Selector: Key Parameters
No forming
Threshold Voltage (V_{th})
On current (I_{on}) and density (J_{on})
Off current (I_{off}) and density (J_{off})
Selectivity (On/Off ratio)
Thermal stability
Switching speed
Endurance (AC, DC)

- Selector devices are critical to eliminating sneak current paths
- Disruptive selectors needed to address performance, density and reliability

New NVM Selector Device Comparison

INTERMOLECULAR

	Selector Req'ts	MSM	Oxide-PN[4]	MIEC[6]	Metal-Oxide Schottky[5]	MIIM Bi-directional Varistor[7]	Chal OTS[8]
Max Forward Current Density/ Feature Size	~10^{6-7} A/cm^2	~10^{6-7} A/cm^2	~$5x10^4$ A/cm^2@2V 0.5x 0.5um	~10^{5-6} A/cm^2@1V ~80nm bot	$3x10^5$ A/cm^2@2V 2x2um	~$3x10^7$ A /cm^2 @2.5V 250nm hole	Feasibility shown for 90nm PCM
J_{FB}/J_{RB} Ratio & $J_{+Vs}/J_{+Vs/2}$ Ratio	> 10^5 > 10^3	~ 10^3	~10^4 ~100	~10^4	$2.4x10^6$ ~10^3	~10^4	Met PCM Req
Directionality	Uni or Bipolar	Bipolar	Unipolar	Bipolar	Unipolar	Bipolar	Bipolar
Switching Time/ Endurance	< 10ns/ > 10^8	<10ns > 10^7	10-100ns/ ?	~ 1us/ > 10^6	< 1ns ?	< 1ns/ > 10^{10}	Feasibility shown for 90nm PCM
Deposition Temp/ Thermal Stability	< 400C/ > 400C	< 400C/ > 400C	< 400C/ ?	200C/ > 400C	250C/ ?	300C/ ?	< 400C/ Issue
Typical Materials/ Stacks Used	Fab Friendly	Semiconductors	CuO/IZO NiO/IZO	Cu in Solid Electrolyte	Pt/TiO_2/ TiO_{2-x} /Pt	Pt/TaO_x/TiO_2 /TaO_x/Pt	As, Ge, Si, S, Se, Te, N
I – V Curves							

Choice of selector determined by trade-off between performance, reliability and ease of integration

High Throughput Experimentation Methodology

INTERMOLECULAR

Process → ***Physical Characterization*** → ***Test Vehicle*** → ***Device Characterization***

PVD Co-sputter

- **Composition**
- **Crystallinity**
- **Resistivity**
- **Thermal Stability**

Re-insertion (Dep & Send)

Dep & Test

- **Device Types**
- **Leakage**
- **DC IV**
- **Pulse IV**
- **Endurance**

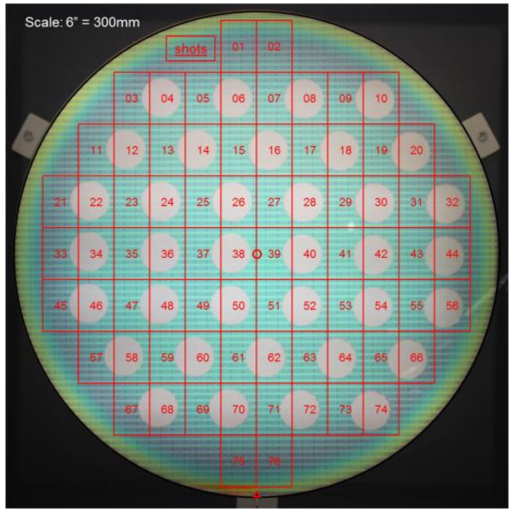
Fast material screening for selector innovation:

- **Metal Chalcogenide : 2500+ experiments**
- **MIEC: 2000+ experiments**
- **Transition Metal Oxide: 1000+ experiments**

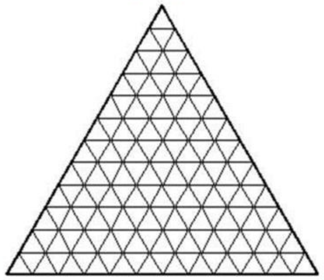
Process and Physical Characterizations

IMI P-30 PVD Chamber

Site Deposition on 300mm wfr

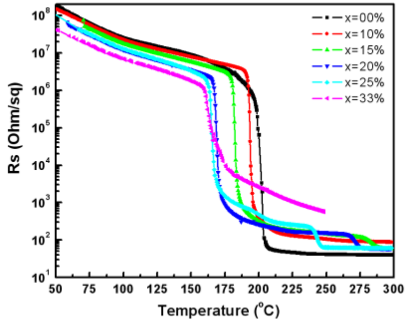


Composition



Pre-filter non-viable compositions

Thermal Stability & Resistivity



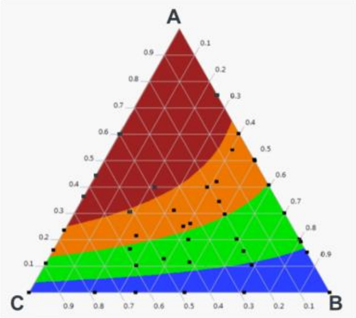
Pre-filter non-performing

Site-isolated PVD Deposition

- Each spot is an experiment
- Each layer can be deposited by 1 to 5 sputter sources
- Multilayer stack capability
- Shutters for aperture and targets prevent cross-contamination

Physical Characterizations

- Thickness
- Composition
- Crystallinity
- Resistivity
- n & k
- Thermal stability



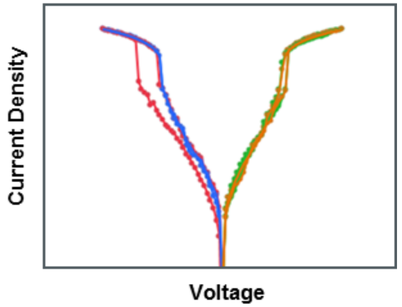
Response Surface:
Tc, Crystallization Temp

Electrical Characterizations - Overview

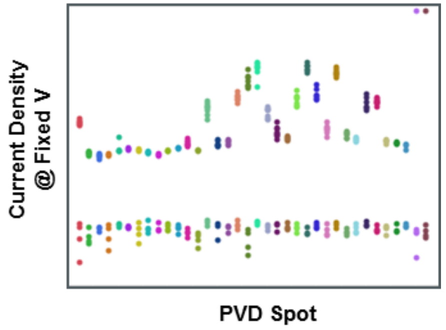
Available E-Test Modules

E-TEST MODULES		
CATEGORY	**NAME**	**DESCRITPION**
Imaging	Camera Box	Low magnification image
	E-Vision	High magnification image
DC-V	DC-V Uni	Single voltage sweep w/wo return
	DC-V Bip	Double voltage sweep w/wo return
	V-Cyc	Endurance uni/bip w/wo return
	Leak	Leakage checks
	CVf	Capacitance vs. voltage and/or frequency
	V-t	Voltage stress vs. time
	V-arb	Arbitrary voltage sweep
	Rho	Sheet Resistance (w/wo T sweep)
DC-I	DC-I Uni	Single current sweep w/wo return
	DC-I Bip	Double current sweep w/wo return
	I-Cyc	Endurance w/wo return
	I-t	Current stress vs. time
	I-arb	Arbitrary current sweep
Pulse	P-IV Uni	Single sweep w/wo return/op-amp
	P-IV Bip	Double sweep w/wo return/op-amp
	P-Cyc	Endurance w/wo return/op-amp
	P-End	Burst/Endurance w/wo op-amp
	P-Verify	Program Verify
	Tran	Transient Waveforms

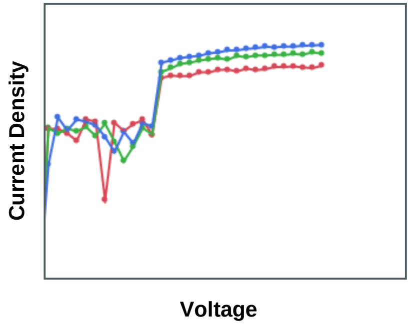
DC-V Bip



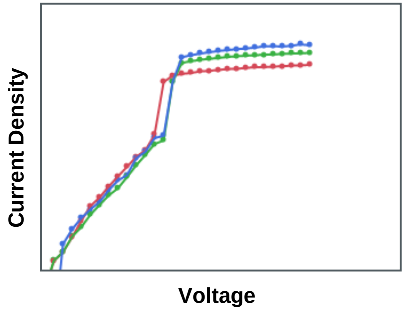
Leak



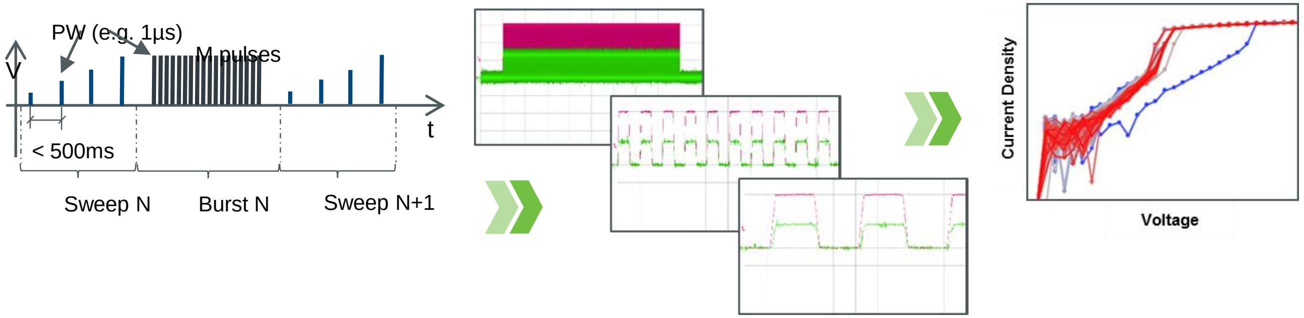
P-IV Uni (without op-amp)



P-IV Uni (with op-amp)

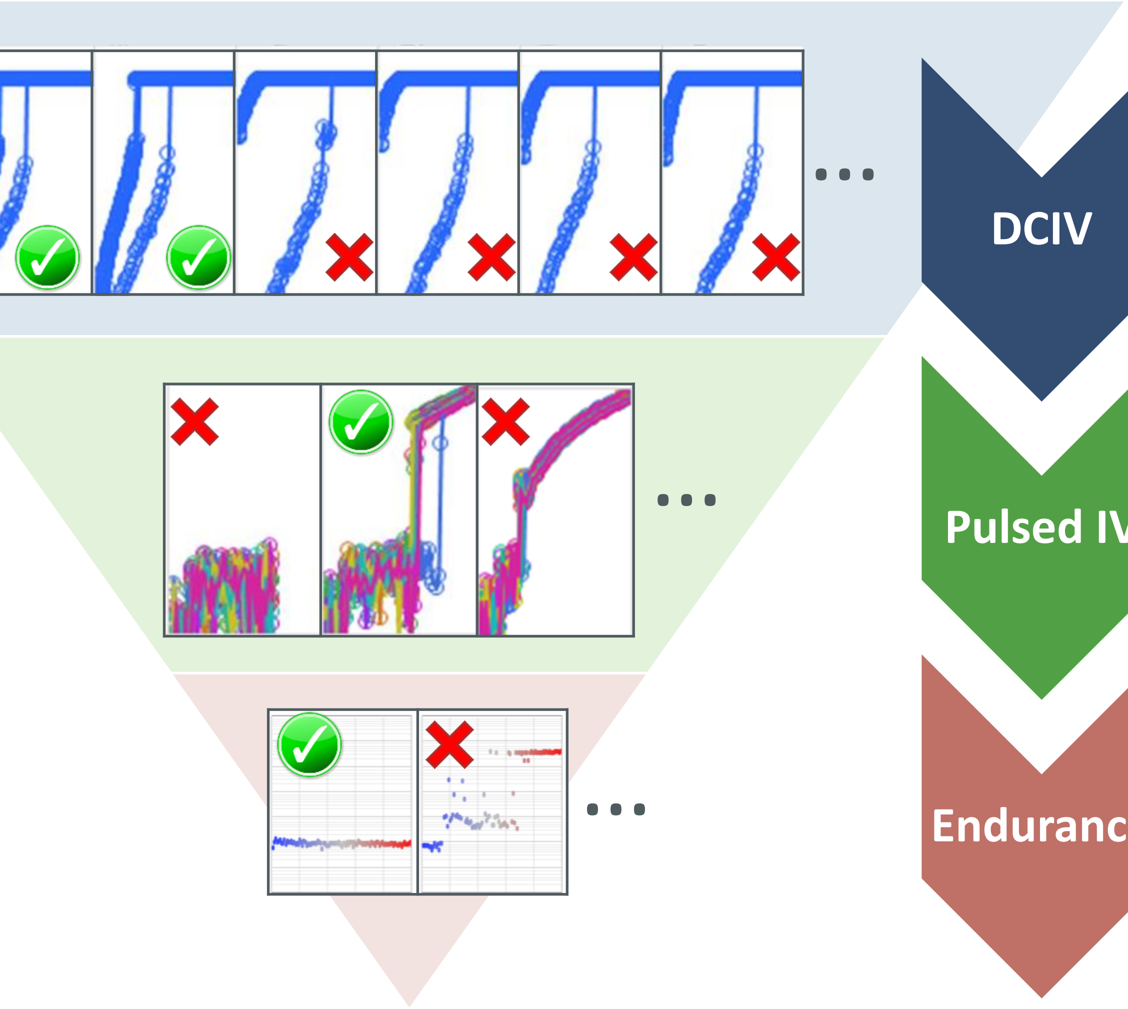


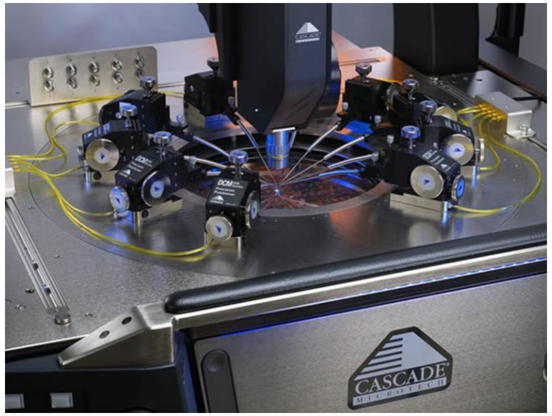
P-End



Selector Candidates Screening Stages

INTERMOLECULAR





DCIV
- Level 1 screening
- All splits

Pulsed IV
- Level 2 screening
- Selected splits

Endurance
- Level 3 screening
- Champion splits

Increasingly advanced electrical characterization to realize promising selector candidates

Summary

- New selector innovation needed to eliminate sneak current for cross-point memory architecture

- High-Throughput-Experimentation methodology accelerates and de-risk new selector material screening and device innovation

- IMI has successfully collaborated with customers to realize novel selector devices using HTE methodology

- Acknowledgments: J Watanabe and Customer+IMI collaboration teams

INTERMOLECULAR