SEM ADC
(Auto Defect Classification)

How it improves the Cost of Ownership without Risk of Yield Loss

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Contents

1. Introduction

- ITRS (International Technology Roadmap for Semiconductors) requires SEM ADC classification capability for 10-15 defect types with 90% accuracy and 90% purity at 720 DPH (defects per hour).

- Practically, redetection defect size is limited by resolution and the throughput is limited by physical parameters such as detector sensitivity (S/N) and stage vibration. Improvement in these areas depends on SEM physical and theoretical breakthroughs.

1. Introduction (continue)

- As a result of complicated semiconductor processes, the typical 15 types of defects can be classified with 85-90% of accuracy by trained operators. However, even the state-of-the-art technology of ADC can not classify 10 types of defects with 85-90% accuracy. It is a question of whether ADC is worth installing or not.

- Introducing SIC (significant impact class) classification and the real-time yield excursion detection method. The benefit of the cost reduction by ADC was estimated.

1. Introduction (continue)

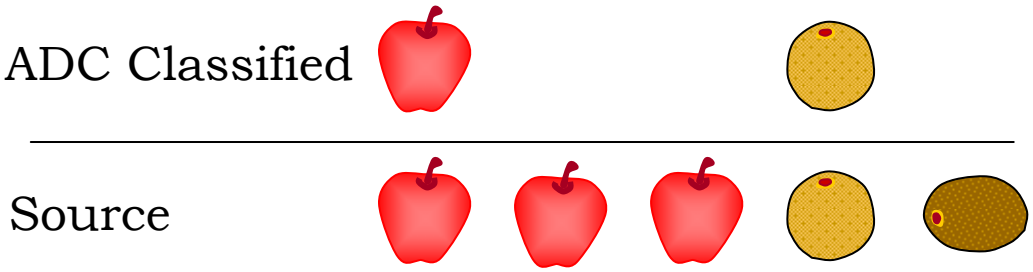
- Formula for Evaluation

$$Purity = \frac{the\ number\ of\ \ defects\ which\ human\ agrees}{the\ number\ of\ \ defects\ which\ ADC\ classified} \cdots\cdots\cdots (1)$$

$$Accuracy = \frac{the\ number\ of\ \ defects\ which\ ADC\ agrees}{the\ number\ of\ \ defects\ which\ human\ classified} \cdots (2)$$

1. Introduction (continue)

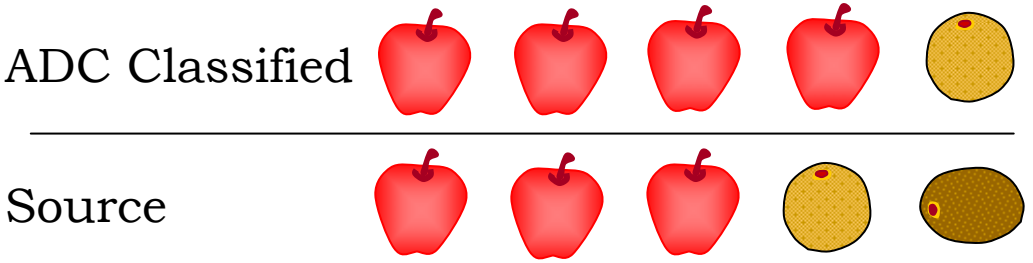
- Purity is important for SPC (Statistical Process Control)
  - Purity: I never tell a lie.



Apple purity:

$$\frac{\text{Correct} = 1}{\text{ADC Classified} = 1} = 100\%$$

  - Accuracy: I never miss (apple).



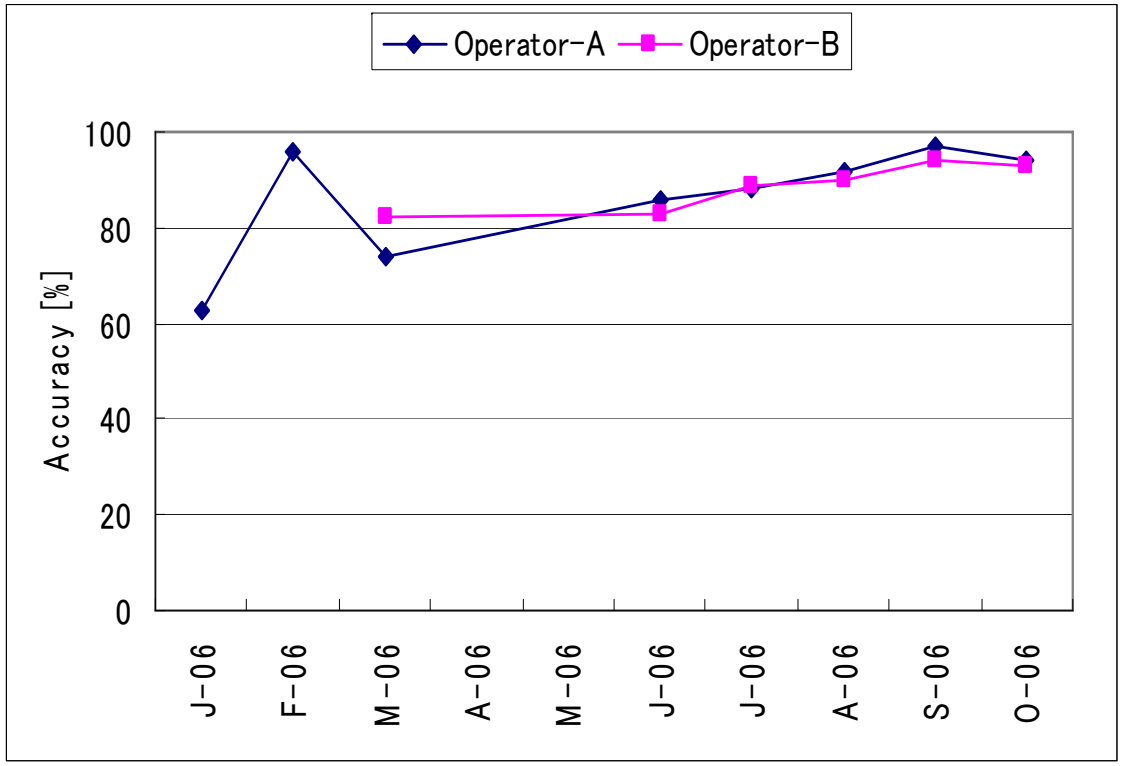
Apple accuracy:

$$\frac{\text{Correct} = 3}{\text{Human Classified} = 3} = 100\%$$

2. Concept (Needs)

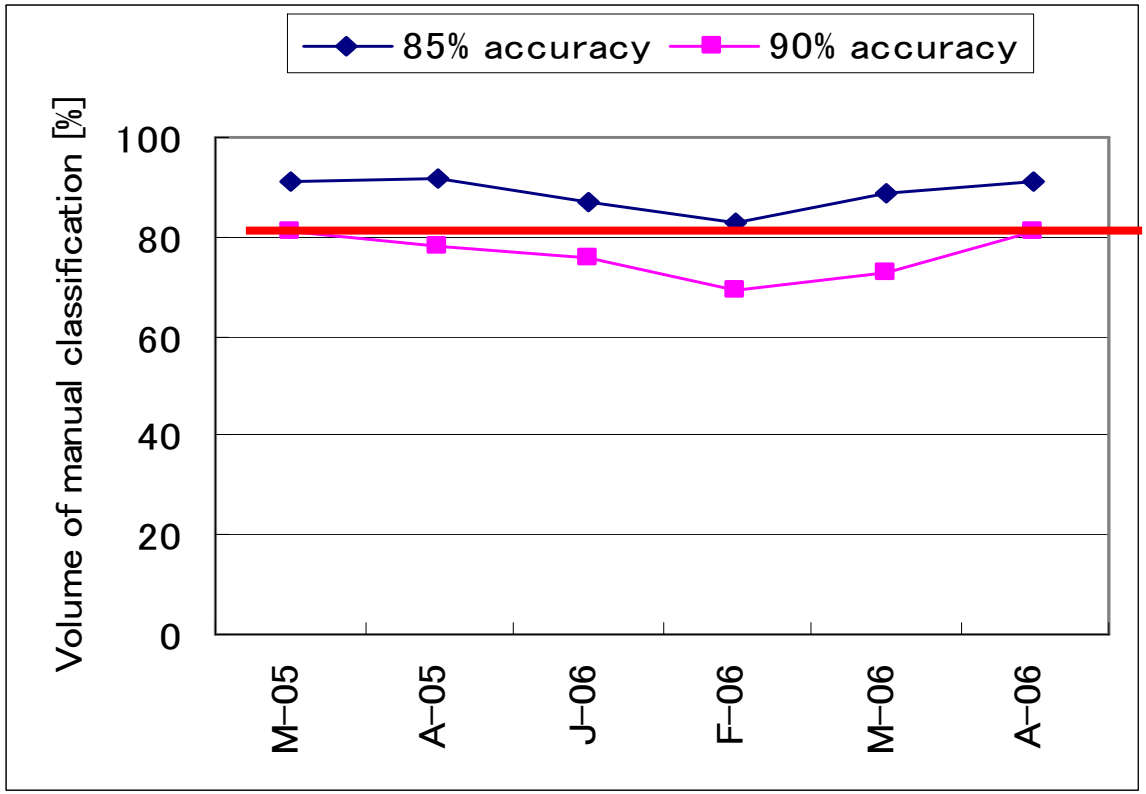
- Needs for Auto Defect Classification (ADC)
  - Importance of Defect Classification
    - Define defect type could predict the end of the line yield impact
    - The correct defect ID could lead the defect source and eliminate further yield impact
  - Human-factor for Manual Defect Classification (MDC)
    - MDC needs highly trained personal with time delay impact
    - Human limitation to classify volume > 90% with high accuracy and purity
  - ADC Improvement Requirements to Use inline
    - ADC must classify > 10 types of defects with 85-90% purity and accuracy
    - ADC needs proper methodology without time delay

Example of Human-factor: Learning Curve of Classification Accuracy



6 Months to achieve > 90%

Example of Human-factor: The Limitation of Classification-Capability



Human
Never > 80%

No one can exceed 80% of volume with 90% match.

≒

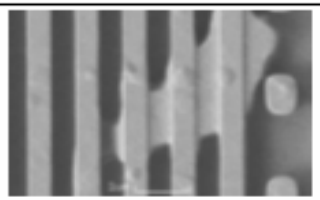
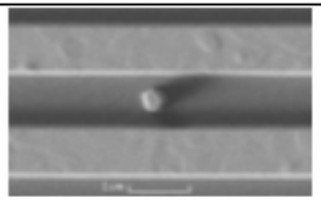
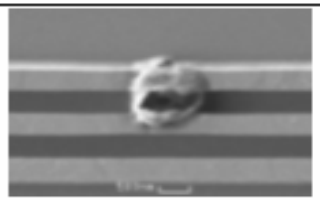
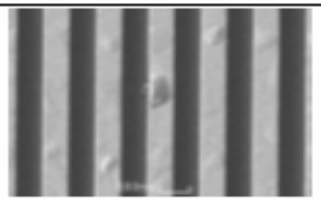
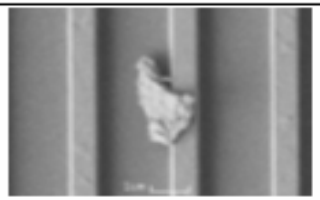
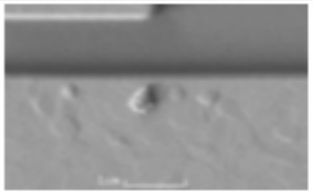
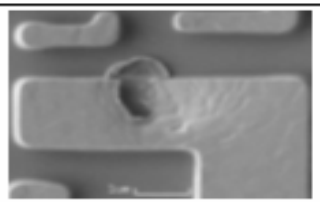
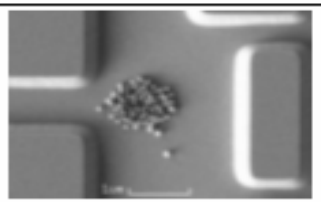
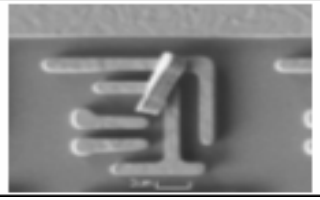
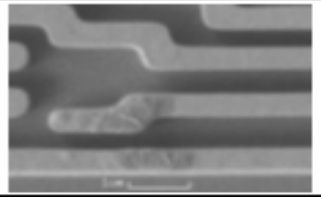
Accuracy/Purity of Human Classification is <80/90 % Or ~85/85 %.

2. Concept (Solution)

- ADC Improvements
  - Multiple detectors on the SEM greatly improve ADC accuracy.
  - Advanced ADC algorithm provides accurate output for a few defect types with high accuracy and purity.

- Using ADC for Killer Defect Classification
  - ADC can classify the killer types of defects
  - Cost of classification is reduced
  - Yield loss is reduced and the CoO is decreased
    - Excursion will be detected earlier
    - Problem resolution will be tackled before heavy yield loss occurs

Example of ADC Classification of Killer/Non-Killer Defect Types

Class	Killer (*_K)	Non-Killer (*_NK)
PAT_FLAT		
INFLM_PART		
PARTICLE		
PAT_OTHER		
OTHER		

3. Experiment

- Experiment Condition
  - SEM Review Tool: JWS7555S
  - ADC Architecture: Trainable classification
  - Sample: FEOL (front end of line) six layers, and BEOL (back end of line) two layers
  - Classes: Total fifty standard classes mapped to user classes and high purity classes are chosen

- Killer grouping
  - Focus on Killer defects
  - All killer classes is classified as “Killer_X”
  - High purity killer classes is classified as “Killer_Y”

ADC results of a FEOL layer (Purity of 5 classes > 85%)

	Class Name	ADC												MDC Total	Accuracy[%]
		PAT_FLAT_K	INFLM_PART_K	Particle_K	Other_K	PAT_FLAT_NK	PAT_OTHER_NK	INFILM_PART_NK	Particle_NK	CANT_FIND	SmallDefect	Exception	Unknown		
MDC	PAT_FLAT_K	193	1	1	99	0	0	0	1	0	0	7	46	348	55.5
	INFLM_PART_K	0	3	0	8	0	0	0	0	0	0	0	0	11	27.3
	Particle_K	1	0	84	206	0	0	0	2	0	0	2	6	301	27.9
	Other_K	1	0	19	201	0	14	3	4	0	0	5	15	262	76.7
	PAT_FLAT_NK	4	0	0	128	71	54	2	37	0	1	10	13	320	22.2
	PAT_OTHER_NK	0	0	0	160	0	731	1	4	0	49	19	11	975	75.0
	INFILM_PART_NK	1	0	0	124	0	0	303	5	0	0	10	5	448	67.6
	Particle_NK	2	0	0	446	6	32	2	110	0	63	15	17	693	15.9
	CANT_FIND	0	0	0	0	0	0	0	0	261	0	0	0	261	100.0
	SmallDefect	0	0	0	0	0	0	0	0	0	4	0	0	4	100.0
	Exception	0	0	0	8	0	0	0	0	0	4	168	6	186	90.3
	Unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	na
ADC Total		202	4	104	1380	77	831	311	163	261	121	236	119	3809	–
Purity[%]		95.5	75.0	80.8	14.6	92.2	88.0	97.4	67.5	100.0	3.3	71.2	0.0	–	–

Killer Grouping of a FEOL layer

(killer_X: all killers, killer_Y: high purity killers)

		ADC							
Class Name		PAT_FLAT_K	INFLM_PART_K	Particle_K	Other_K	MDC Total	Accuracy[%]	Killer_X Accuracy[%]	Killer_Y Accuracy[%]
MDC	PAT_FLAT_K	193	1	1	99	348	55.5	88.6	90.3
	INFLM_PART_K	0	3	0	8	11	27.3		
	Particle_K	1	0	84	206	301	27.9		
	Other_K	1	0	19	201	262	76.7		
ADC Total		202	4	104	1380	3809	–		
Purity[%]		95.5	75	80.8	14.6	–	–		
Killer_X Puirty[%]		48.3							
Killer_Y Purity[%]		97.7				=(195+4+104)/(202+4+104)			

(A)

(B)

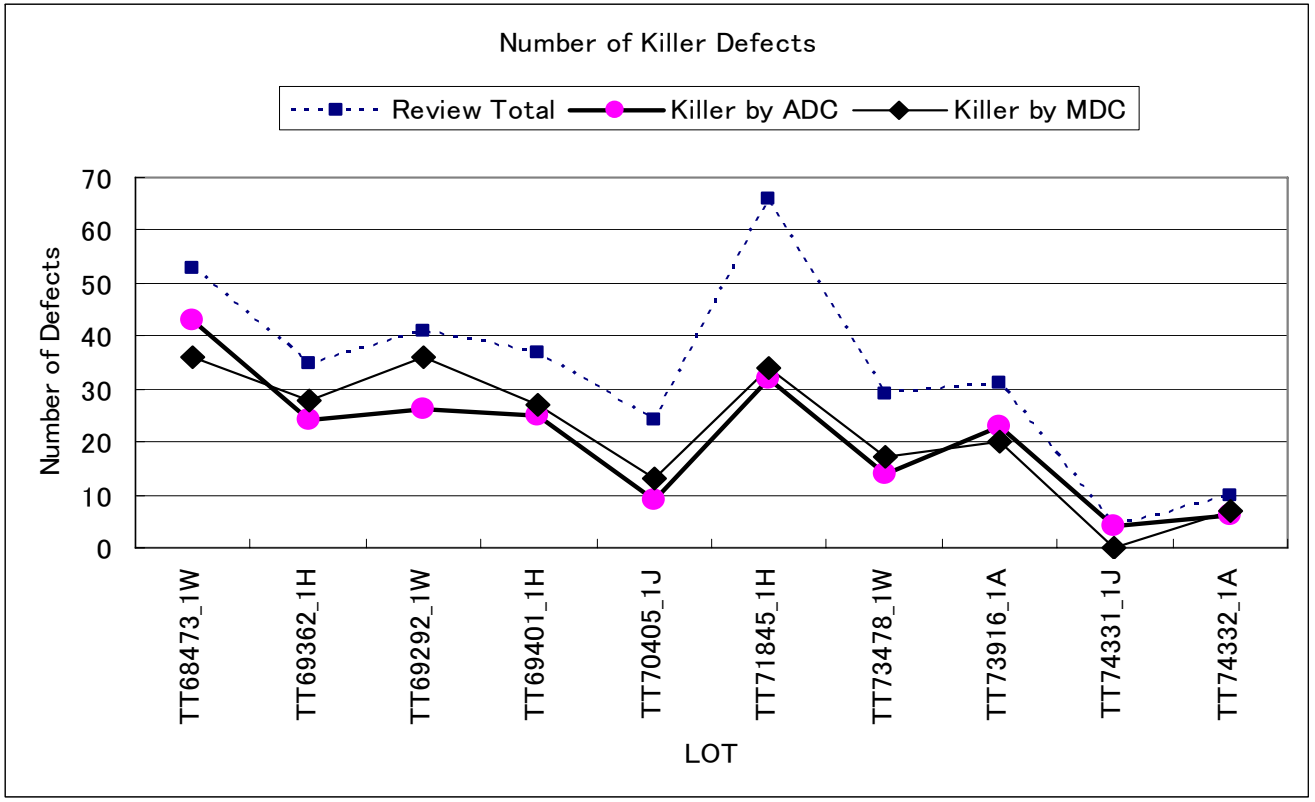
Killer_X Purity = #of human agreed killer defects/#of all killer classified defects by ADC = (A)/(B) = (195+4+104+514)/(202+4+104+1380) = 48.3%

Killer Grouping Summary (FEOL layer)

(killer_X: all killers, killer_Y: high purity killers)

Class	Purity	Accuracy
Killer_X	**48.3%**	**88.6%**
Killer_Y	**97.7%**	**90.3%**

Killer_X trend



- *ADC's killer defect classification capability ~= MDC's*

4. Consideration

- In order to use killer classes for yield management, both purity and accuracy need to be greater than 85%.
  - Killer_Y can be used by YMS
  - Killer_X *CAN'T* be used by YMS
- Introducing Significant Impact Classes (SIC)
  - SIC is the sum of high impact classes (normally killer_X and non-killer high purity classes).
  - Can SIC be used for yield management?
- ADC Cost Reduction Estimation
  - Can ADC reduce CoO?

Yield Impact Calculation Formula

$$I_y = R_{kill} \times F_d$$

I_y	Yield impact
R_{kill}	Kill ratio of the defect class of the layer
F_d	Occurrence frequency of the classified defect

Other formula

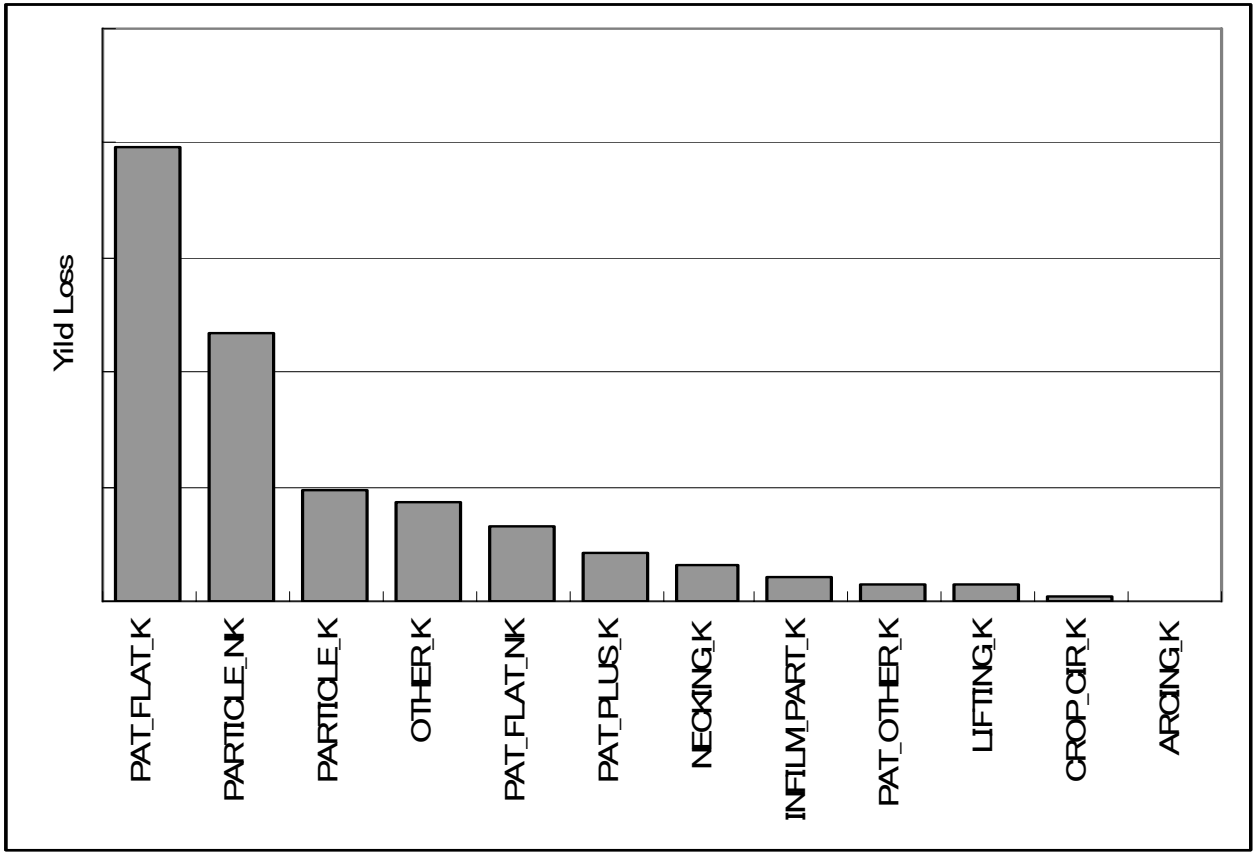
$$R_{iadc} = I_{adc} / I_{total} \times 100\%$$

R_{iadc}	ADC detection ratio
I_{adc}	Impact the ADC can detect
I_{total}	Total imapct by all defects

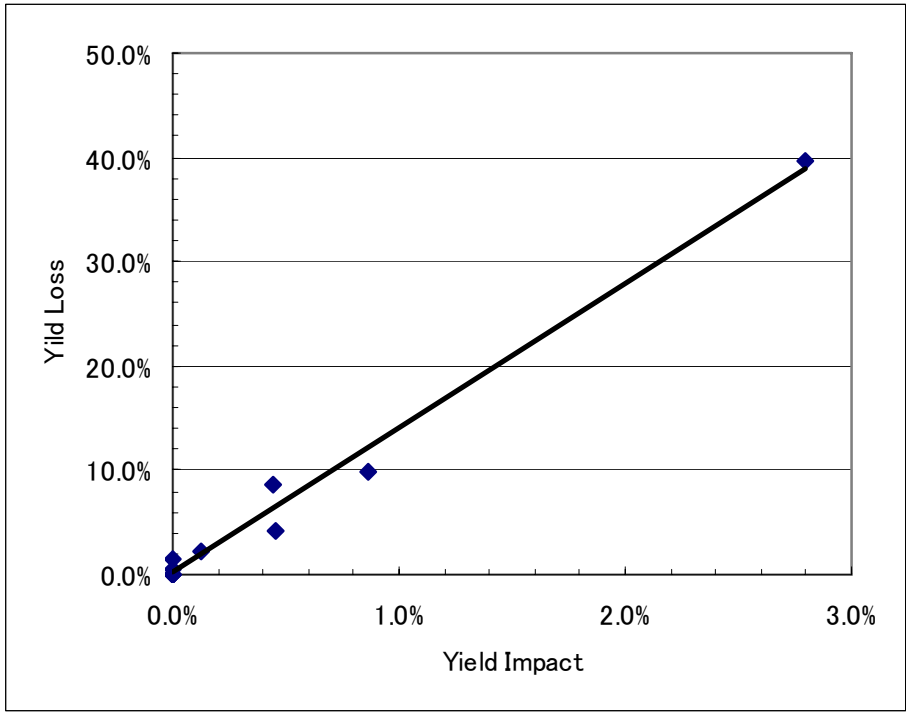
$$C_{hp} = N_{hipurity} / N_{adc} \times 100\%$$

C_{hp}	Coverage of high purity classes
$N_{hipurity}$	Number of defect with high purity classes
N_{adc}	Number of ADC(ed) all defects

Yield Loss Pareto of a FEOL Layer

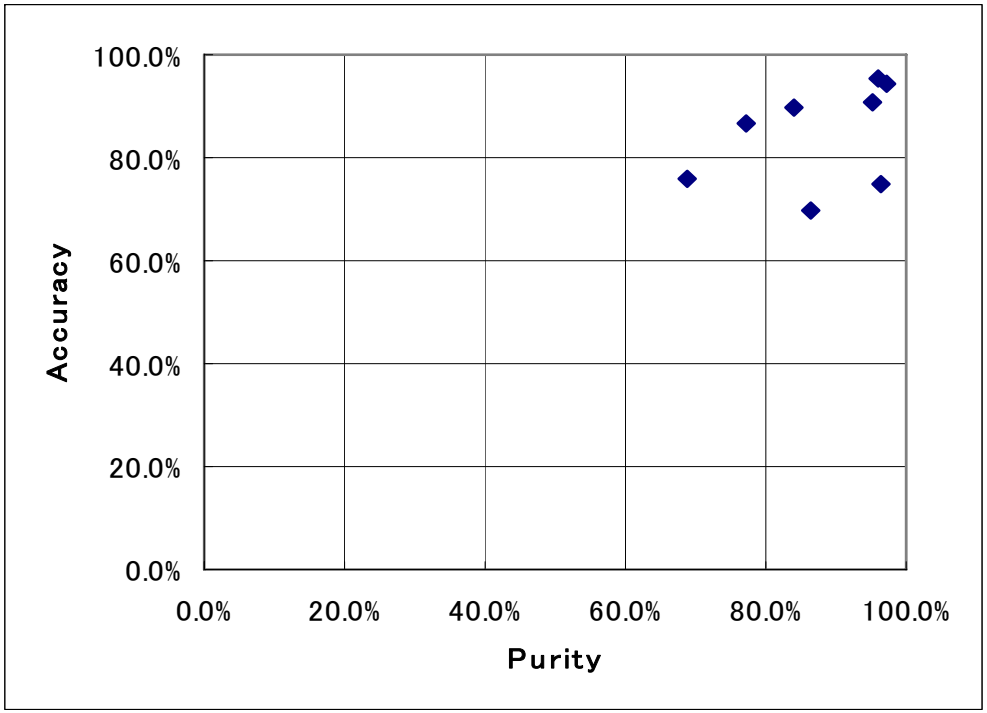


Yield Impact vs Yield Loss



- *Yield loss has strong correlation with yield impact*

Result of Significant Impact Classes in Each Layer



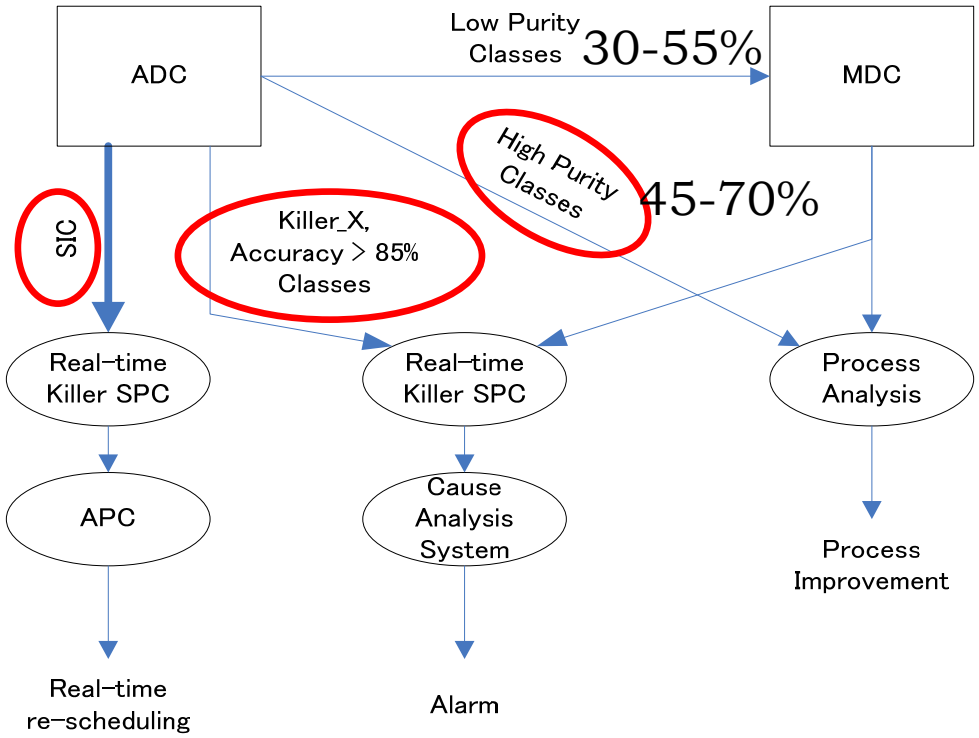
- *Purity and accuracy of SIC > 80%*

Calculated Yield Impact from ADC Result

Class Layer	Impact [%]					Ri_{adc}: Yield Impact Detected Ratio by SIC [%]
	Killer_X	Killer_Y	High Purity Non-killer	SIC	Total	
FEOL	4.7	3.8	2.8	7.5	7.5	100
BEOL	34.1	18.2	0.6	34.7	34.7	100

- *All Impact for the layer was detected by SIC*

Further ADC Works: Real-time Excursion Control System



- *All yield loss is detected by SIC*
- *Excursion is detected at real-time by Killer_X and high accuracy classes*
- *High purity classes can be used for process analysis*
- *MDC work load can be reduced to 30-55%.*

ADC Cost Reduction Estimation

$$C_p = N_{product} \times I_y \times N_d \times T_{ddetection} \times P_{chip}$$

C_p	:	Cost reduction of the process
$N_{product}$	:	Number of production wafers per hour of manufacture equipment (subject of inspection)
I_y	:	Impact of a defect
N_d	:	Average defects per wafer after fault occurrence
$T_{ddetection}$	:	Detection lag time caused by manual classification [hour]
P_{chip}	:	Price of a chip.

Cost Reduction for Short Term Excursions

- If the time taken in the classification and reaction by an engineer were 2 hours, the time of recovery from a failure could be less than 2 hours with ADC. It prevents the large yield loss and reduces the cost significantly.
- When assuming the average detection lag time caused by manual classification is 1 hour, the calculated value for total cost reduction due to ADC is $105K/year (*).

(*) Assumed that 30,000 8-inch wafers are manufactured per month (*Nproduct* = 41.7 [wafer/hour]). Process equipment fault caused defectivity is estimated at a frequency of one event per month in 2 layers, and assumes 100 defect per wafer increase at the time of the event (*Nd* = 100 [defect/wafer]). The average detection lag time caused by manual classification is 1 hour (*Tddetection* = 1 [hour]). When assuming the price of one chip to be $5 (*Pchip* = 5 [$]) and average yield impact through layer Iy was 21%, the total cost reduction Cp = 41.7[wafer/hour] x 21% x 100[defect] x 1 [hour] x 5[$] x 2[layer] x 12[month] = $105K/year.

Cost Reduction for Long Term Excursions

- Minimization of excursion impact by ADC also shows a tremendous cost saving;
  > $800K (*).

(*) Assuming there were one major excursion (> 300 wafers scrapped), two minor excursions (> 100 wafers scrapped) during a one year period using in-line monitor inspection with ADC feedback loop, and $2000/ wafer

5. Conclusion

- The preliminary result has shown that off-line ADC with SEM images provides significant information and tremendous opportunities for yield improvement and yield prediction.

- Applying the SIC detection method to ADC, almost all excursions will be detected by SPC with ADC.

5. Conclusion (continue)

- Rapid feedback will reduce yield loss significantly.
- ADC will be expanded into the yield improvement world with various types of SEM.
- It is expected that ADC will be incorporated into APC in the near future.