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Bringing Technology to the Surface

Where Crystal Planes Meet:

Contribution to the Understanding of the Tin Whisker Growth Process

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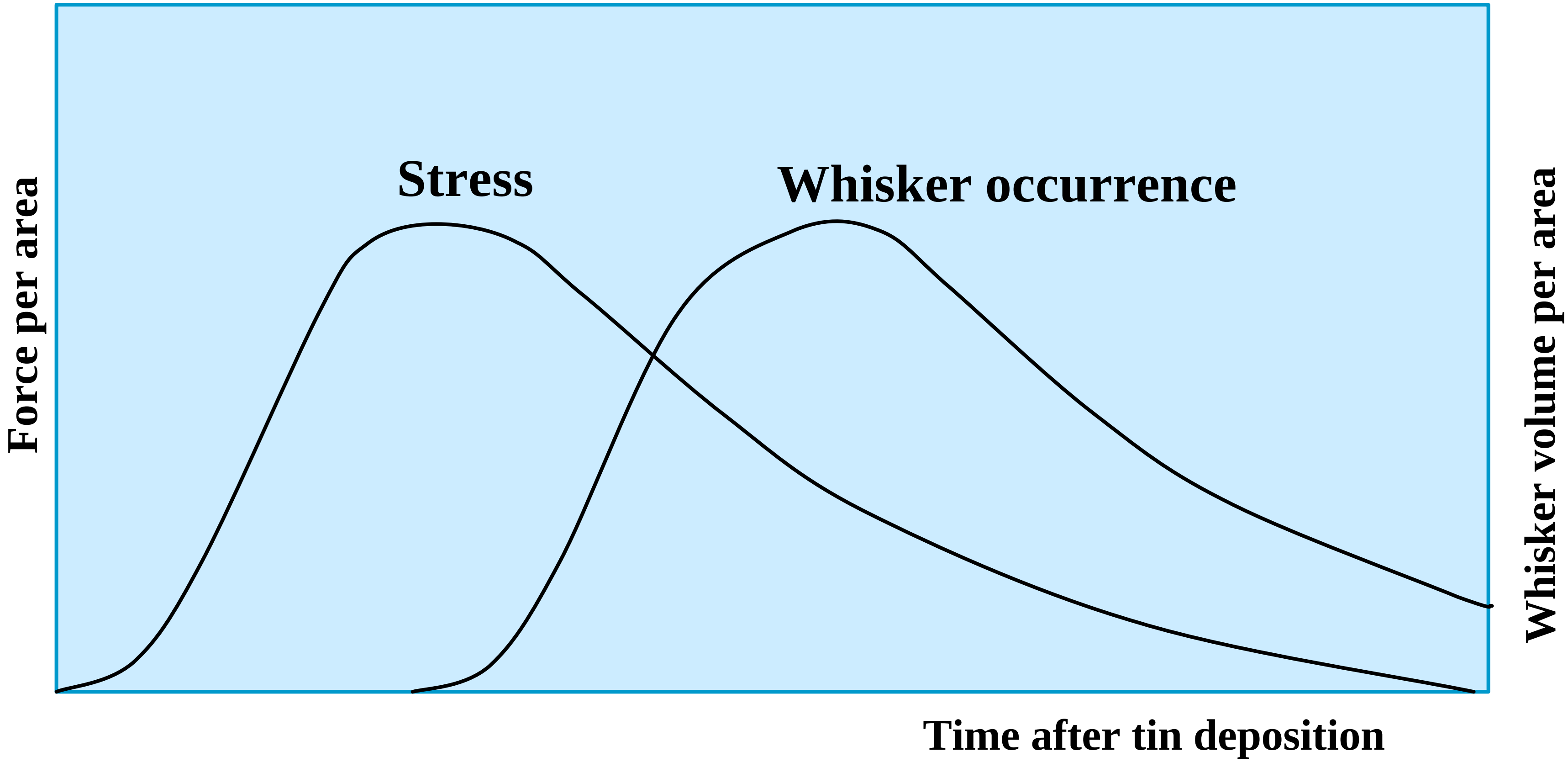
Stress-Whisker Relationship (SWR)



Deductions from SWR

1. Whisker growth is a direct result of stress
2. Whisker growth is directly related to the stress which builds-up after deposition
3. Intrinsic stress of the deposit is neglected
4. Control of stress changes = Control of whisker growth

Concept for Whisker-Free Deposits

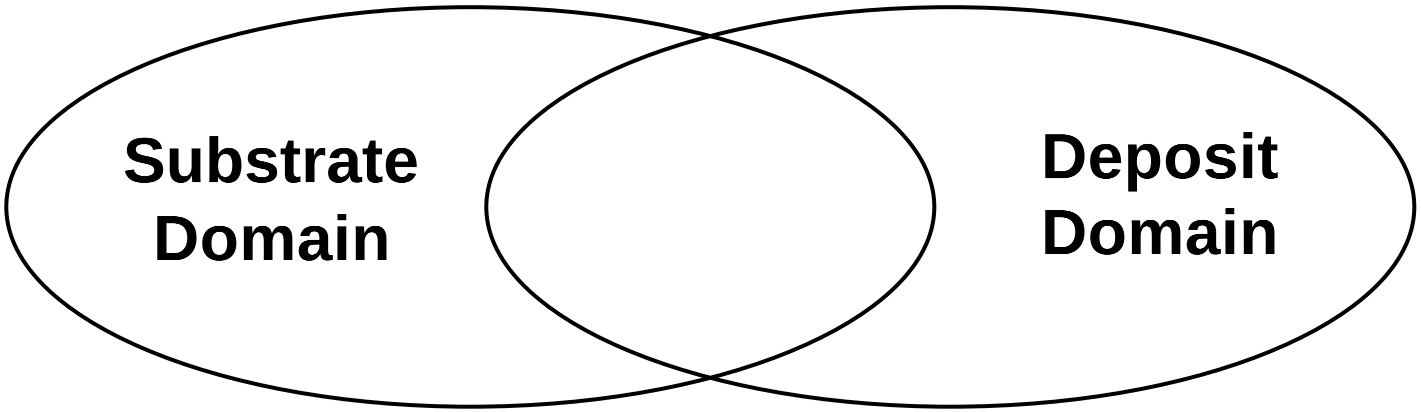
1. Identify and eliminate sources of stress build-up
2. Identify stress release pathways different from whisker growth

Two Compartment Approach

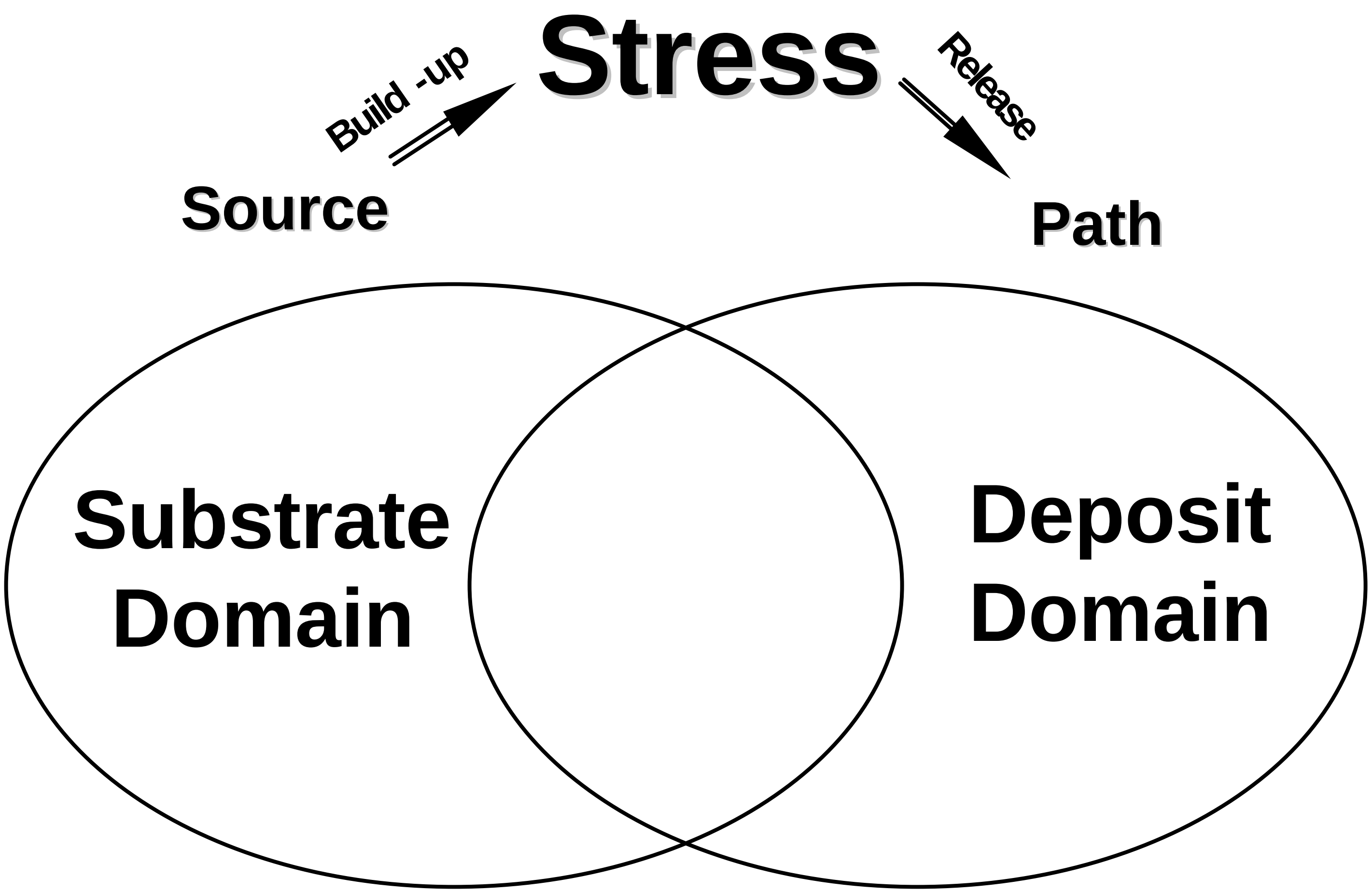
Whisker growth influencing parameters:

Different substrates
Different underplates

Deposit thickness
Grain size
Organic additives

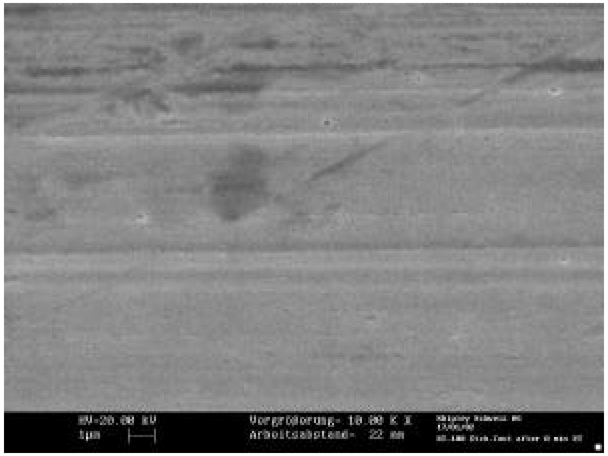


Tentative Stress Model

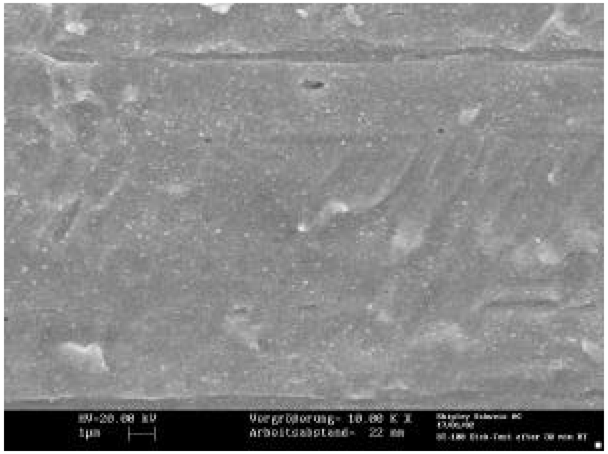


Origin of Stress: IMC Formation (at RT)

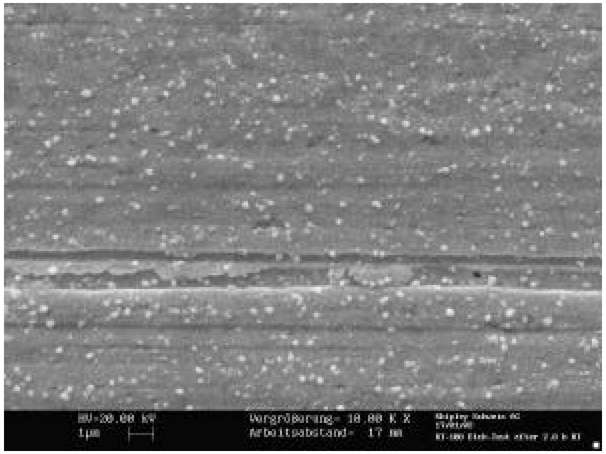
‚0 min‘



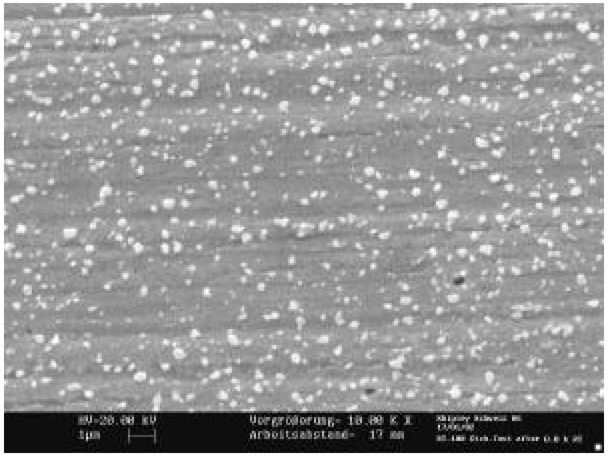
30 min



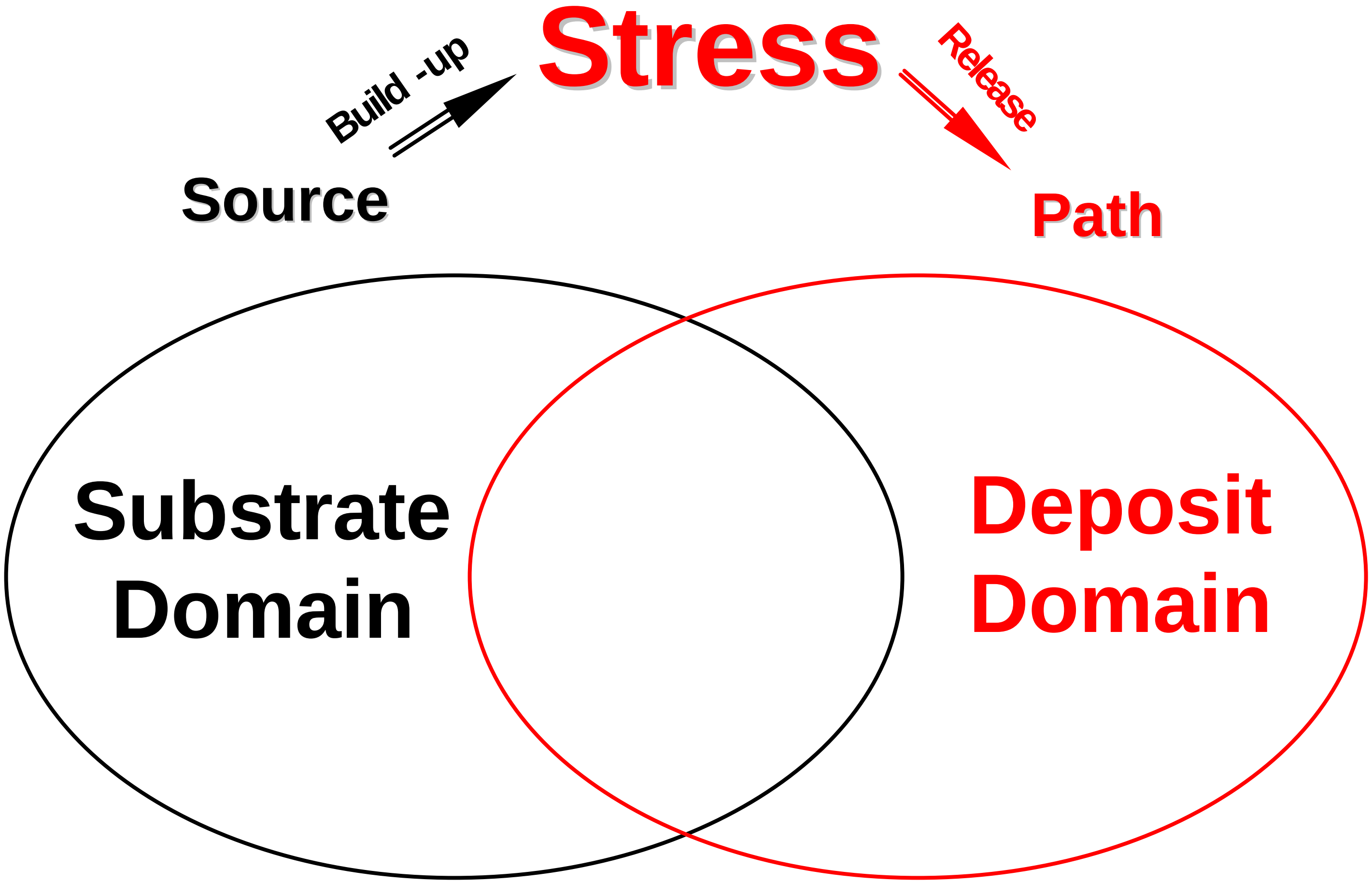
2 hrs



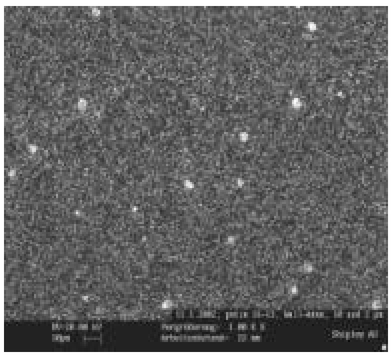
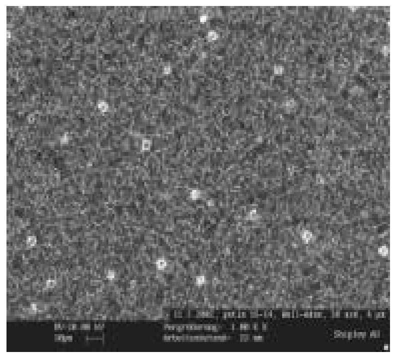
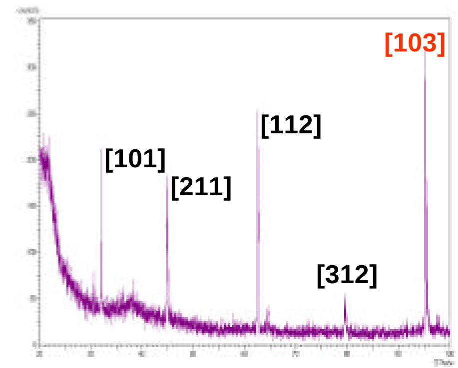
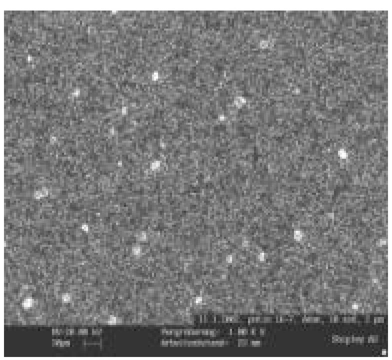
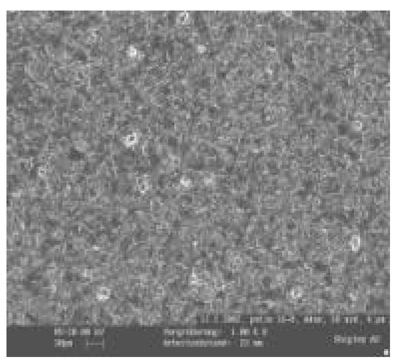
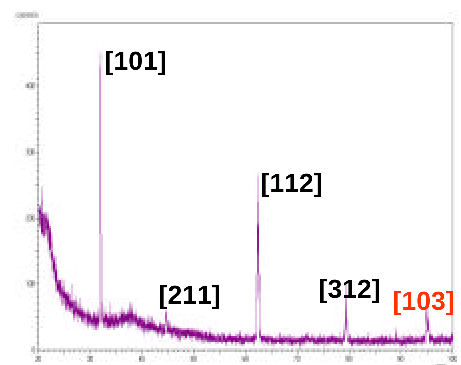
8 hrs



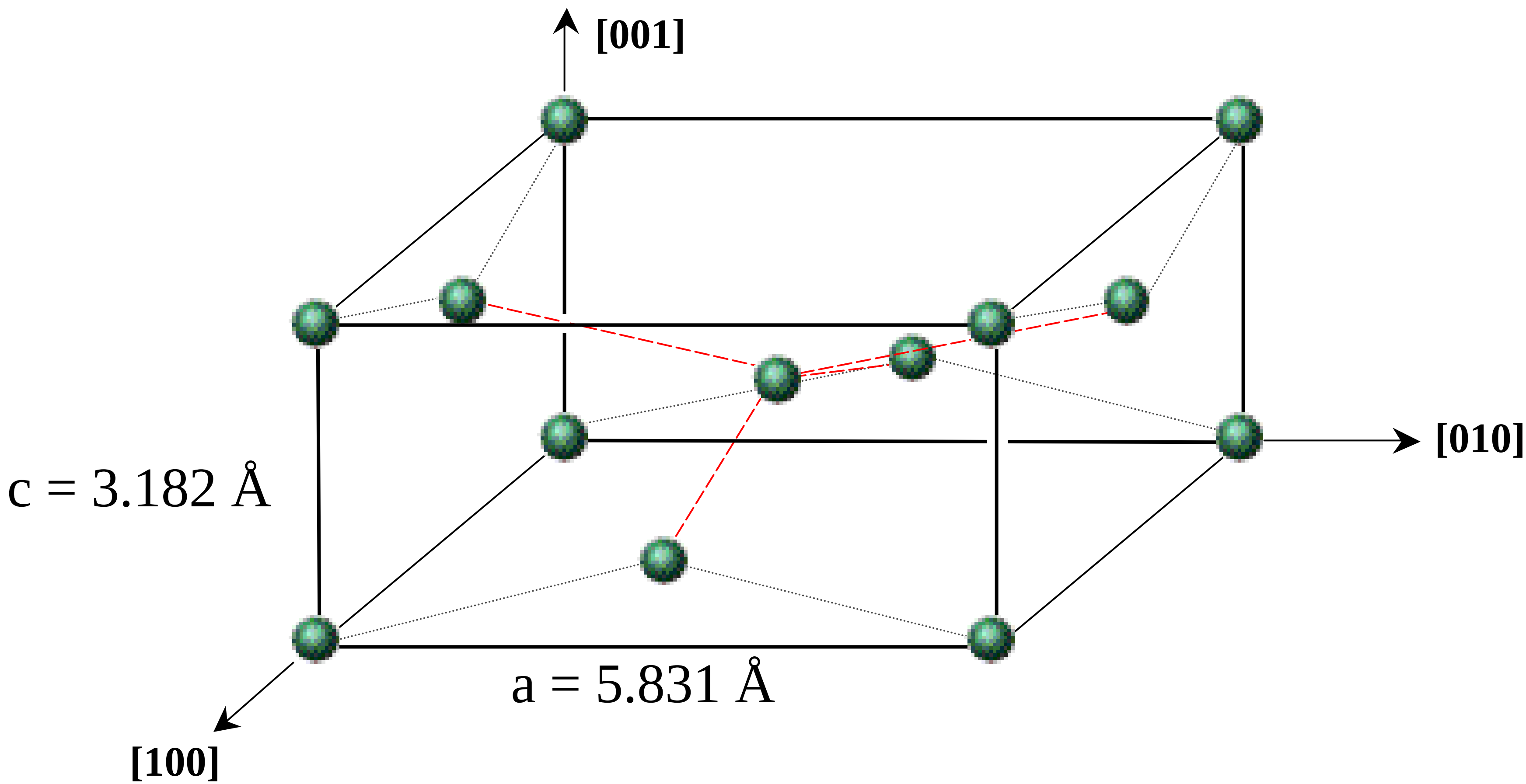
Pathways for Stress Relief



Influence of Crystal Planes on Whiskers

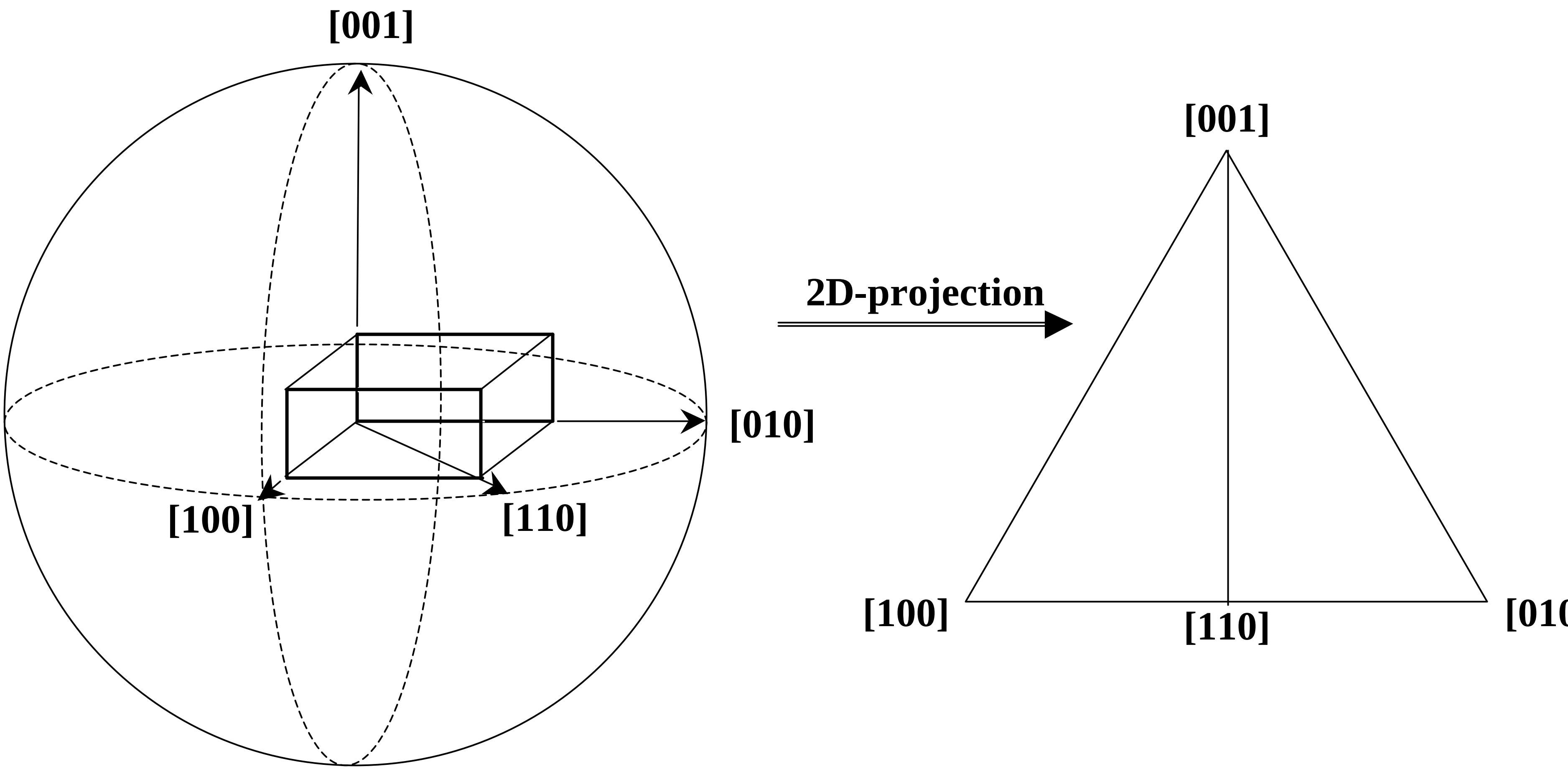
	2 µm	4 µm	XRD	No. of whiskers
A)				thin deposit = thick deposit
B)				thin deposit > thick deposit

Crystallography of b-tin

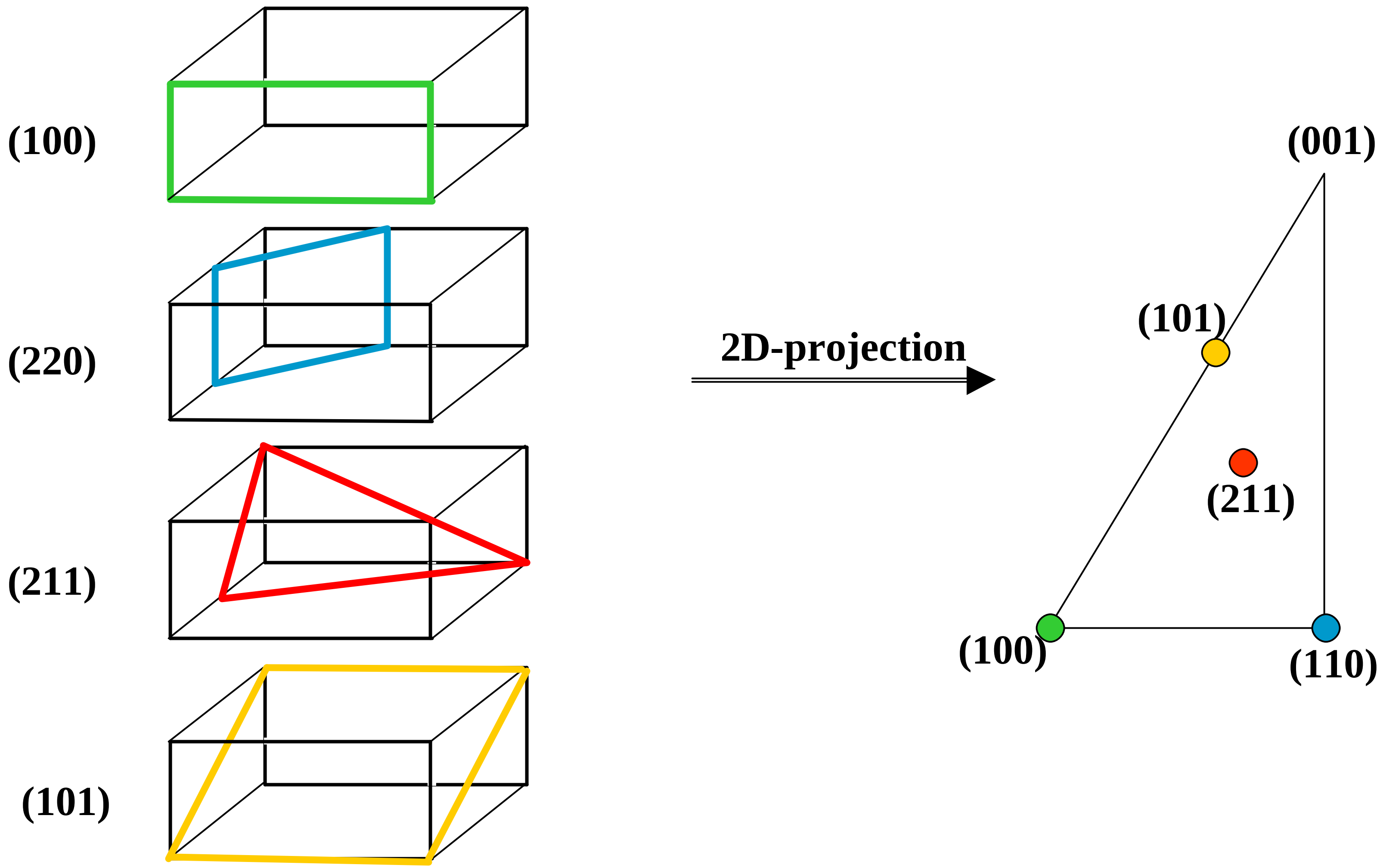


Space group: *I*41/amd (No.141)

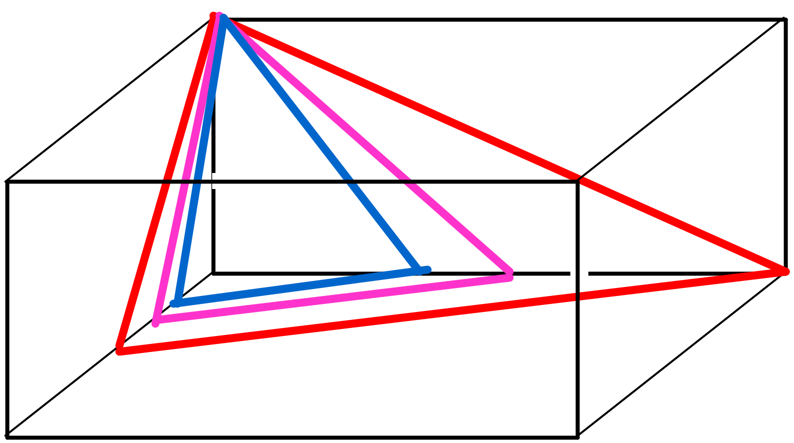
Stereographic Projection of b-tin



Stereographic Projection of b-tin

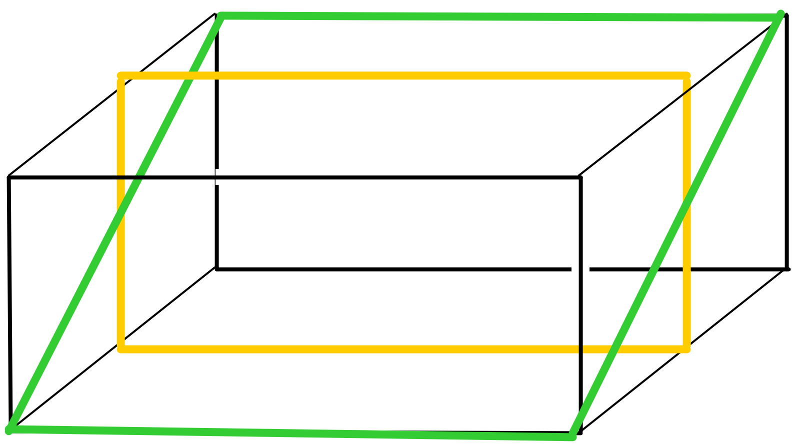


Influence of Crystal Planes on Whiskers



(211) (321) (431)

Electroplated deposit



(101) (200)

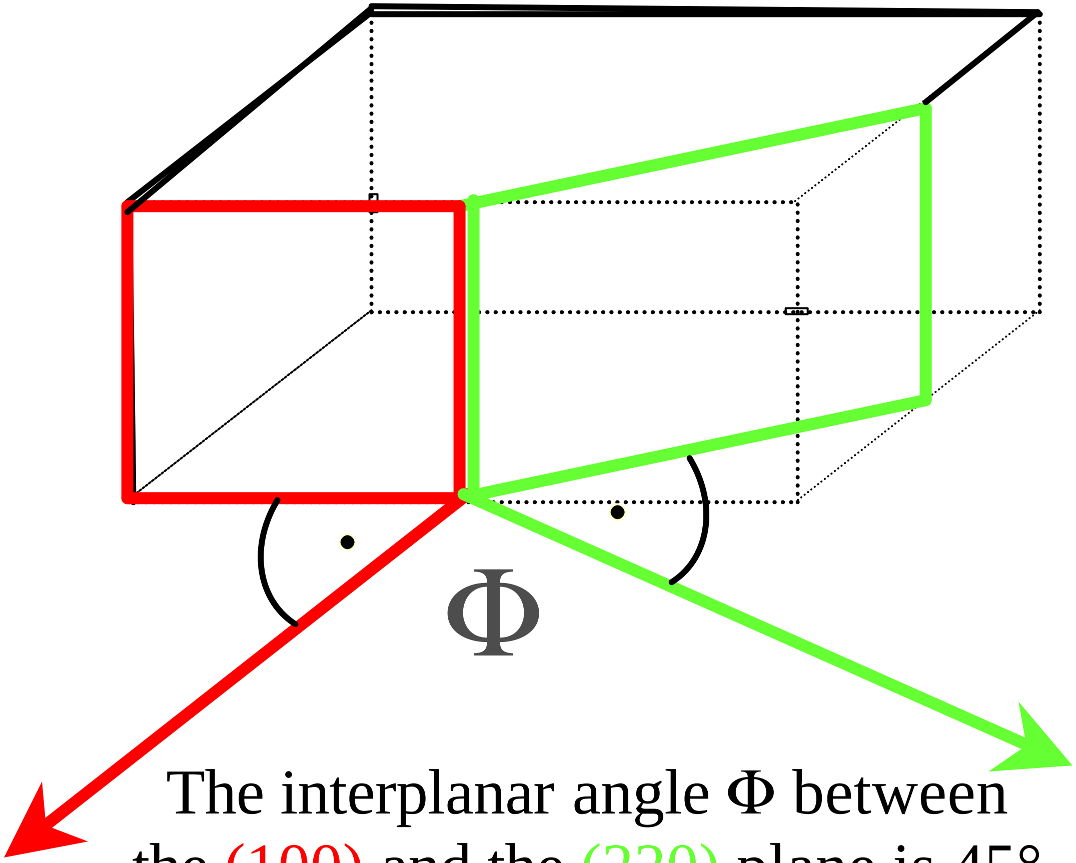
Wrought tin

Influence of Crystal Planes on Whiskers

Hypothesis: The smaller the angle between two crystal planes, the higher the risk of whisker growth

Observation: 5 - 22° is considered as the critical range

Interplanar Angles



The interplanar angle Φ between the (100) and the (220) plane is 45°

Angle Correlation Map

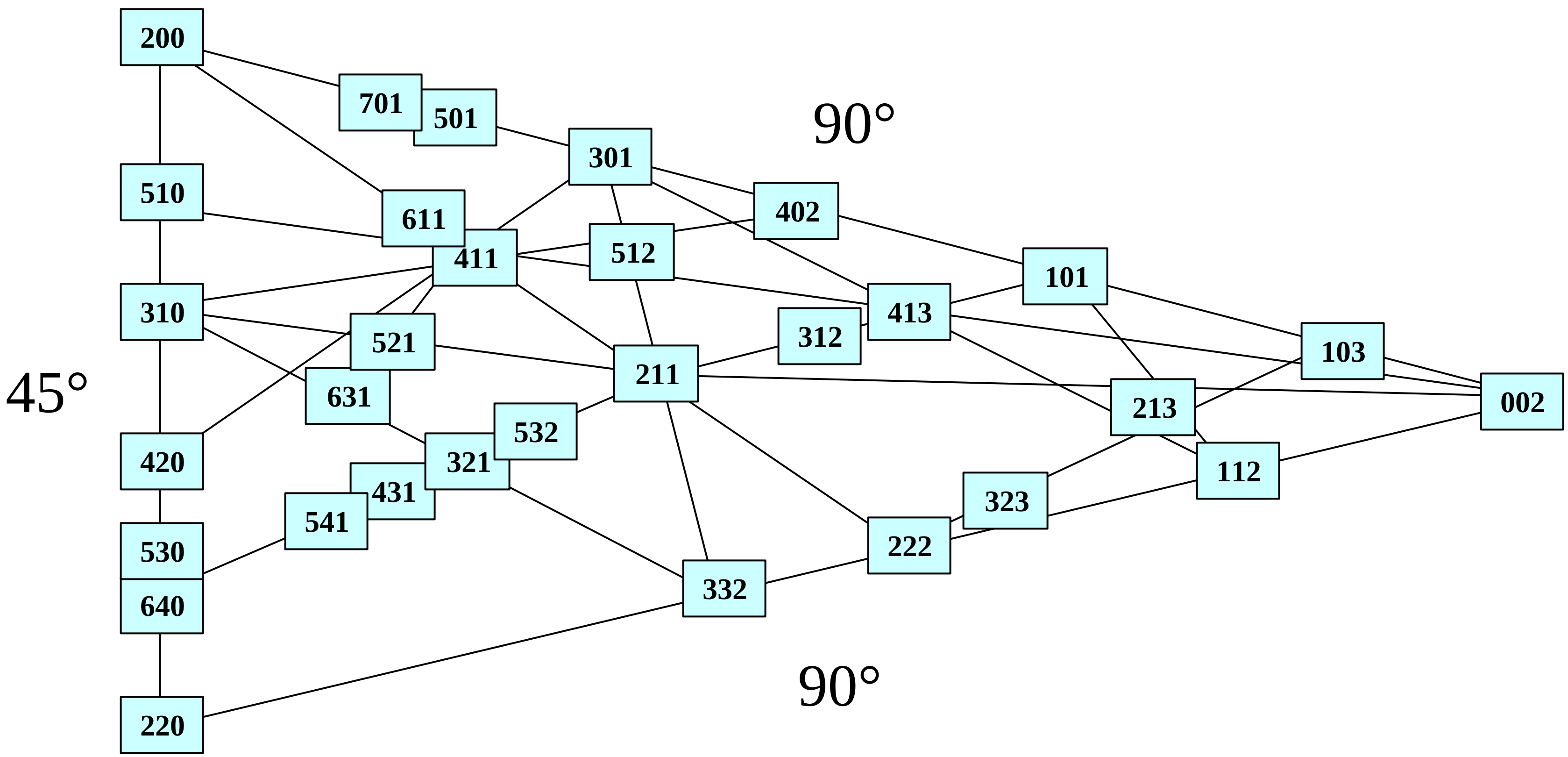
200	101	220	211	301	112	321	420	411	312	431	103	332	521	
	61.4	45.0	46.2	31.4	75.3	42.1	26.6	27.6	51.7	41.3	79.7	57.6	28.5	200
		70.2	27.4	30.0	19.8	41.1	64.6	38.6	16.0	48.6	13.0	33.9	45.3	101
			42.8	52.9	68.9	29.1	18.4	38.4	54.2	21.6	82.7	40.8	29.5	220
				23.0	31.2	13.7	39.9	18.7	11.4	21.2	41.6	14.2	21.0	211
					45.3	29.6	40.2	14.5	22.6	34.9	48.3	37.1	23.4	301
						42.5	70.0	48.6	23.6	49.0	15.5	28.1	52.1	112
							27.8	18.0	25.2	7.41	54.7	16.7	13.6	321
								26.9	49.7	22.5	80.8	44.1	19.4	420
									25.5	21.5	56.1	30.9	8.89	411
										32.6	31.2	20.4	30.5	312
											61.8	21.8	14.3	431
												42.4	74.8	103
													29.6	332
														521

< 22

- 30

- 40

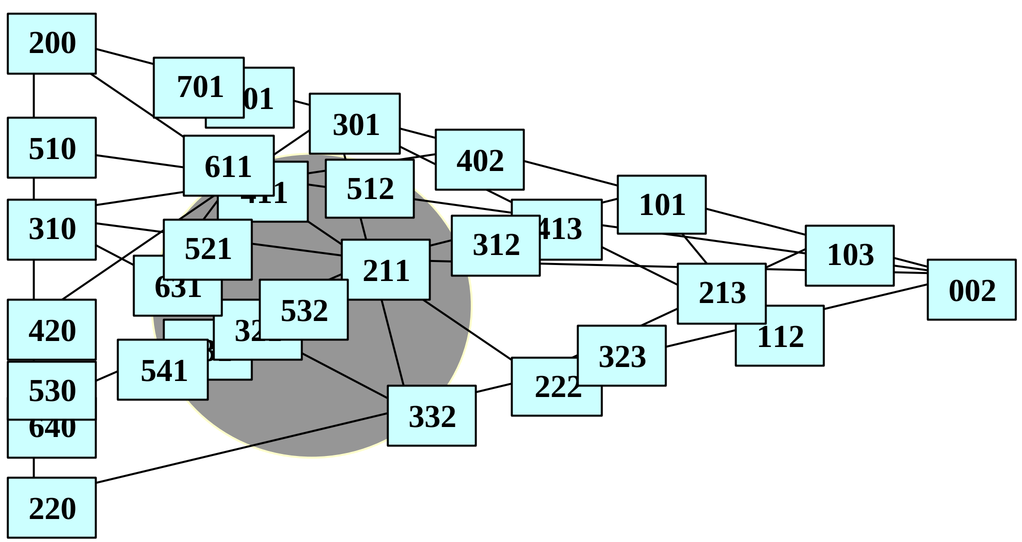
Detailed 2D-Projection of b-tin



Frequent Crystal Planes in Matte Tin

211	321	431	
28.3°	13.7°	21.2°	211
	20.1°	7.41°	321
		15.3°	431

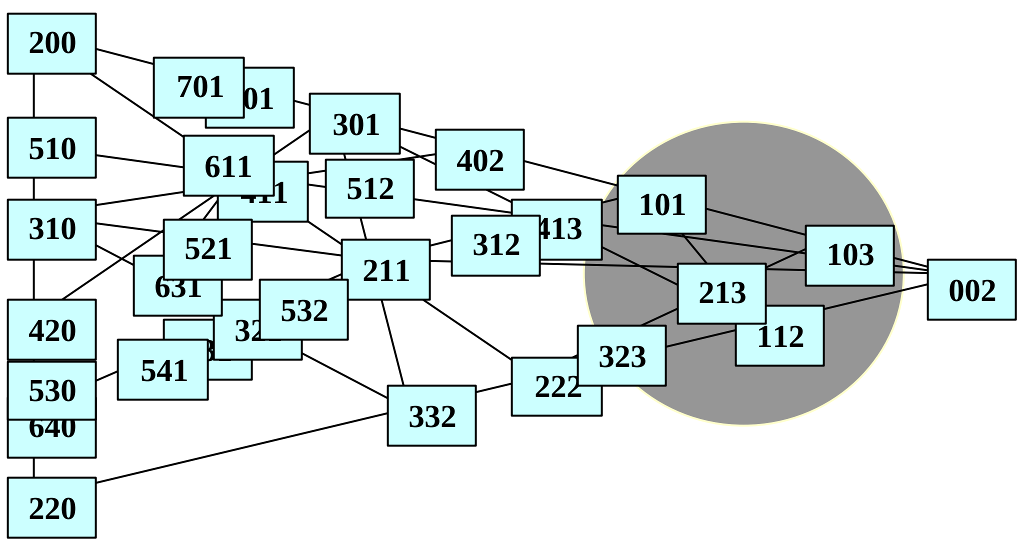
The most frequently observed crystal orientations in the investigated matte tin deposits (with whiskers) are showing small angles



Frequent Crystal Planes in Bright Tin

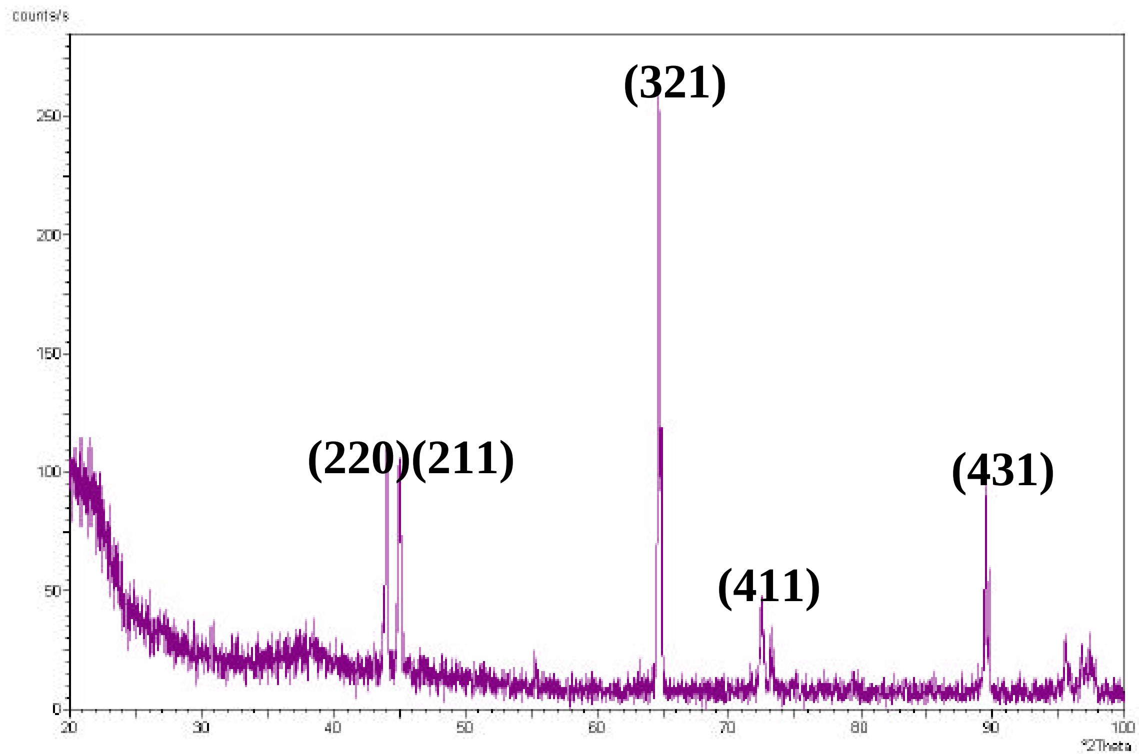
101	112	103	
40°	19.8°	13.0°	101
	29.5°	15.5°	112
		14.6°	103

Completely different observed crystal orientations in the XRD compared to matte tin deposits, but similar angles between crystal orientations



XRD of a Typical Matte Tin Deposit

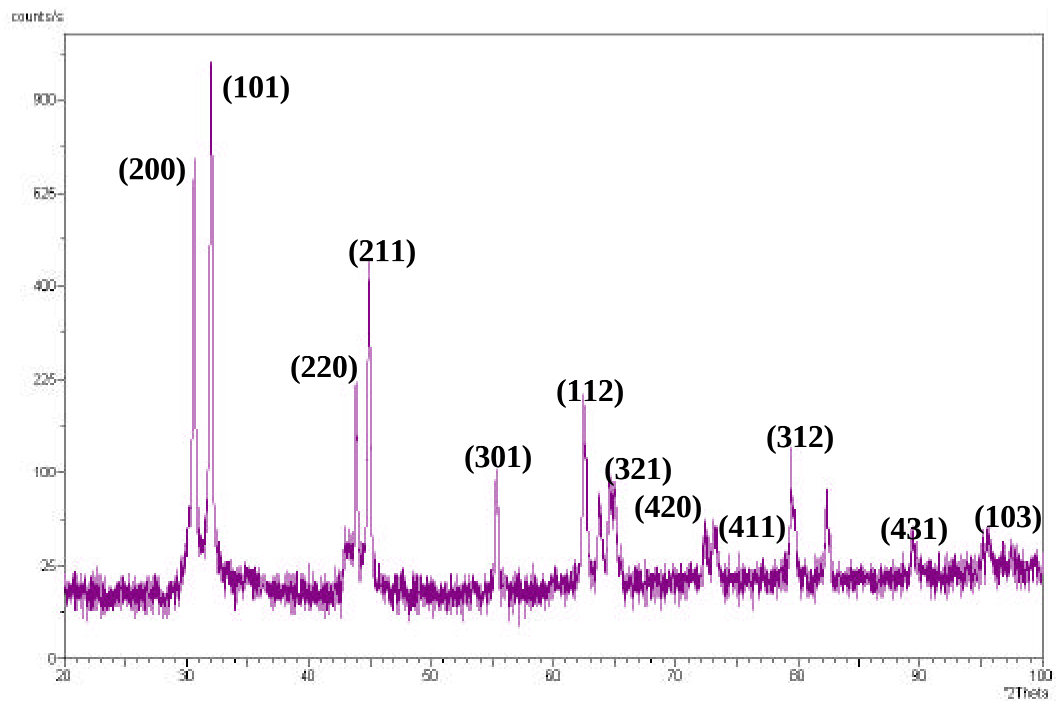
220	211	321	431	
90°	42.8°	29.6°	21.8	220
	28.3°	13.7°	21.6°	211
		20.1°	7.41°	321
			15.3°	431



Whisker risk

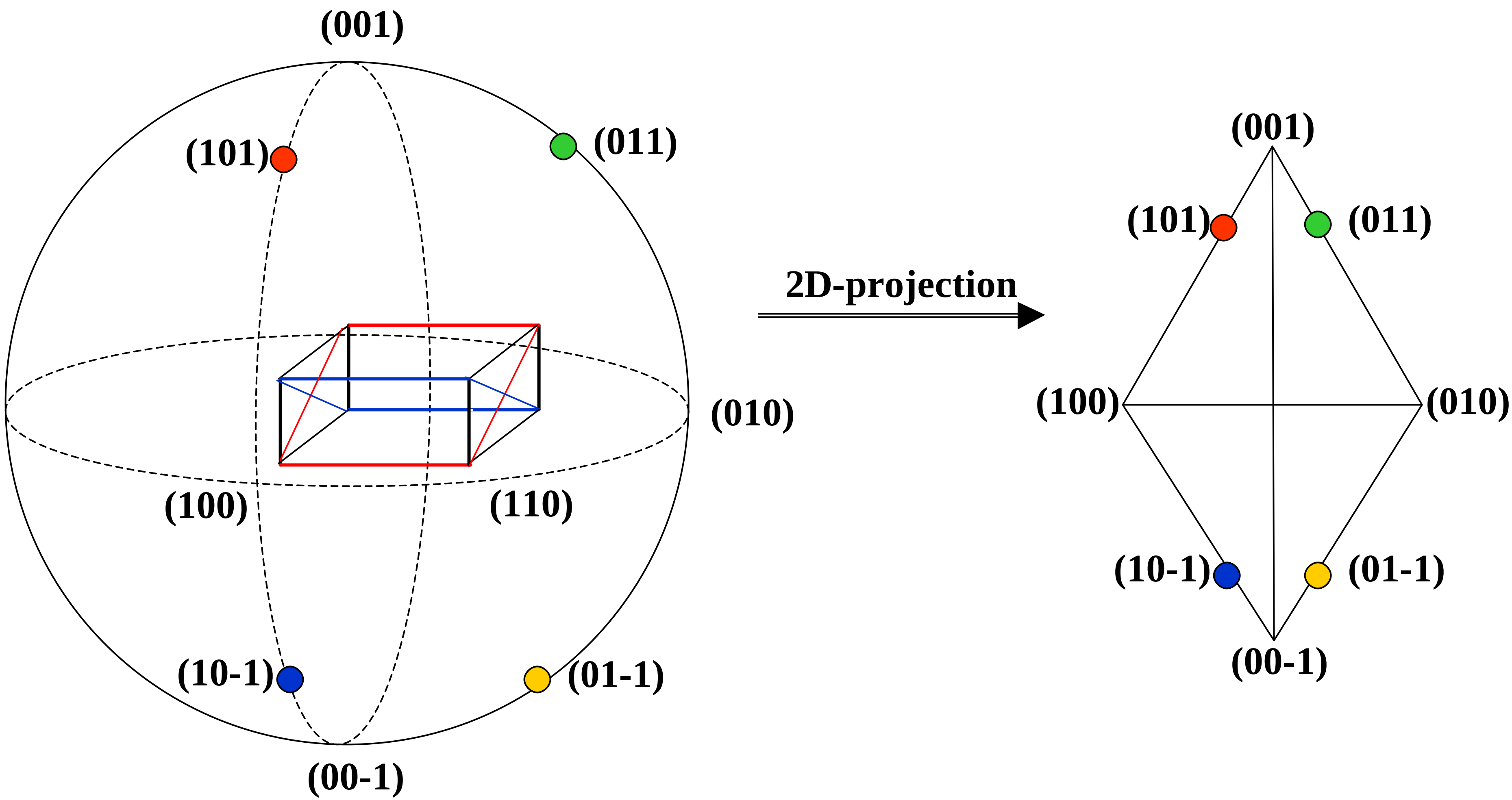
XRD of a Non-Typical Bright Tin Deposit

200	101	220	211	
90°	61.4°	45°	46.2	200
	40°	70.2°	27.4°	101
		90°	42.8°	220
			28.3°	211



→ Very low whisker risk

XRD-Equivalent Crystal Planes



Selected Equivalent Crystal Planes

101	101	0°
	011	39.6°
	-101	57.2°
	0-11	39.6°

101	112	19.8°
	-112	45.8°
	1-12	19.8°
	-1-12	45.8°

101	103	18.3°
	013	30.3°
	-103	38.9°
	0-13	30.3°

103	112	15.5°
	-112	29.3°
	1-12	15.5°
	-1-12	29.3°

103	103	20.6°
	013	14.5°
	-103	20.6°
	0-13	14.5°

112	112	0°
	-112	29.5°
	1-12	29.5°
	-1-12	42.2°

9 out of 24 combinations are considered as critical (37.5 %)

Reduced Set of Crystal Planes

101	101	0°
	011	39.6°
	-101	57.2°
	0-11	39.6°

101	112	19.8°
	-112	45.8°
	1-12	19.8°
	-1-12	45.8°

101	103	[illegible].3°
	[illegible]13	30.[illegible]
	-10[illegible]	38.[illegible]
	0-13	[illegible]3°

10[illegible]	112	[illegible].5°
	[illegible]12	29[illegible]°
	1-1[illegible]	15[illegible]°
	-1-12	[illegible].3°

10[illegible]	103	[illegible].6°
	[illegible]13	14[illegible]°
	-10[illegible]	20[illegible]°
	0-13	[illegible].5°

112	112	0°
	-112	29.5°
	1-12	29.5°
	-1-12	42.2°

2 out of 12 combinations are considered as critical (16.6 %)

Reduced Set of Crystal Planes

101	101	[illegible]
	[illegible]11	39[illegible]°
	-10[illegible]	57[illegible]°
	0-11	[illegible].6°

101	112	[illegible].8°
	[illegible]12	45[illegible]°
	1-1[illegible]	19[illegible]°
	-1-12	[illegible].8°

101	103	[illegible].3°
	[illegible]13	30[illegible]°
	-10[illegible]	38[illegible]°
	0-13	[illegible].3°

103	112	15.5°
	-112	29.3°
	1-12	15.5°
	-1-12	29.3°

103	103	20.6°
	013	14.5°
	-103	20.6°
	0-13	14.5°

112	112	0°
	-112	29.5°
	1-12	29.5°
	-1-12	42.2°

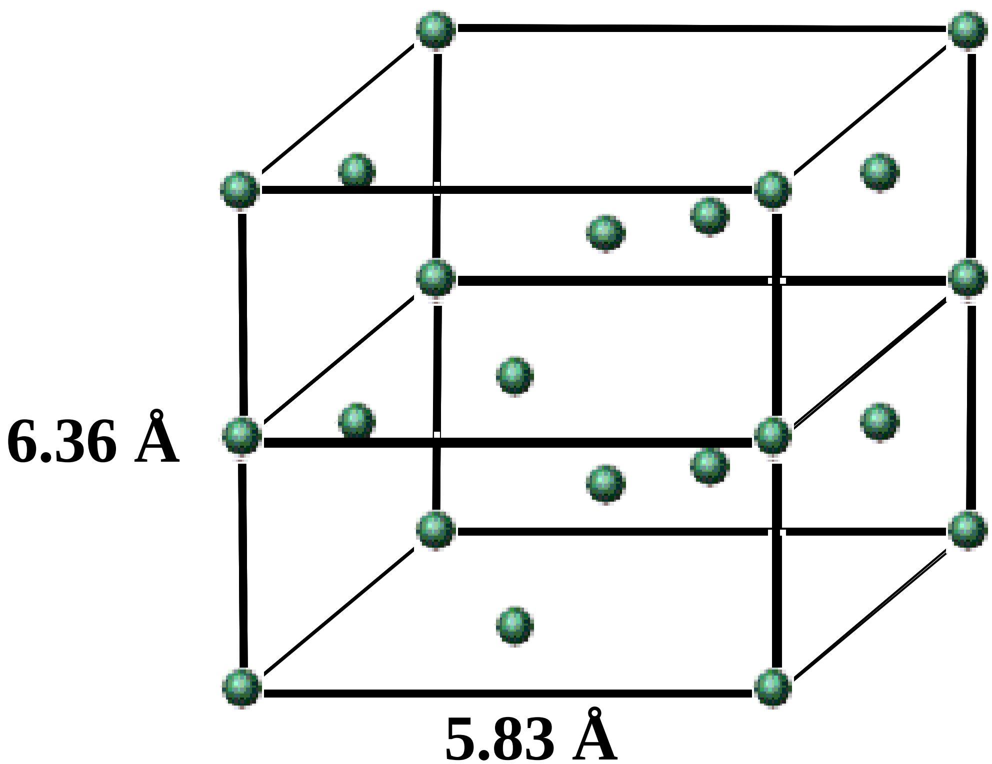
6 out of 12 combinations are considered as critical (50 %)

Summary of Equivalent Crystal Planes

Crystal plane combinations	Probability to form critical angle
(101)-(112)-(103)	37.5 %
(101)-(103)	50 %
(101)-(112)	16.6 %
(101)	0 %
(103)	100 %

Assumption: All crystal orientations have the same intensity

Tetragonal b-Tin Resembles Cubic Cell



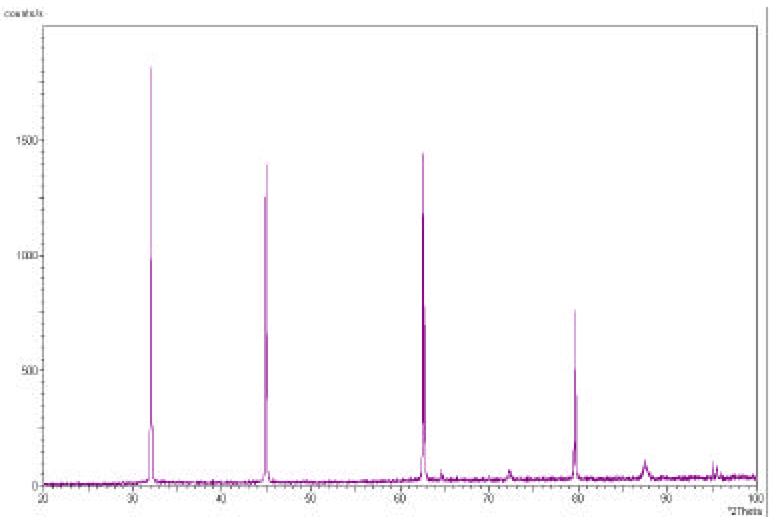
Interplanar angles of 90° +/- 10° are also critical

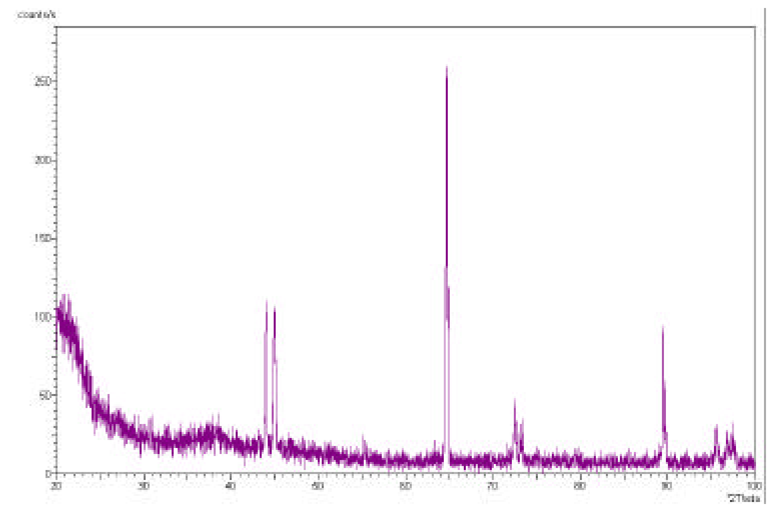
Critical Ranges and Definition of F_{CA}

The portion of interplanar angles within the critical ranges that are formed between all equivalent planes of a crystal plane pair and expressed as a fraction of 1 is called whisker weighting parameter F_{CA} (Fraction of critical angles).

The Whisker Probability Number N_{WP}

$$N_{WP} = [S\{(Irel_{Ka1,h1k1l1} * Irel_{Ka1,h2k2l2}) * F_{CA}\}_x] * 100$$



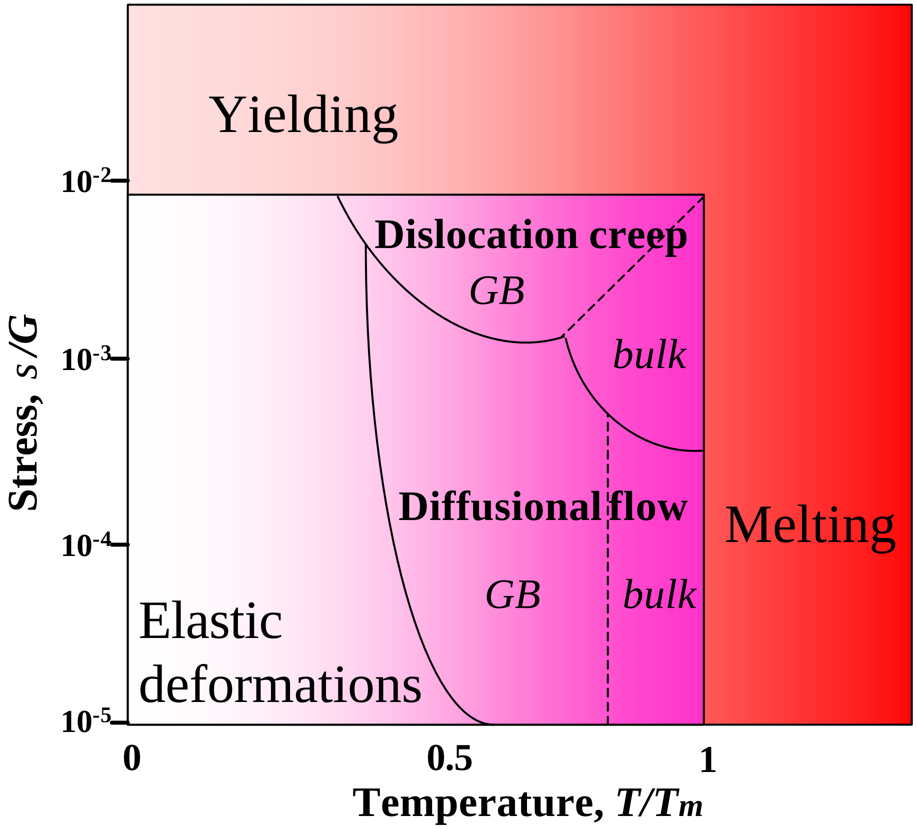


N_{WP}	8	20

Limitations to N_{WP}

- Thickness
- Grain size
- Base material
- Pre-treatment conditions
- Storage conditions

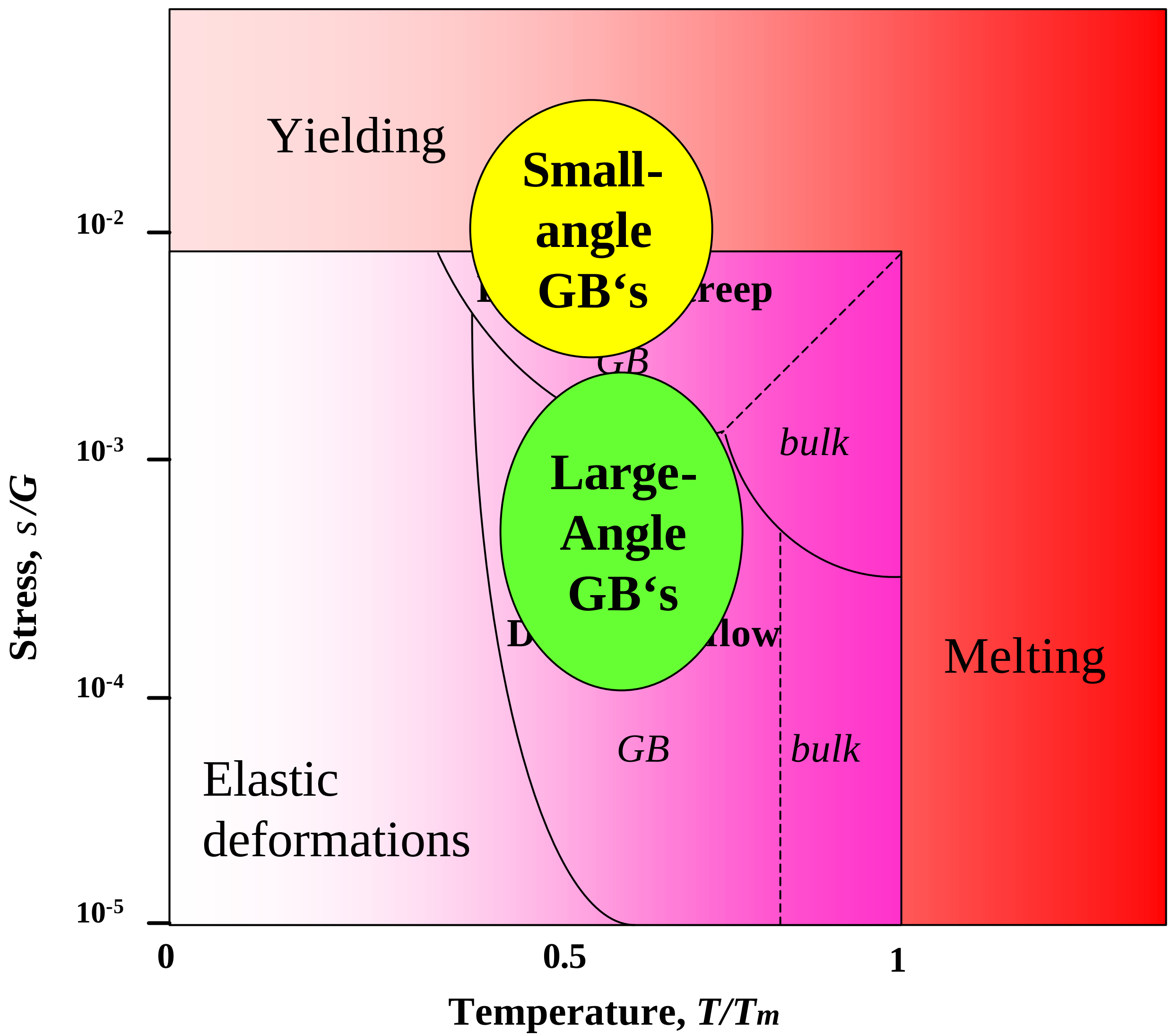
Tin Whisker Growth Mechanism



Deformation-mechanism diagram

(After Ashby and Jones, 1981)

Tin Whisker Growth Mechanism



Tin Whisker Growth Mechanism

- Local yielding nourished by tin, provided by diffusion and creep mechanisms = whisker growth

- Most critical situations: Dimensional changes of grain boundaries (tin flow encounters small grain boundary, many grain boundaries unite in one single grain boundary)