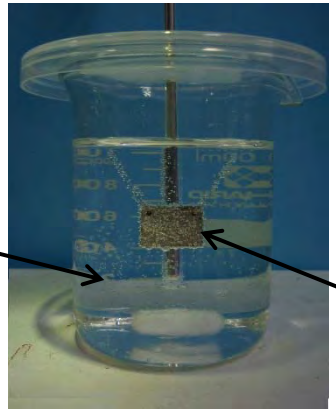
Corrosion Phenomenon Evaluation of Mg Alloys Using Surface Potential Difference Measured by SKPFM

Background

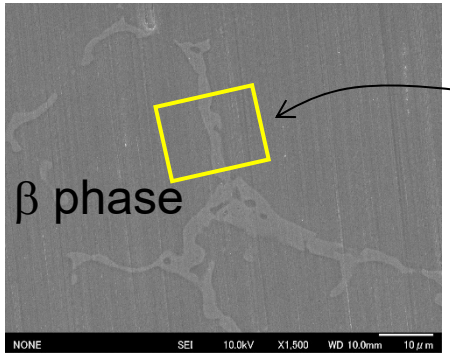
Mg : Lightest industrial materials with Poor corrosion resistance caused by galvanic potential



What causes corrosion ?

Volumetric loss

Focusing on interface between α-Mg and dispersoids



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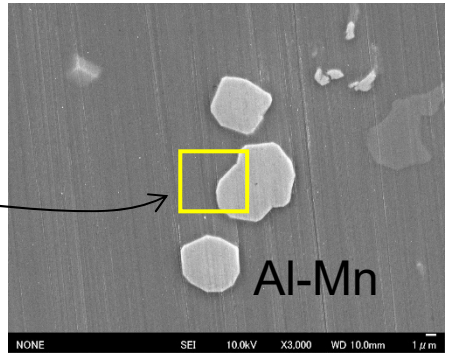
Interface between α-Mg and dispersoids



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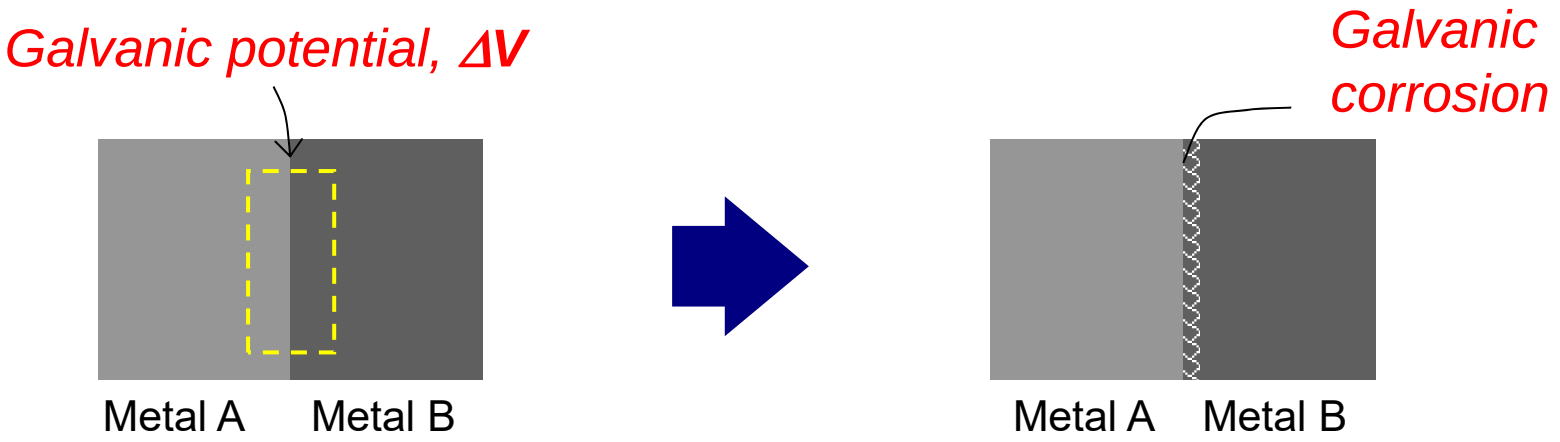
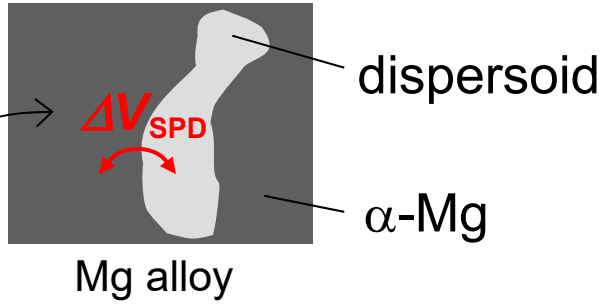
Objectives



SKPFM
Scanning Kelvin Prove Force Microscope

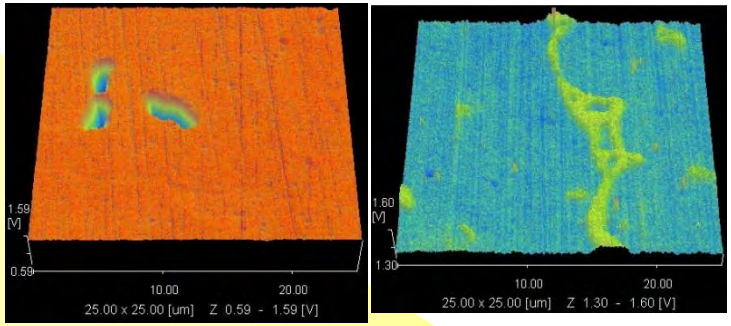


Surface Potential Difference

- **Galvanic corrosion was quantitatively evaluated by surface potential difference ΔV_{SPD}.**

Corrosion phenomenon analysis

Measurement of surface potential

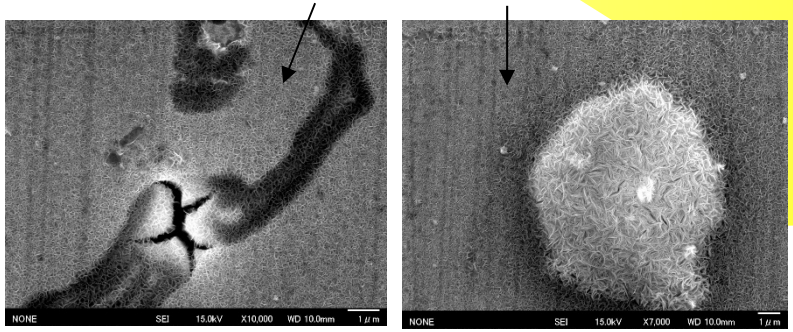


Surface potential map

5wt% Salt water immersion test
Corrosion time : 18 hour
Solution temperature : 30 °C

Salt water immersion test

What phases are corroded ?



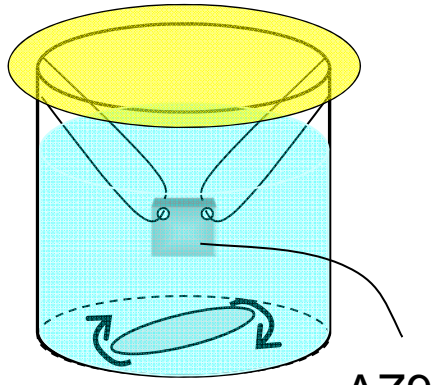
Topographic changes at interface

Macro-scale corrosion analysis

Salt water immersion test

Experimental condition

- Solution concentration : 5 wt%
- Solution temperature : 30 °C
- Testing time : 18 hours
- Rotation rate of stirrer : 420 rpm



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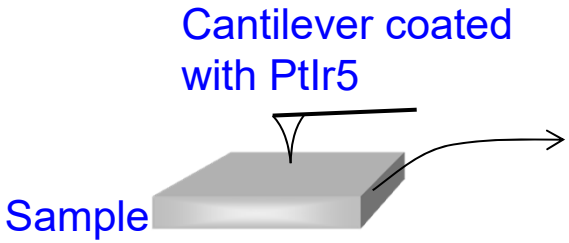
Surface finish

1. Waterproof abrasive paper in tap water up to #4000
2. Mirror finish by buffing using diamond paste

Micro-scale corrosion analysis

Surface potential measurement by SKPFM



Surface finish

i. Diamond paste polishing

ii. Ultrasonic cleaning with ethanol

Surface potential : V_{SP}

Contact potential difference : V_{CPD}

Work function ϕ

$$V_{CPD} = (\phi_{PtIr5} - \phi_{sample})/e$$

$V_{CPD} = V_{SP}$

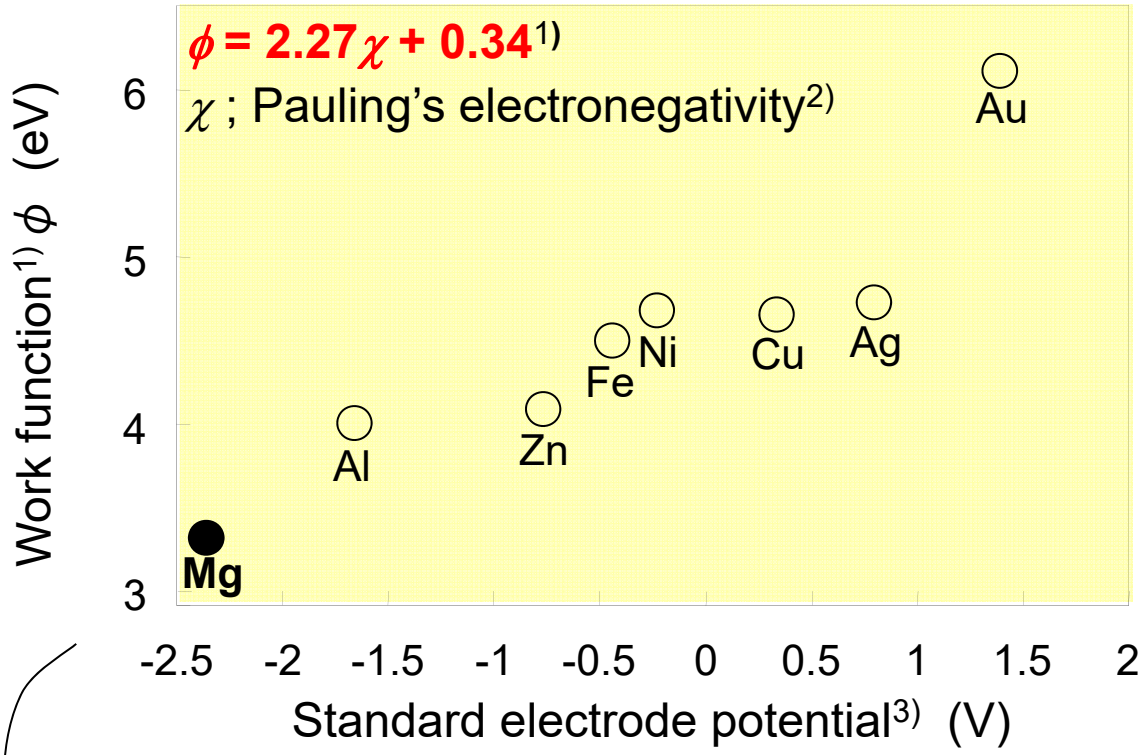
Constant: ϕ_{PtIr5} — Variable: ϕ_{sample}

V_{CPD} is dependent on ϕ_{sample}

How about relationship between standard electrode potential V_{SEP} and work function ϕ ?

Micro-scale corrosion analysis

Standard electrode potential – Work function



1) J.K.Schaeffere, et al.,Microelectronic Engineering,84(2007)2196-2200

2) A.L. Allred, Electronegativity values from thermochemical data, J. Inorg. Nucl. Chem. 17 (1961) 219

3) M.M. Avedesian, H. Baker, Magnesium and Magnesium Alloys, ASM International, OH, 1999, pp.194

$$V_{SP} = V_{CPD} = (\phi_{PtIr5} - \phi_{sample})/e$$

Standard electrode potential	**small ⇔ large**
Work function ϕ	**small ⇔ large**
Surface potential $V_{SP}(=V_{CPD})$	**large ⇔ small**

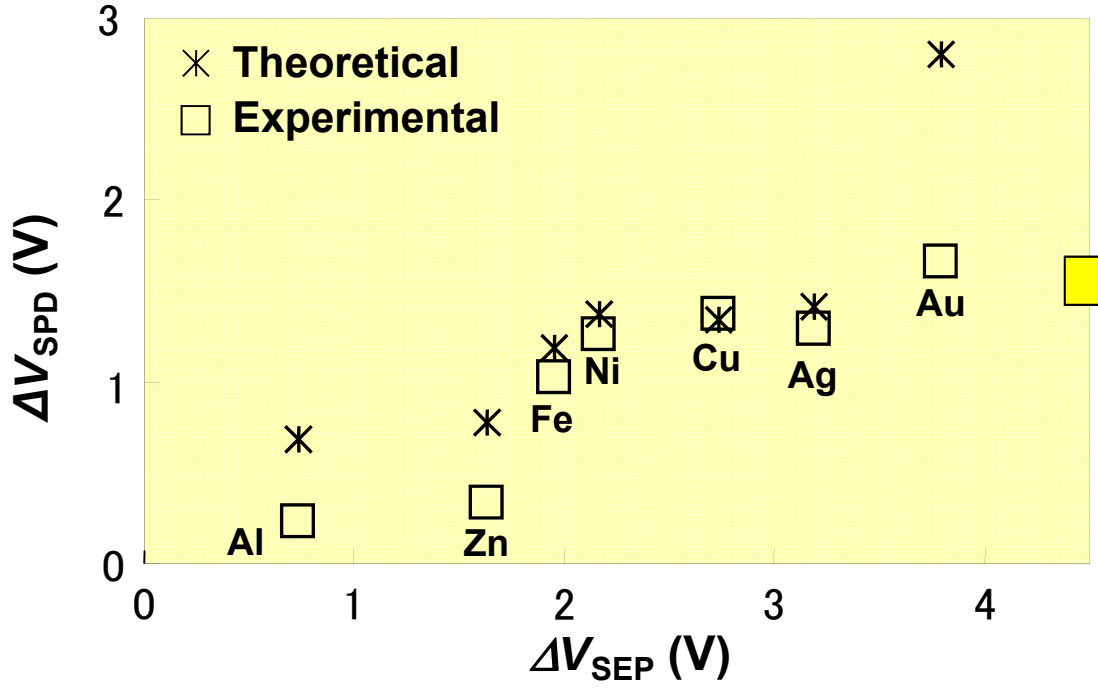
Micro-scale corrosion analysis

Surface potential difference
ΔV_{SPD}

$$\Delta V_{SPD} = V_{Mg} - V_{metal}$$
$$= (\phi_{PtIr5} - \phi_{Mg})/e - (\phi_{PtIr5} - \phi_{metal})/e$$
$$= (\phi_{metal} - \phi_{Mg})/e$$

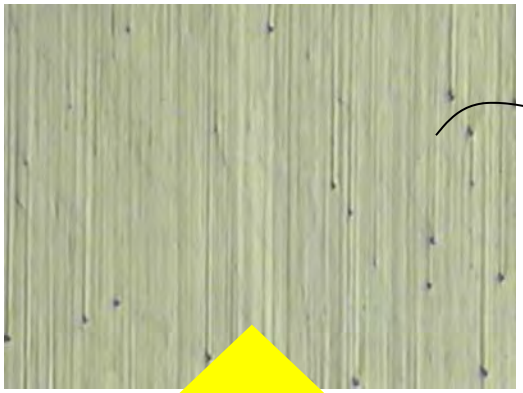
Standard electrode potential difference
ΔV_{SEP}

$$\Delta V_{SEP} = SEP_{metal} - SEP_{Mg}$$

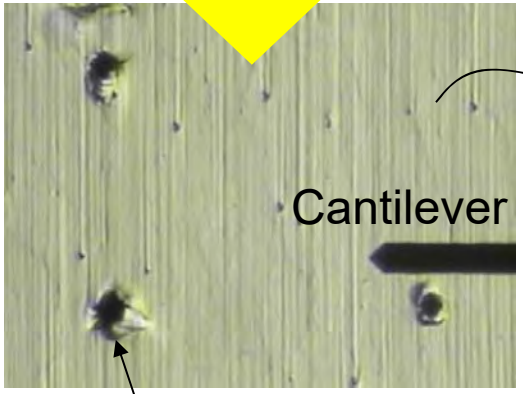


$\Delta V_{SPD} \propto \Delta V_{SEP}$

Identification of dispersoids 1/2



Optical microscope image attached to SKPFM



Marking by Vickers hardness

A) **Difficult to identify dispersoids.**

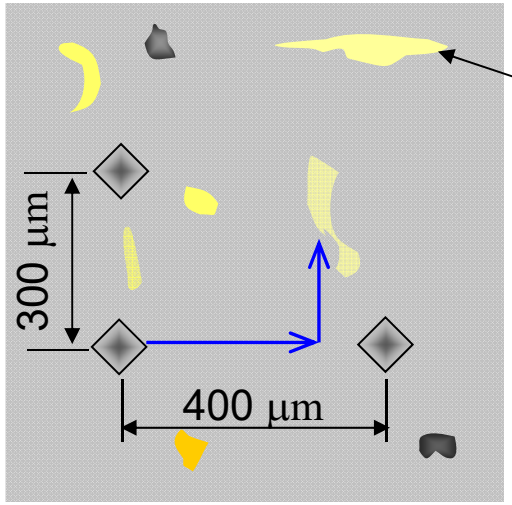
B) **Markings effective to detect the same position before and after corrosion test.**

A) **Easy to identify dispersoids**

B) **Three indentations by Vickers hardness tester.**

Identification of dispersoids 2/2

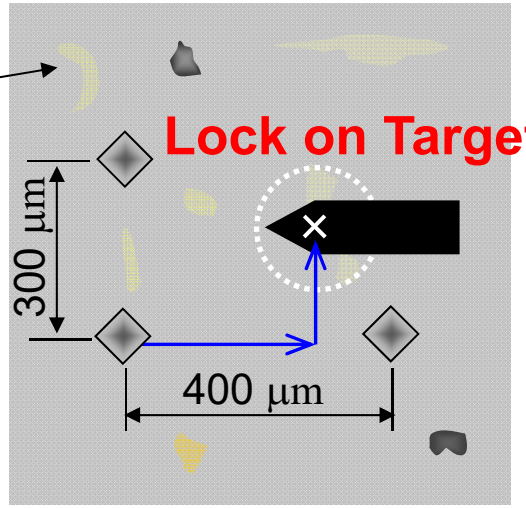
SEM image



clear

blurred

SKPFM image

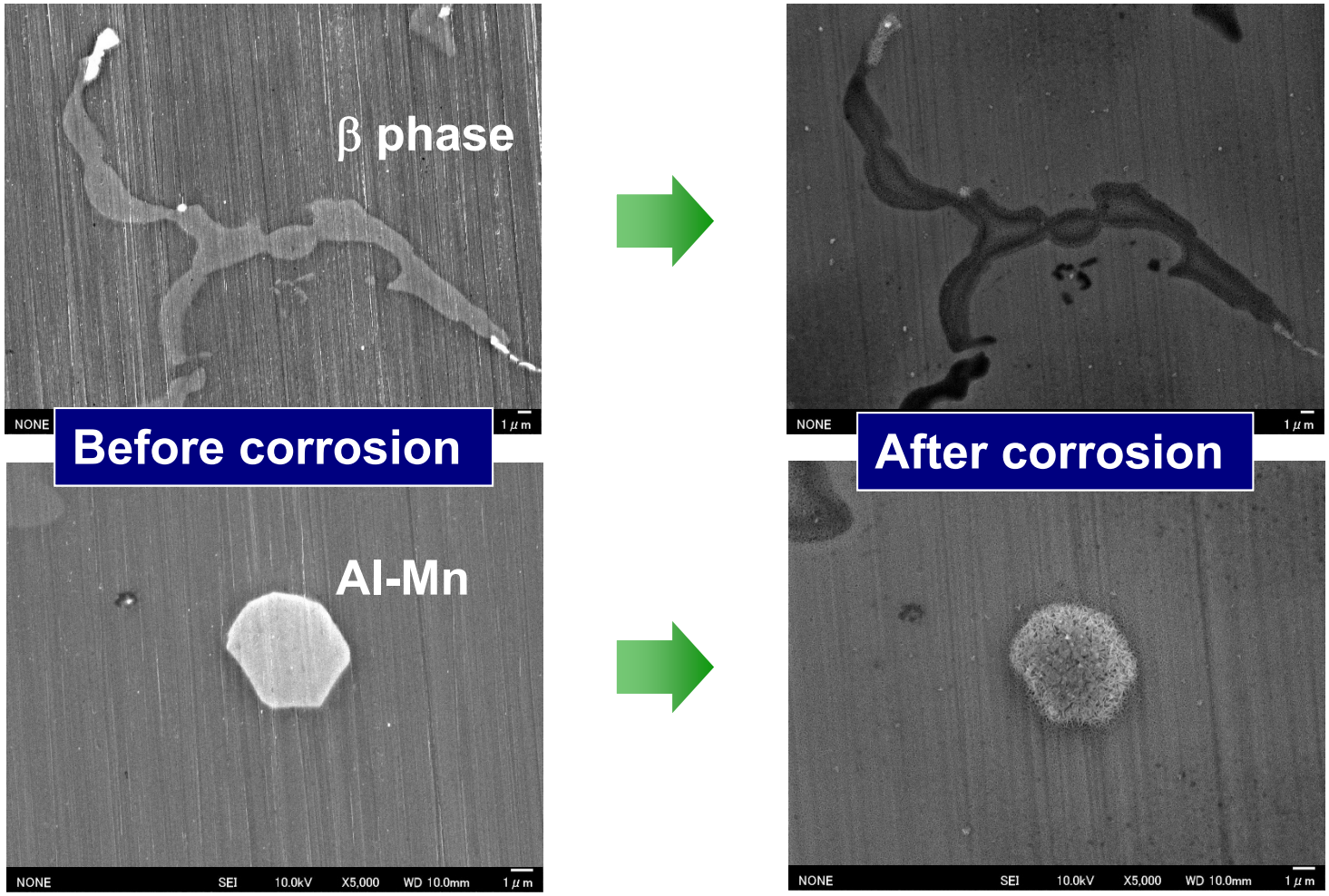


Position of dispersoids can be identified by three indentations.

Cantilever is set to the target position.

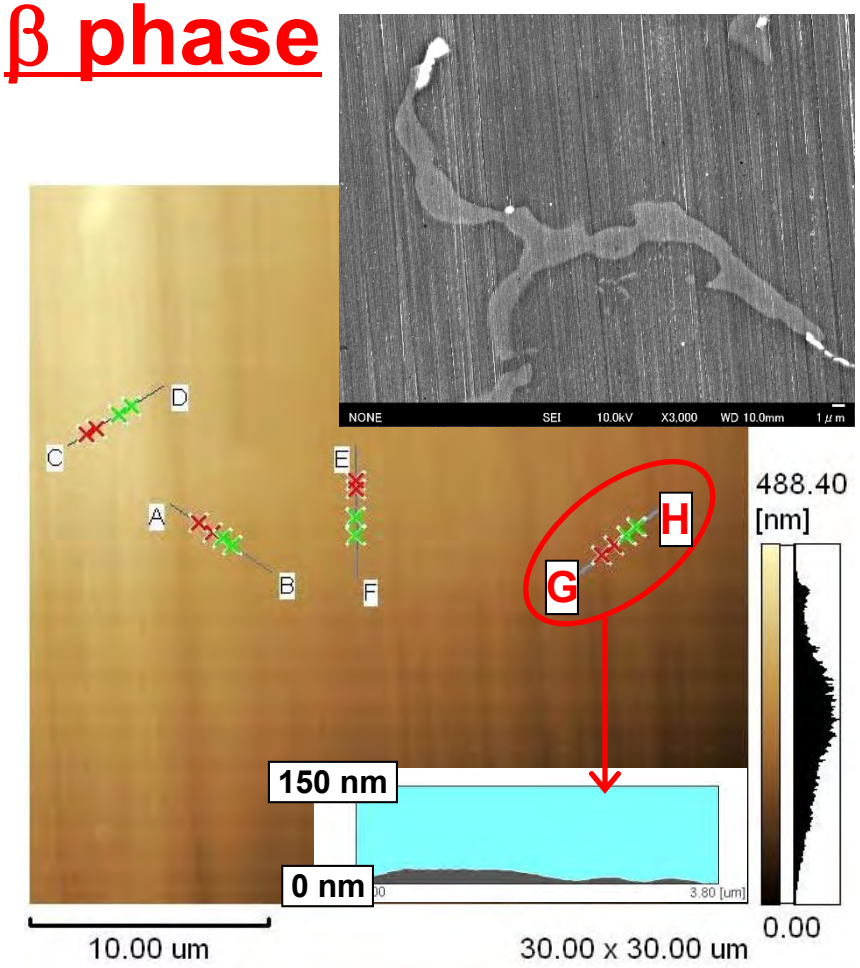
Macro-scale corrosion analysis result

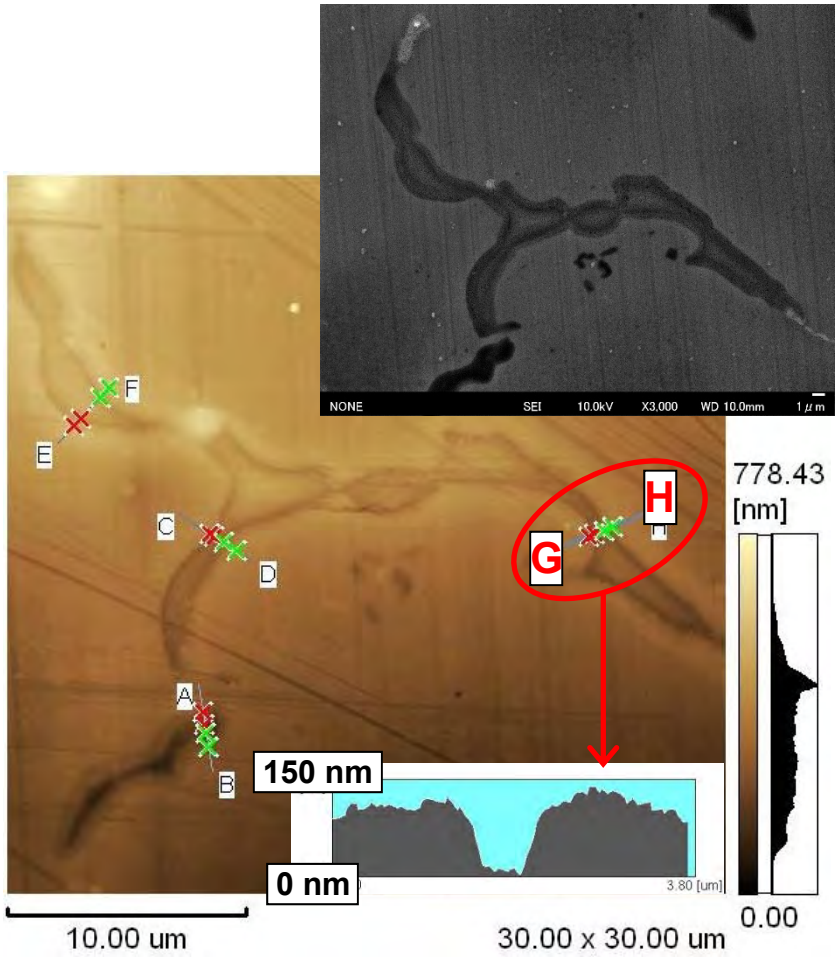
SEM image before and after corrosion by salt water immersion test



Micro-scale corrosion analysis result

β phase

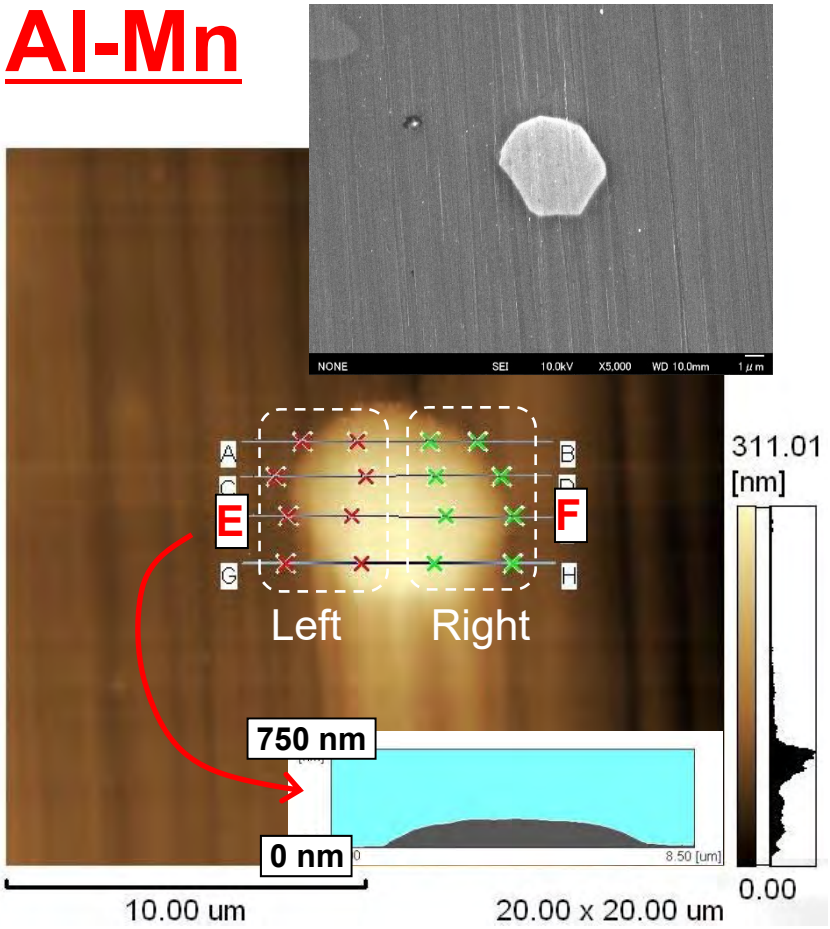


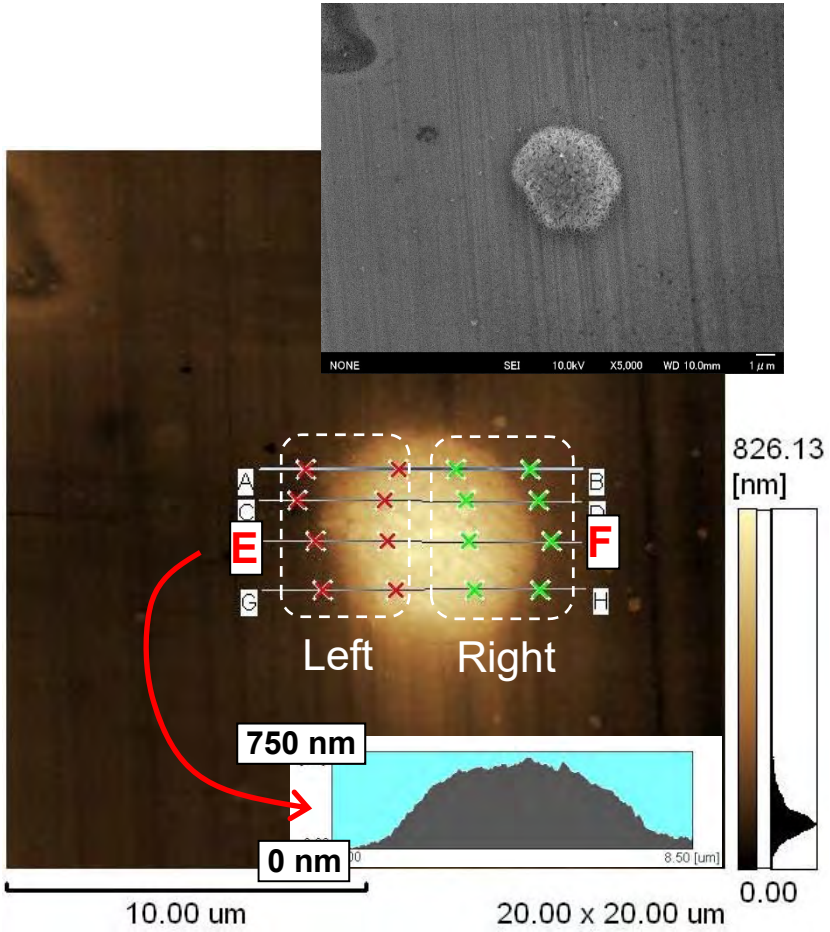


	Before corrosion	After corrosion
Difference of height (nm)	+5 – +20	-89.69

Micro-scale corrosion analysis result

Al-Mn

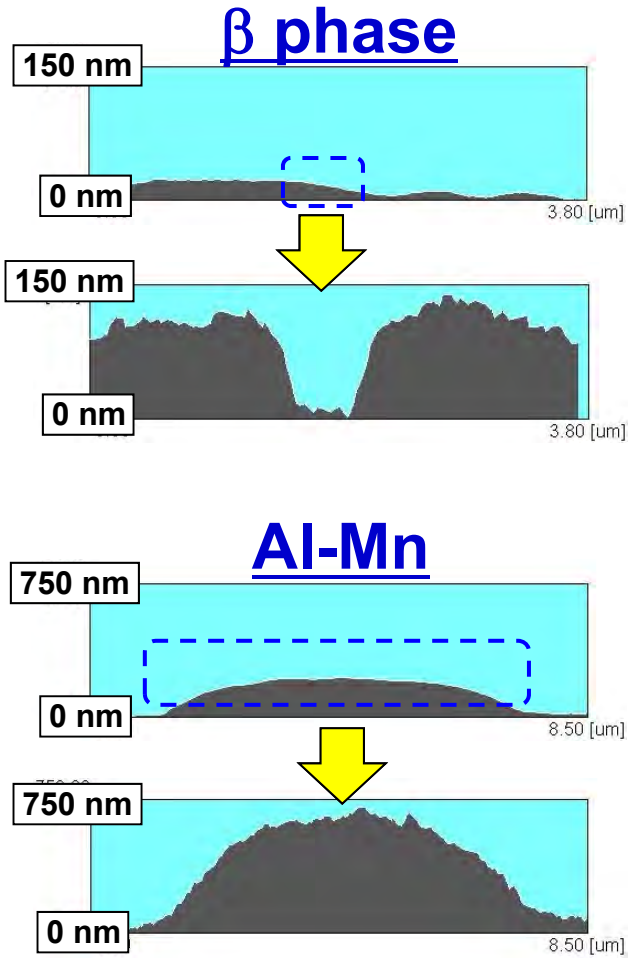


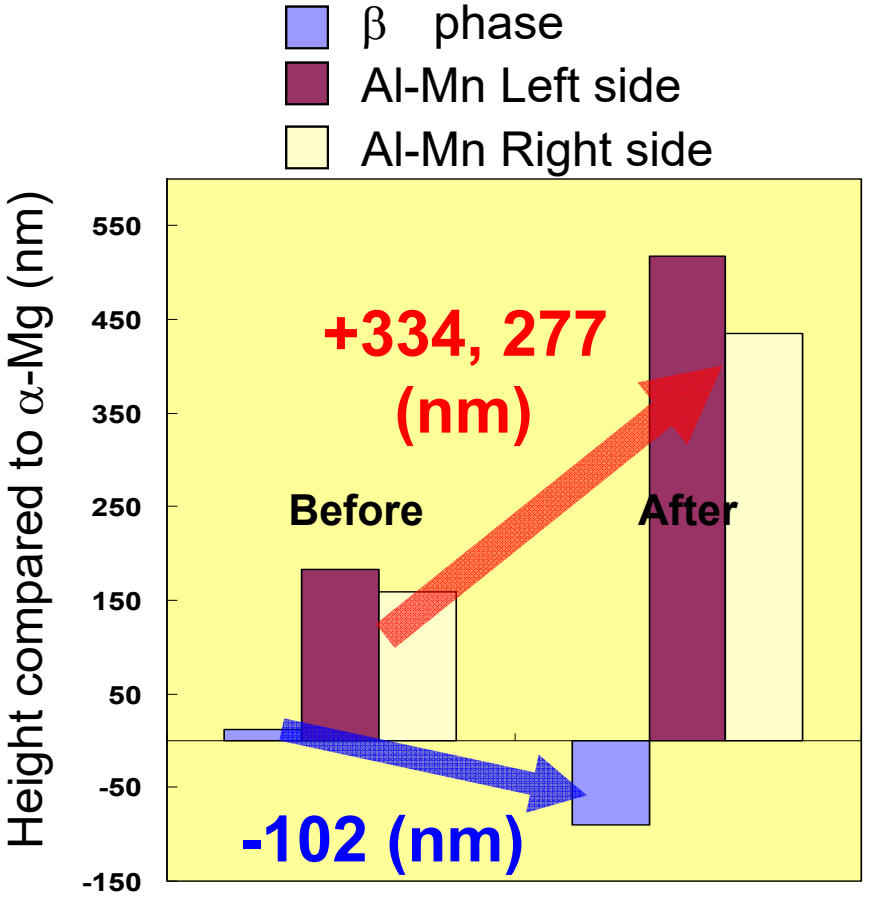


	Before corrosion		After corrosion	
Difference of height (nm)	Left	Right	Left	Right
	+183.58	+158.30	+517.18	+435.04

Micro-scale corrosion analysis result

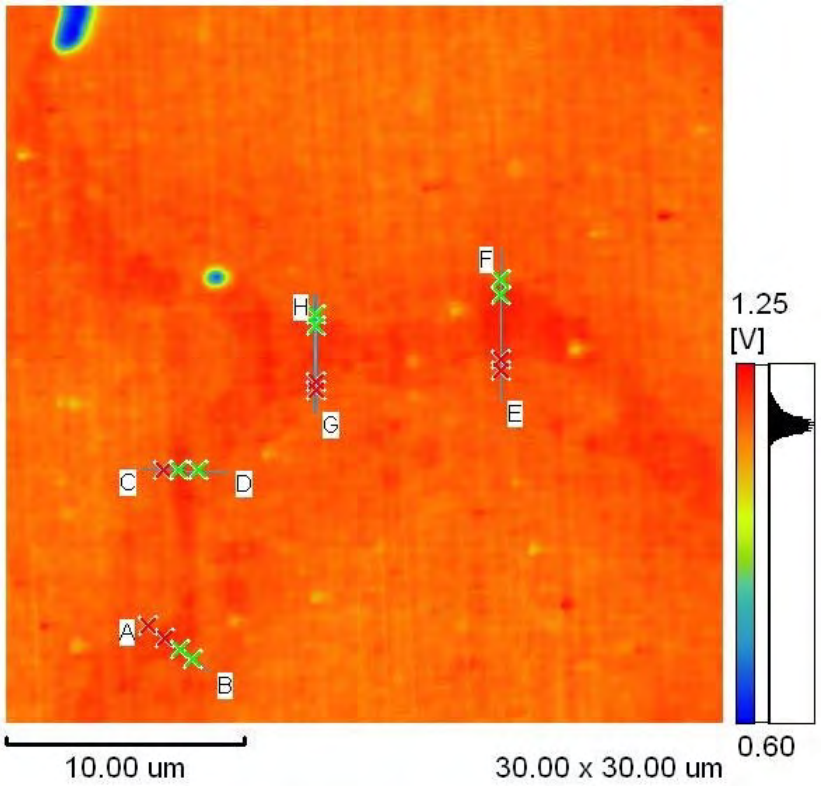
Topographic change before and after corrosion test





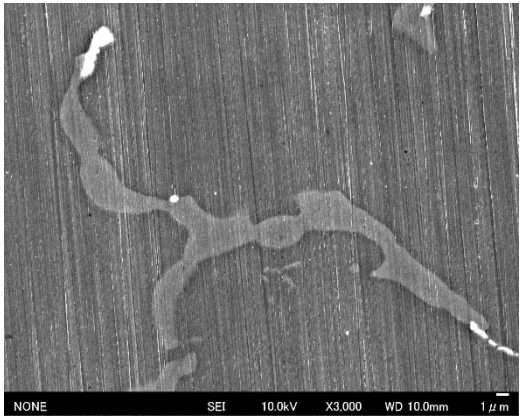
Surface potential difference at β phase

Surface potential map



Surface potential	Low ↔ High
Standard electrode potential	High ↔ Low

SEM image



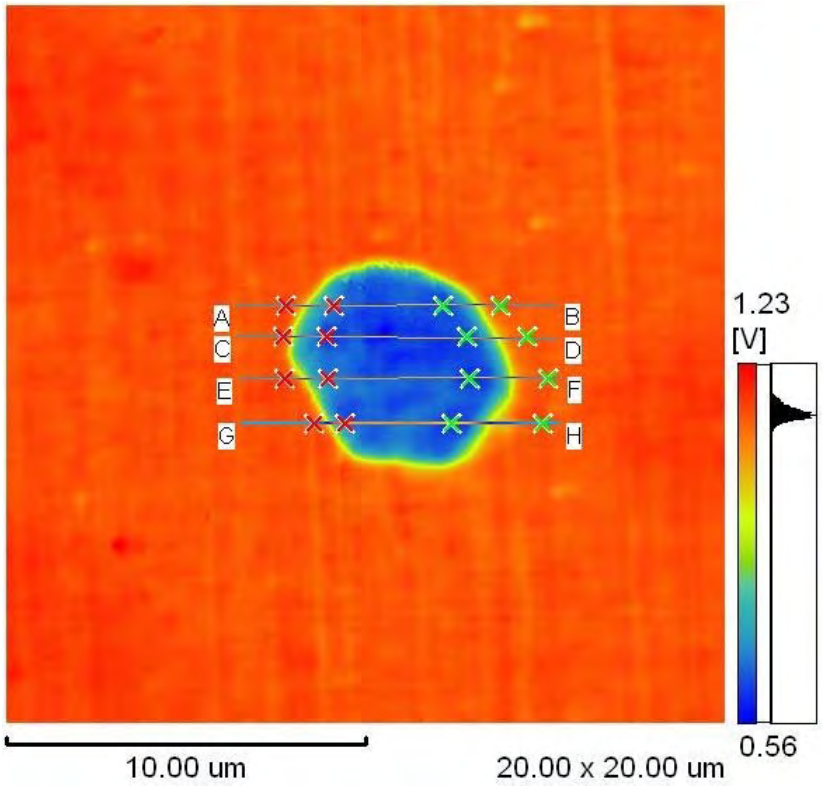
Surface potential difference (V)

Point	A-B	C-D	E-F	G-H
—	+0.06	+0.06	+0.04	+0.05
—	+0.05	+0.06	+0.06	+0.06

Average : 0.055 (V)

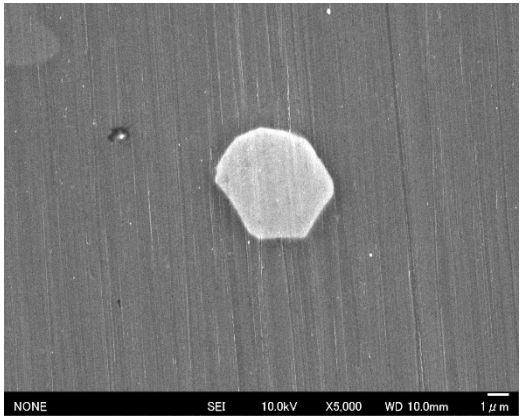
Surface potential difference at Al_6Mn

Surface potential map



Surface potential	Low ↔ High
Standard electrode potential	High ↔ Low

SEM image

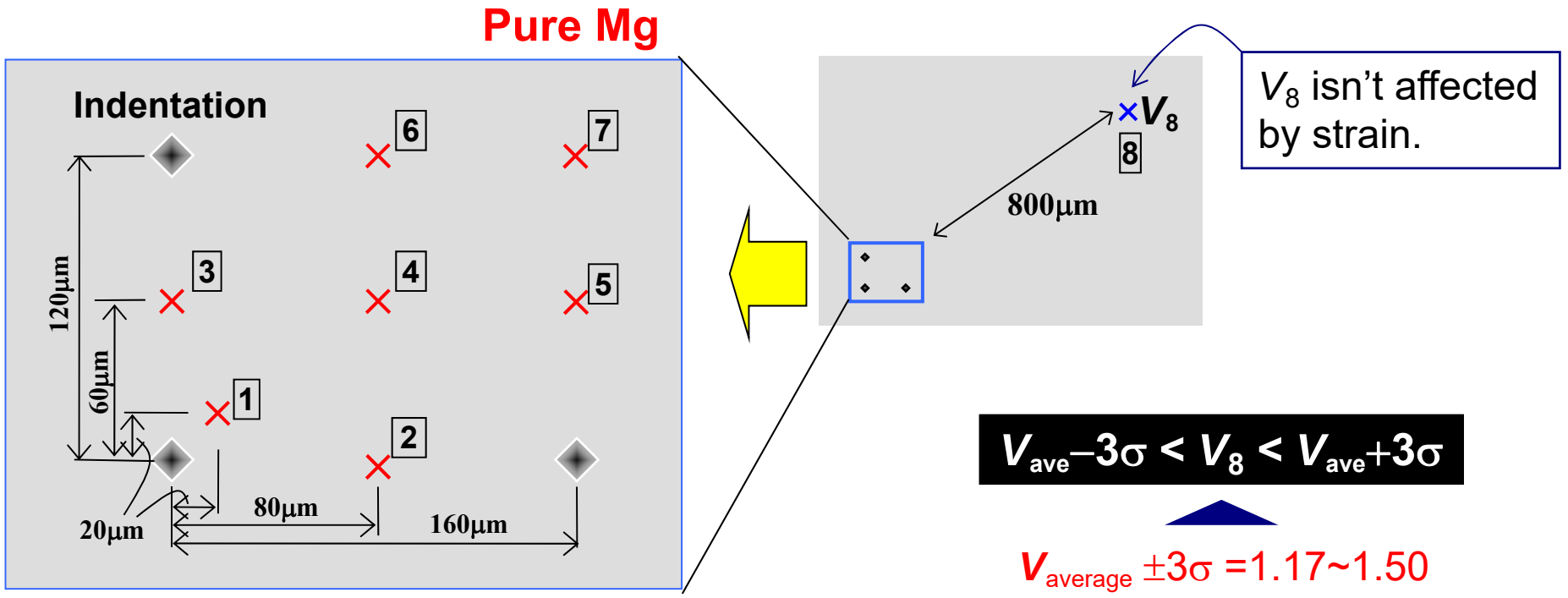


Surface potential difference (V)

Point	A-B	C-D	E-F	G-H
—	-0.46	-0.53	-0.46	-0.45
—	-0.50	-0.50	-0.53	-0.53

Average : 0.50 (V)

Effect of strain on surface potential



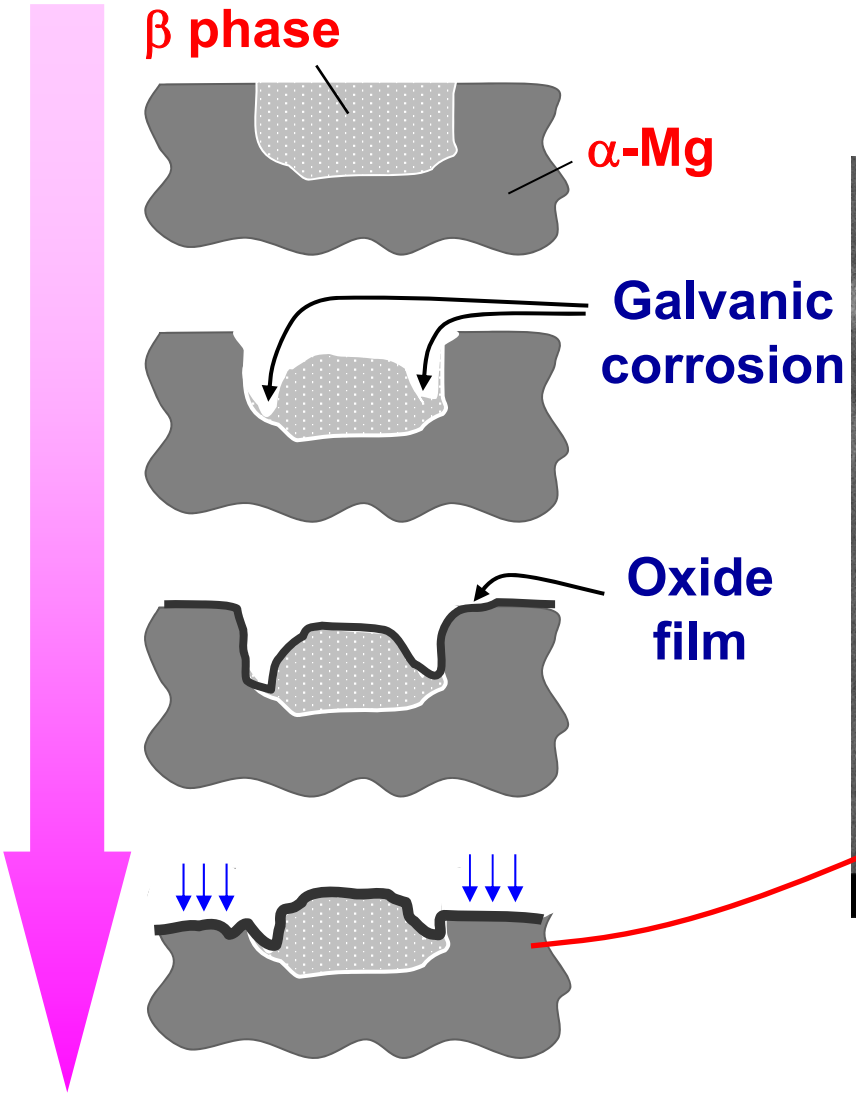
$V_{ave} - 3\sigma < V_8 < V_{ave} + 3\sigma$

$V_{average} \pm 3\sigma = 1.17 \sim 1.50$

σ : standard deviation

Measurement point	1	2	3	4	5	6	7	8
Maximum (V)	1.38	1.37	1.36	1.39	1.40	1.39	1.37	1.40
Minimum (V)	1.31	1.25	1.29	1.31	1.27	1.29	1.28	1.25
Average (V)	1.35	1.31	1.33	1.35	1.34	1.34	1.33	1.33

Transport of corrosion



After 98 hours corrosion test

β phase is higher than α-Mg .

Conclusions

- SKPFM available for quantitative evaluation of corrosion phenomenon.
- Good correlation between surface potential difference and corrosion loss.

		surface potential difference (V)	Difference of height (nm)	
			before corrosion	after corrosion
α-Mg – β phase		0.0 - 0.1	5 - 20 →	89.69
α-Mg – Al_6Mn	Right	0.4 - 0.6	158.30 →	517.18
	Left		183.58 →	435.04