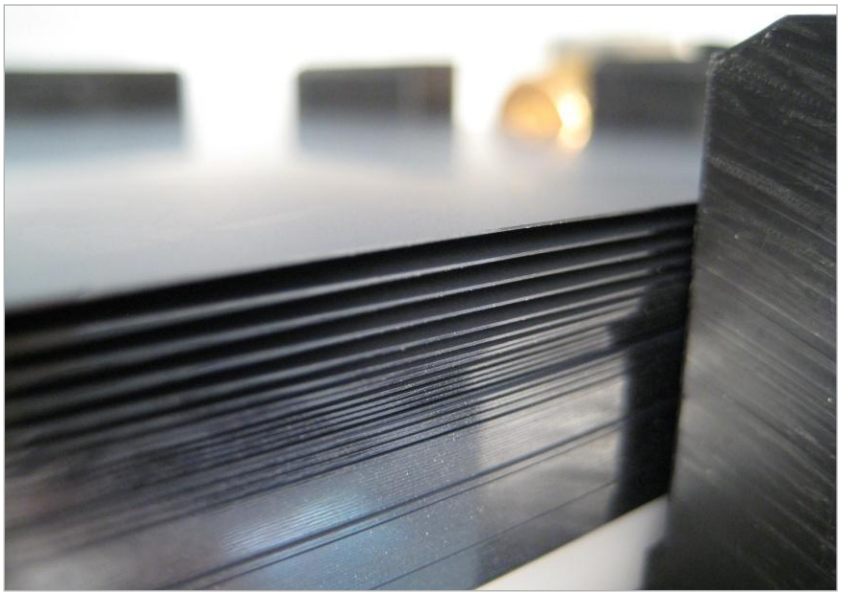
Separation process of thin crystalline silicon-wafer with compressed air

1. Workshop „Handling and Automation of Solar Wafer and Cells“



Stuttgart, 13th January 2011

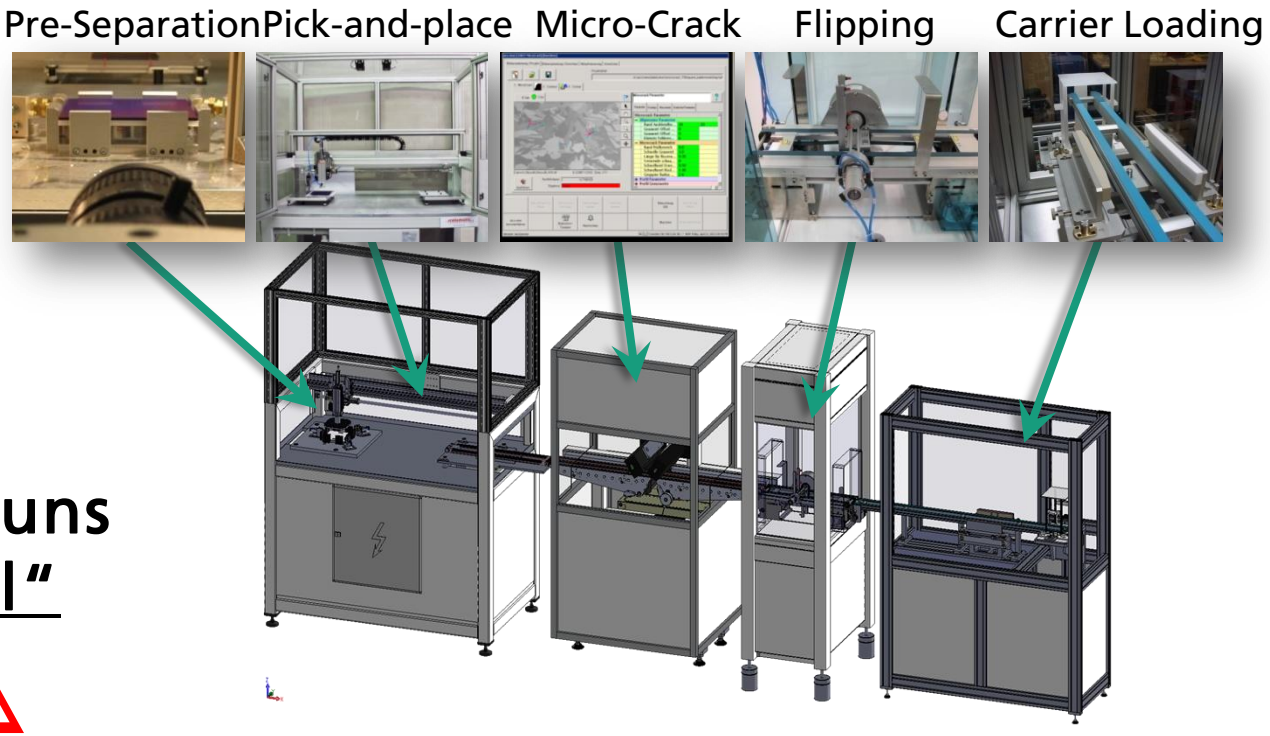
Alexander Ehm

Fraunhofer IPA

Outline

1. Motivation
2. Requirements wafer separation
3. Pick-and-place Process
4. Analysis and optimization of the separation process
5. Summary and Outlook

1. Motivation



Results: Final Test Runs „High Sol“

Station	Pre-Separation	Pick-and-Place	Micro-Crack	Flipping	Carrier Loading
Rel. Breakage Rate [%]	51%	26%	0%	17%	6%

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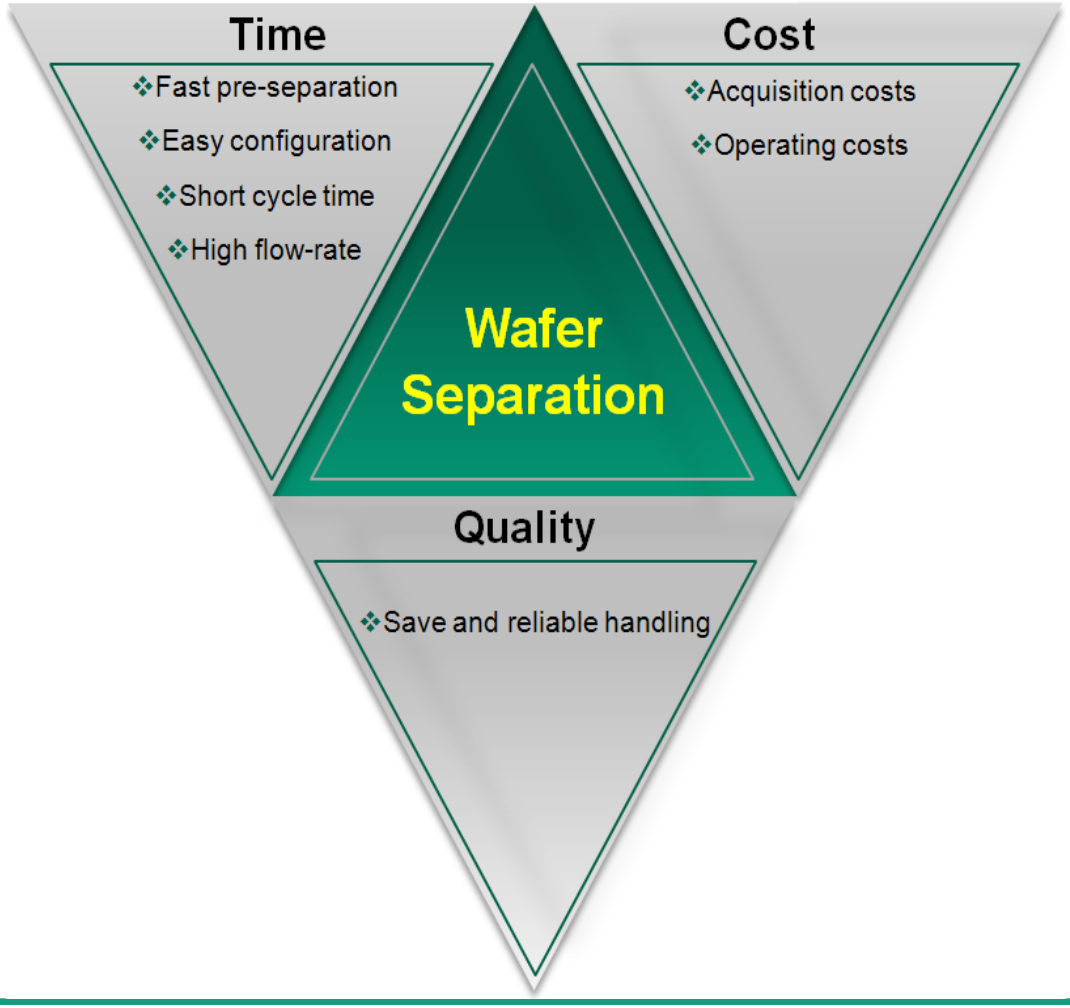
2. Requirements wafer separation

Requirements: Time-Cost-Quality Triangle



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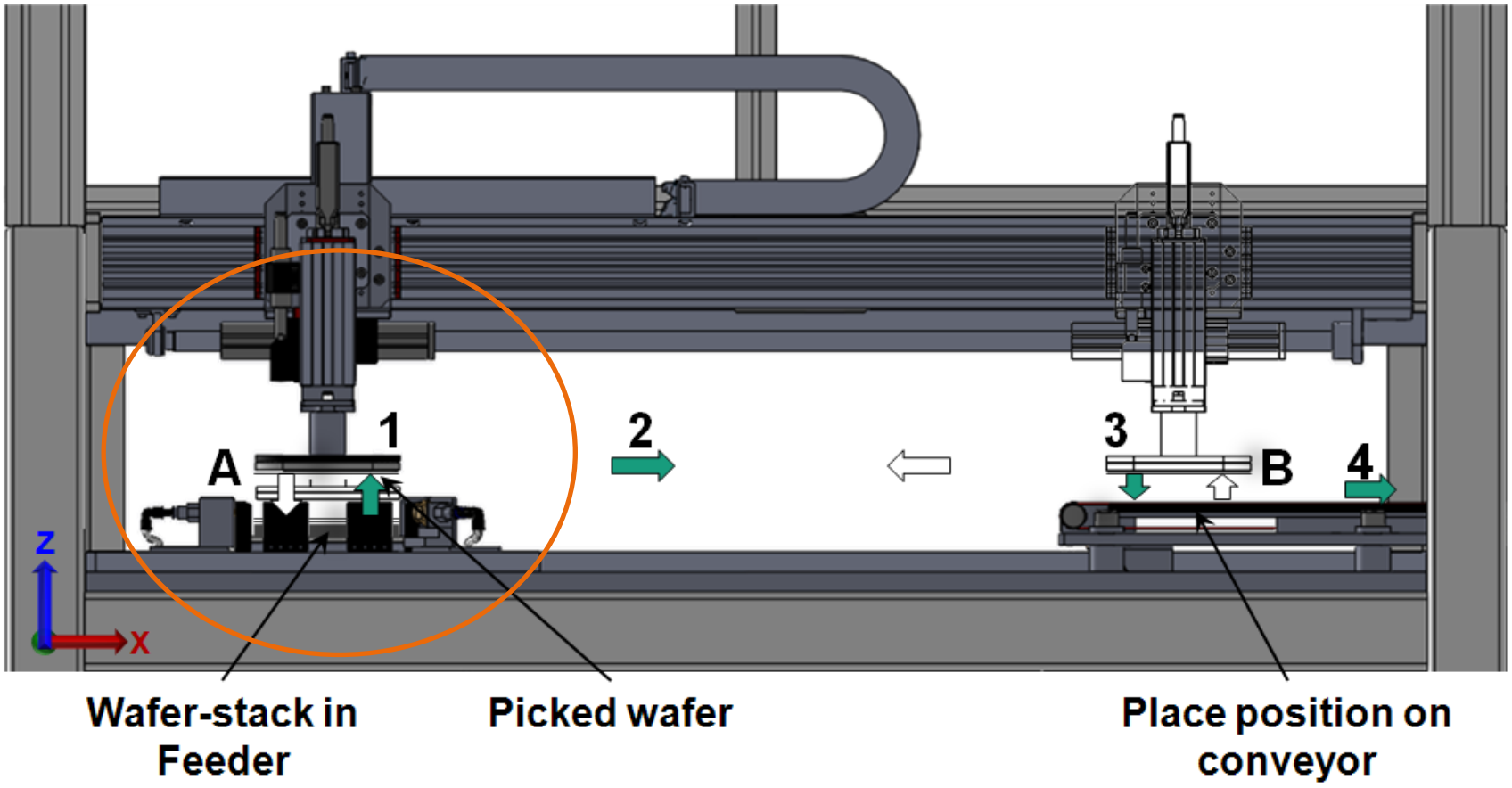
3. Pick-and-place Process



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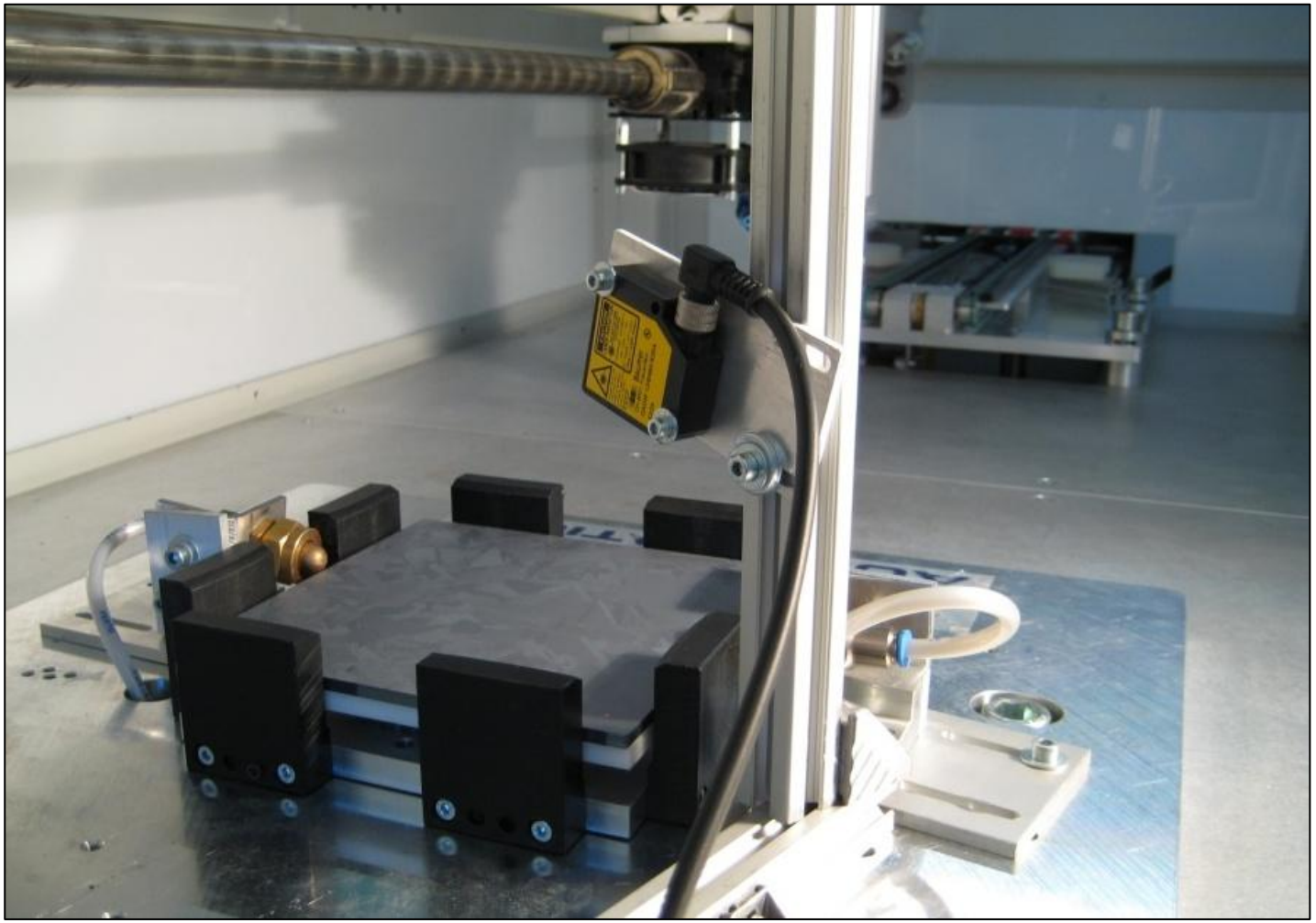
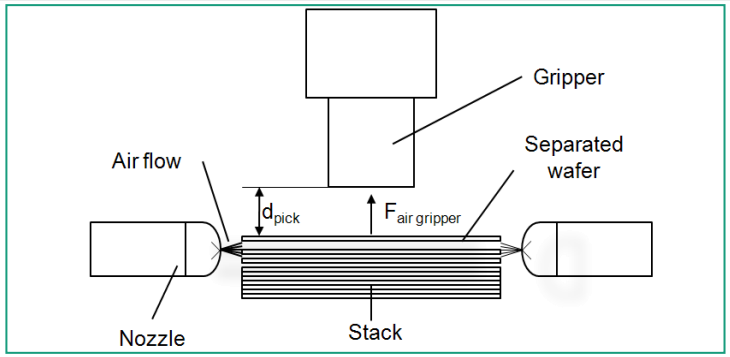
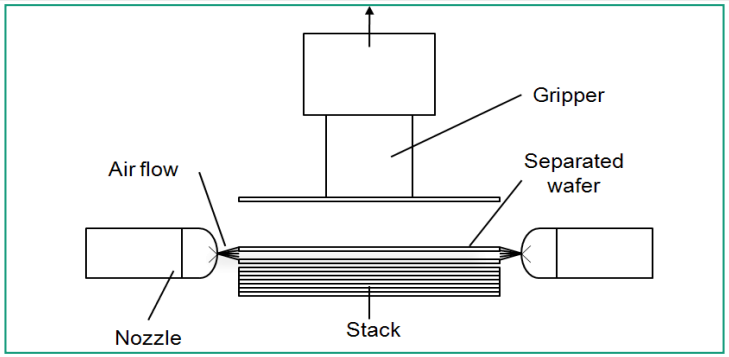
Initial state of Feeder



4. Analysis and optimization of the seperation process

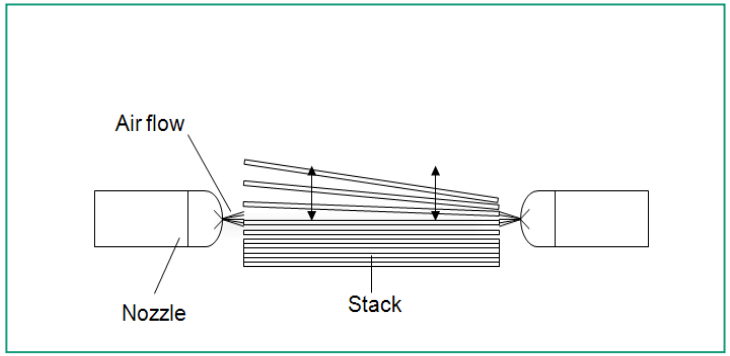
1. Optimal Separation and Picking



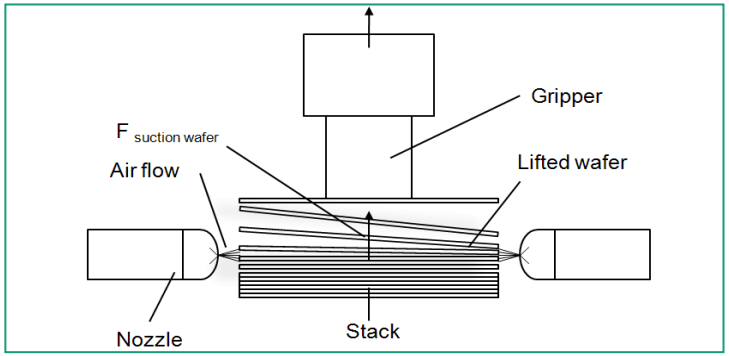


2. Real Separation and Picking

1st challenge:



2nd challenge:



Main Challenges:

1. Precise Pre-Separation
2. Save Gripping Process (repetition)

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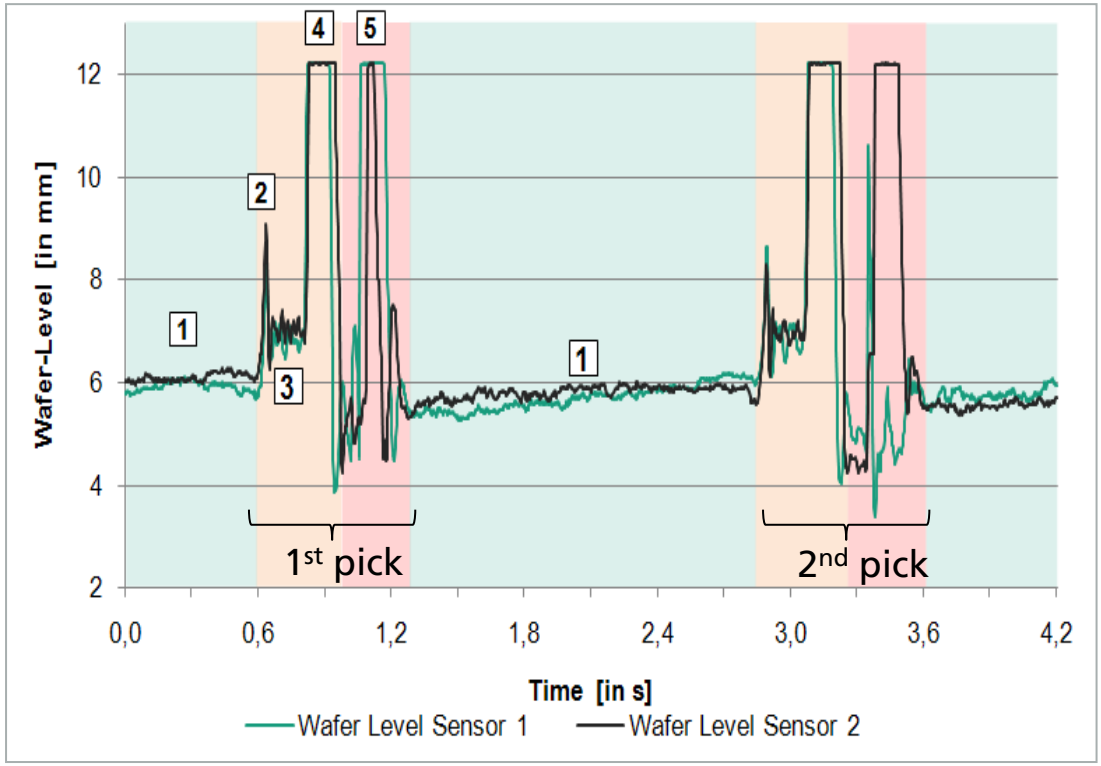
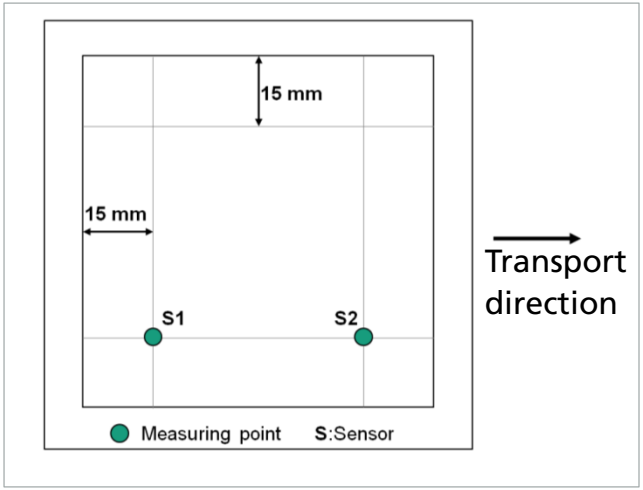
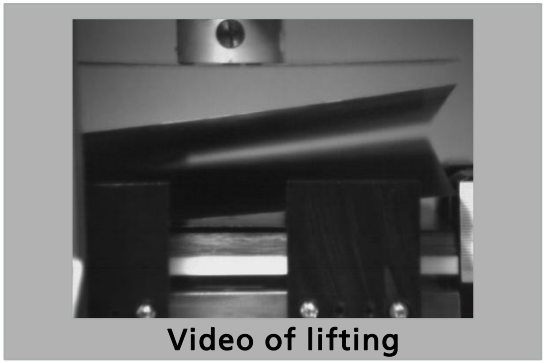
Wafer behavior after gripping (2 sensors)

Wafer-Level



Sensor Positions




Video of lifting

1 Pre-Separation
2 Picking
3 Waiting
4 Transport (z)
5 Lifted 2nd topmost wafer

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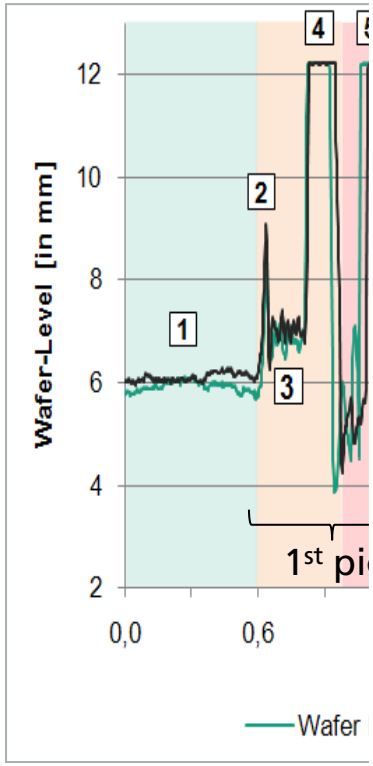
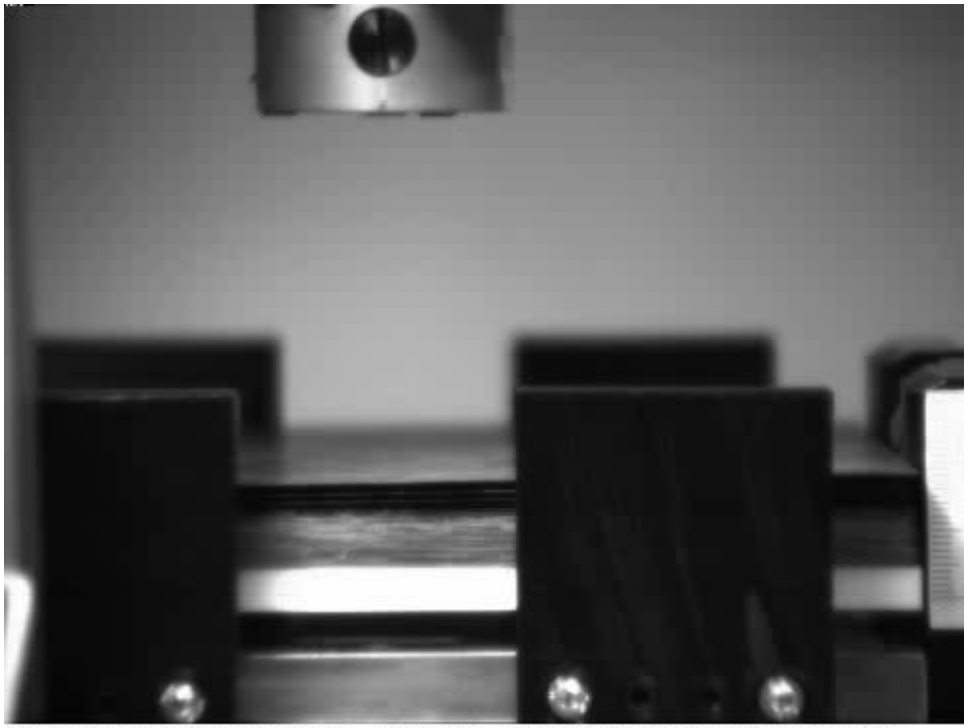
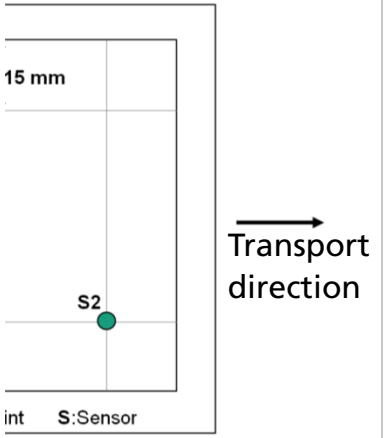
Wafer behavior after gripping (2 sensors)

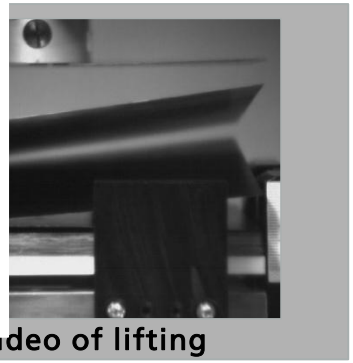




12.10.2010 10:55:50 1900 0635,4[ms] 480x360, 2989 Hz, 60 µs, *2,
MotionBLITZ Cube3 #00163, V1.9.21

or Positions





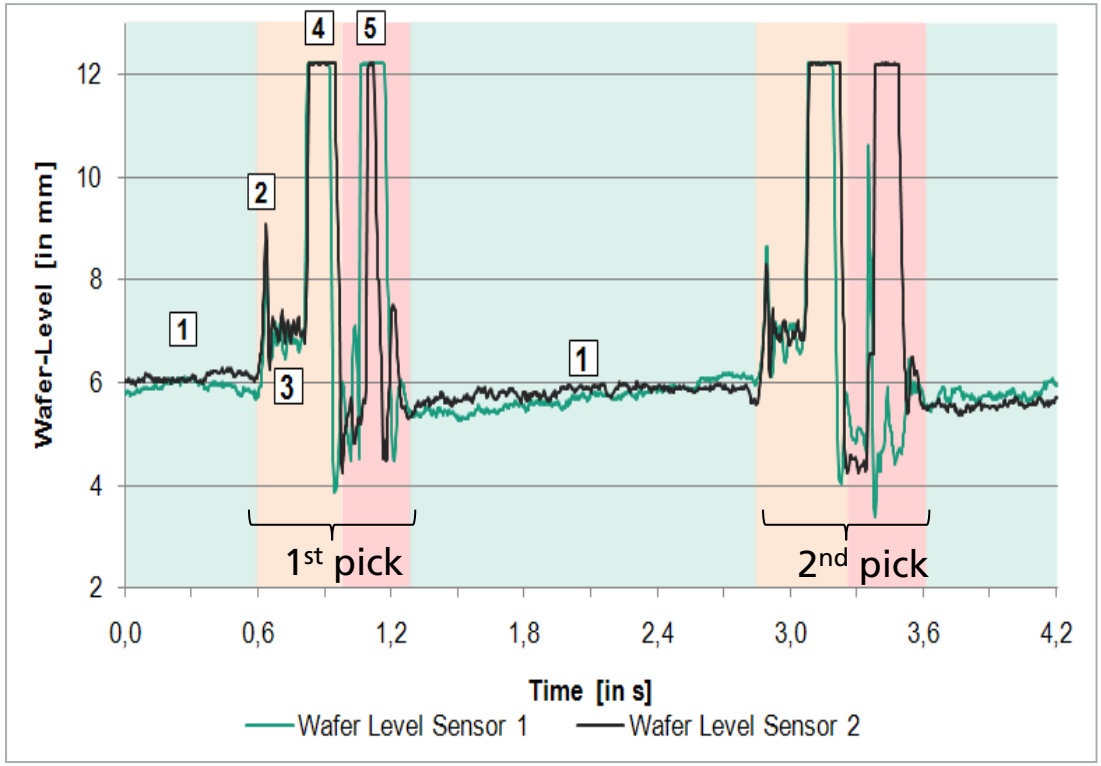
video of lifting

1 Pre-Separation
2 Picking
4 Transport (z)

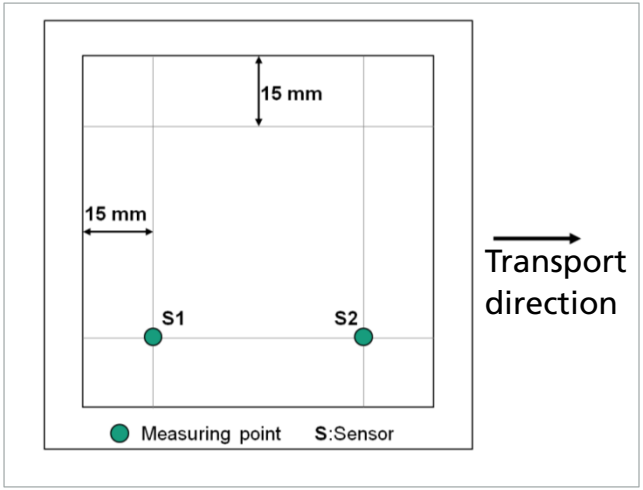
Fraunhofer IPA

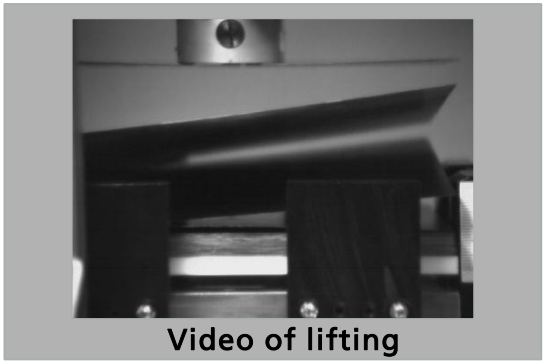
Wafer behavior after gripping (2 sensors)

Wafer-Level



Sensor Positions




Video of lifting

1 Pre-Separation
2 Picking
3 Waiting
4 Transport (z)
5 Lifted 2nd topmost wafer

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Target values and factors of interest

Target Values	*Factors to be investigated*	
1. Vibrations 2. Cycle time 3. Operating costs (compressed air) 4. Wafer stress	1. Number of nozzles 2. Nozzle configuration 3. Nozzle slot shape 4. Pressure 5. Nozzle direction 6. Distance nozzle-wafer 7. Position gripper-wafer for pick-process 8. Different wafer thicknesses 9. Shape of side walls	

1st step: Pre-separation

Control Factor	# Types	Specification				
#Nozzle	4	1	2	3	4	
Nozzle Position						
1 Nozzle	2	1.1	1.2			
2 Nozzles	6	2.1	2.2	2.3	2.4	
		2.5	2.6			
3 Nozzles	10	3.1	3.2	3.3	3.4	3.5
		3.6	3.7	3.8	3.9	3.10
4 Nozzles	12	4.1	4.2	4.2	4.4	
		4.5	4.6	4.7		
		4.8	4.9	4.10	4.11	4.12
Slot	4	|	—	+	×	
Pressure [bar]	3	≤0,7	1,0	≥1,3		
Nozzle direction	3	→	↗	↘		
Distance N-W	3	~0	5	10		

Pretests

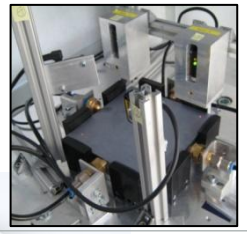
Control Factor	# resulting Types	Specification				
#Nozzles	2	1	2	3	4	
Nozzle Position						
2 Nozzles	2	2.1	2.2	2.3	2.4	
		2.5	2.6			
4 Nozzles	3	4.1	4.2	4.2	4.4	
		4.5	4.6	4.7		
		4.8	4.9	4.10	4.11	4.12
Slot	4	|	—	+	×	
Pressure [bar]	2	≤0,7	1,0	≥1,3		
Nozzle direction	2	→	↗	↘		
Distance N-W	1	~0	5	10		

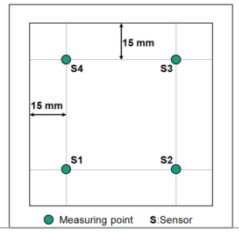
First Results: Separation possible with these settings
Next Step: Determination of factors with main significance

2. Creation of Screening design

Nr.	Position	Slot	Pressure	Nozzle-Direction	Safety Factor
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1
11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

3. Realization of Experiments for 120µm & 200µm wafer





1. Determination of quantitative + qualitative factors with 4 levels

Control Factor	Factor Level 1	2	3	4
Nozzle Position	1.1	1.2	4.1	4.5
Slot	|	—	+	×
Pressure [bar]	0,3	0,5	0,7	1,0
Nozzle Direction	0°	-5°	-10°	+5°

Determination of suitable settings

4. Analysis of Variance Determination of significant factors

	120				200			
	Diff	Sig[1]	SD[2]	Sig[1]	Diff	Sig[1]	SD[2]	Sig[1]
Position	2,895	-	2,582	-	3,455	-	5,131	*
Slot	8,050	**	6,249	*	4,957	*	4,560	*
Pressure	0,430	-	0,358	-	1,366	-	1,365	-
Nozzle Direction	1,473	-	1,130	-	1,928	-	1,823	-

[1] Significance, [2] Standard Deviation

5. Determination of suitable factors for pre-separation

Control Factor	Factor Level 1	2	3	4
Nozzle Position	1.1	1.2	4.1	4.5
Slot	|	—	+	×
Pressure [bar]	0,3[1]	0,5[2]	~~0,7~~	~~1,0~~
Nozzle Direction	0°	-5°	~~-10°~~	~~+5°~~

[1] 120 µm; [2] 200 µm

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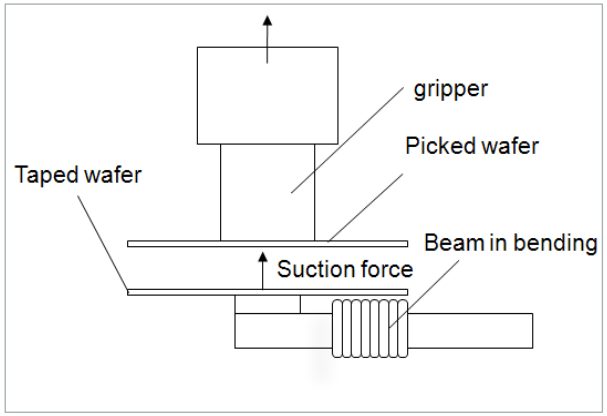
2nd step: picking process

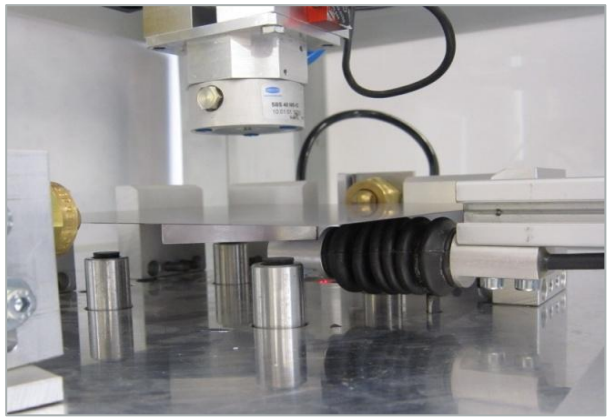
1. Significance of the suction force

- Wafer-weight:

	Wafer-weight depending on wafer-thickness (in N)	
	120	200
Multi	**0,069**	**0,111**
Mono	**0,053**	**0,124**

- Measuring with beam in bending (0-20N):





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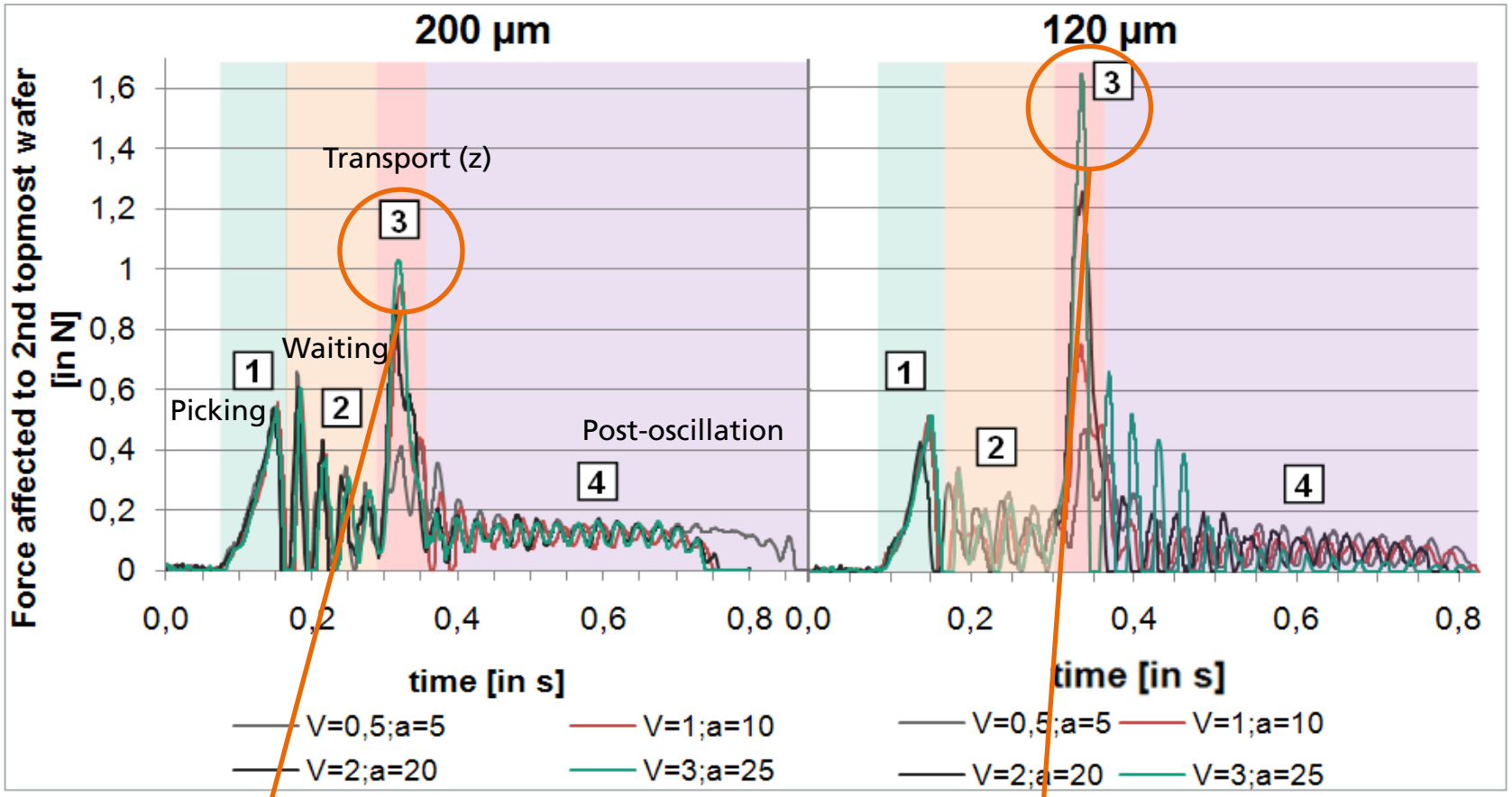
Affected force depending on wafer-thickness



Force ~10 times wafer weight
(200 µm ≅ 0,111N)

Force ~25 times wafer weight
(120 µm ≅ 0,069N)

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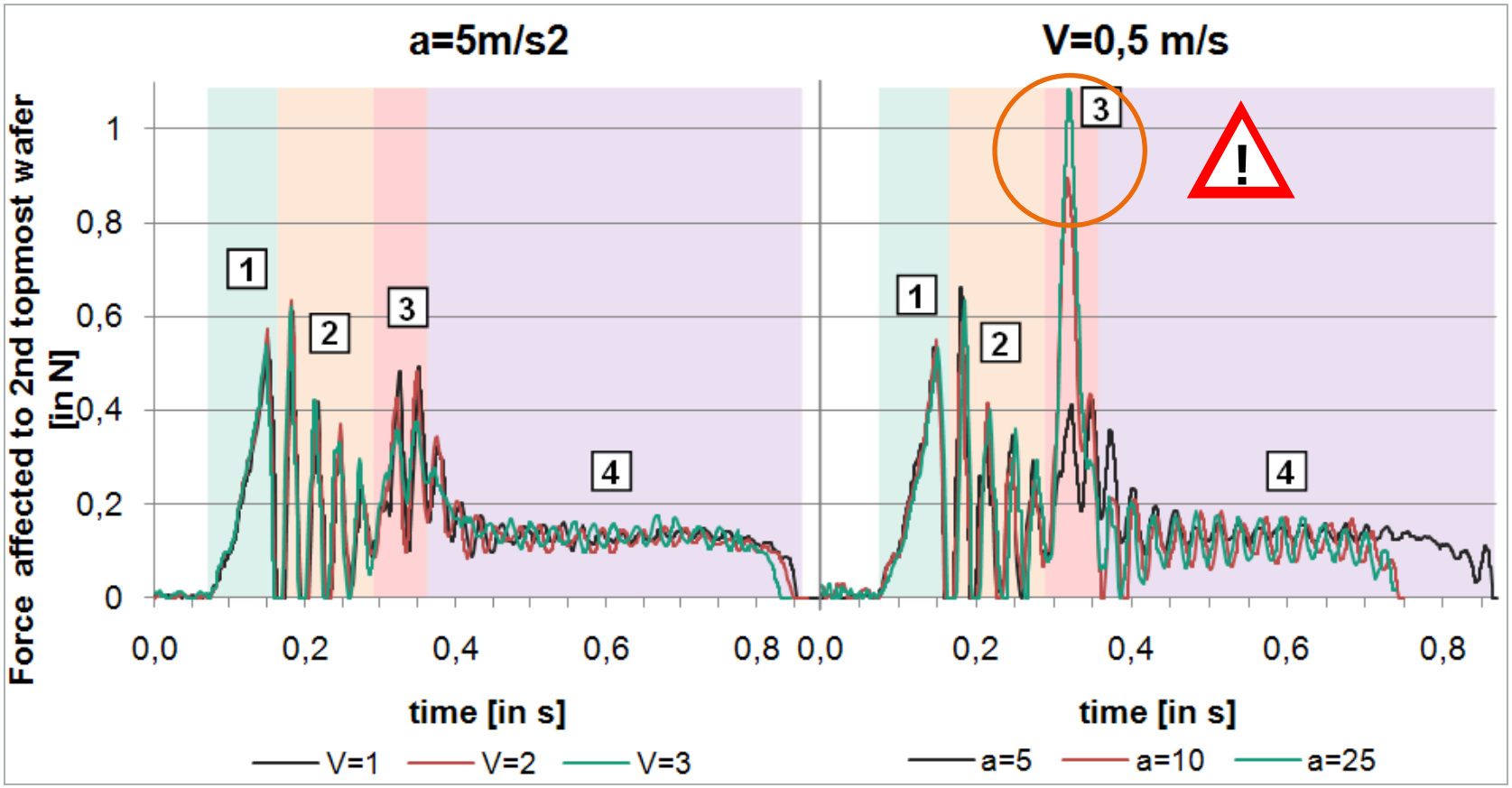
Affected force depending on picking acceleration (a) and velocity (V)



➡ No visible effect of velocity

➡ Crucial factor **acceleration**

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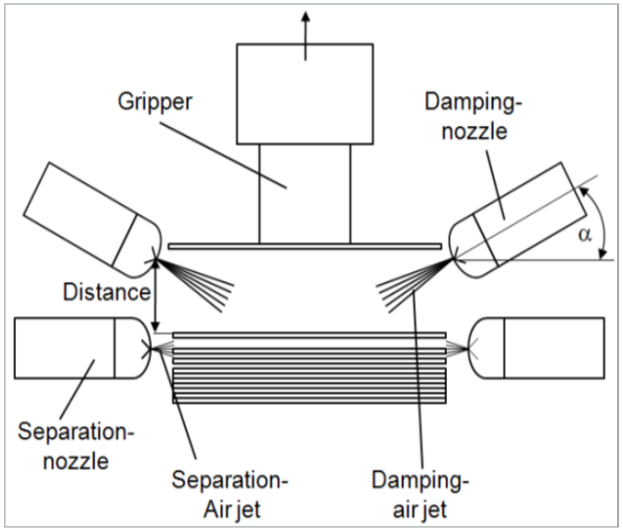
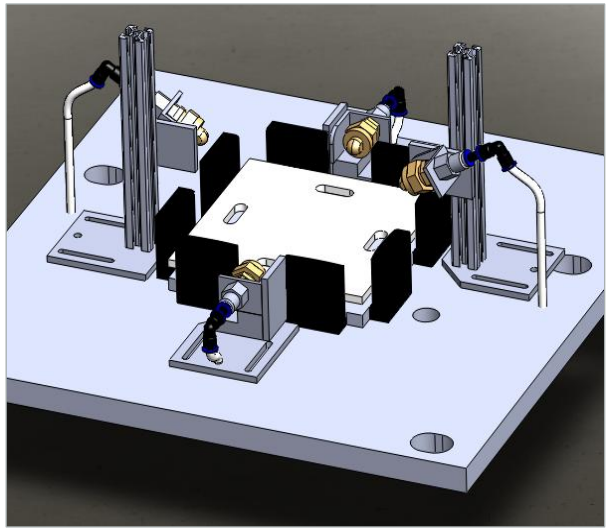
2. Air jet damping





- Vibration damping starts at certain pressure
- No picking possible when air pressure is too high

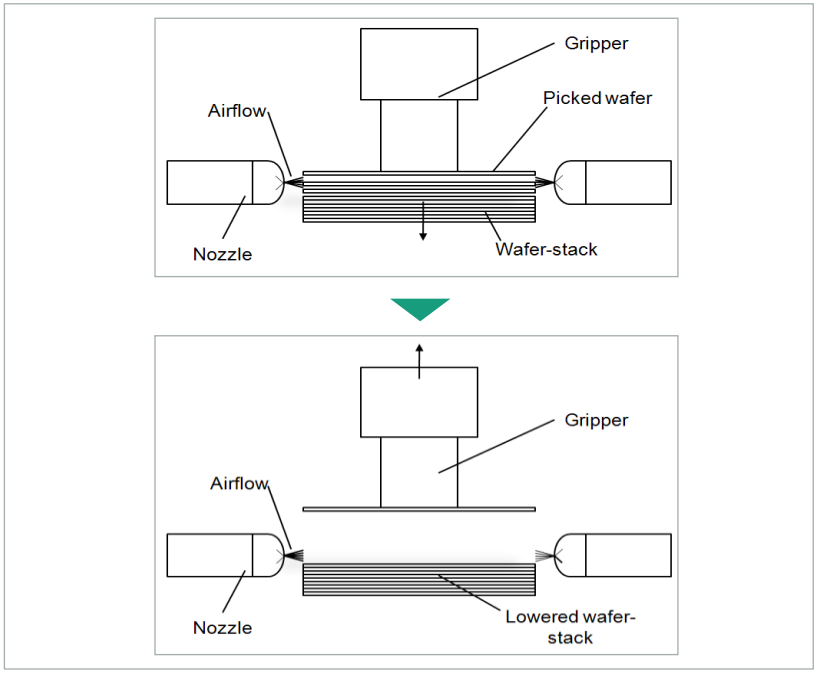
+	-
• Improvement of process	• Extra load on wafer • 120 µm less impact

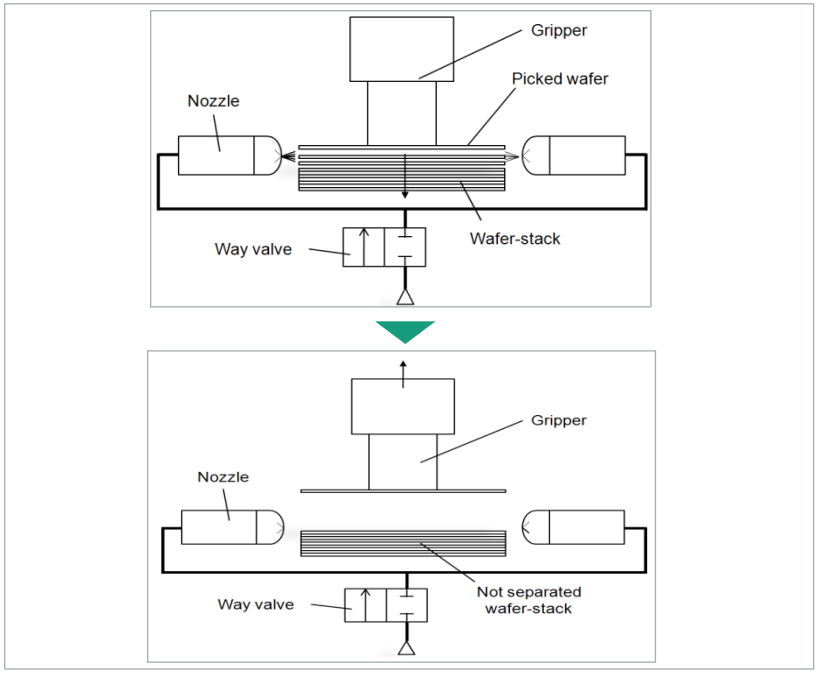
➡ Only as add-on

3. Stack lowering

4. Pulsation of separation airflow

➡ Goal: Reduction of suction force





	Incorrect picking* depending on wafer-thickness (in %)		
	200 µm	180 µm	120 µm
Without stack lowering/ pulsation	15	20	26
With stack lowering	1	7	13
With pulsation	0	0	10

* Picking with maximal parameters: V=3m/s; a,d= 25m/s²

➡
- Pulsation achieves better results
- Critical wafer-thickness 120 µm

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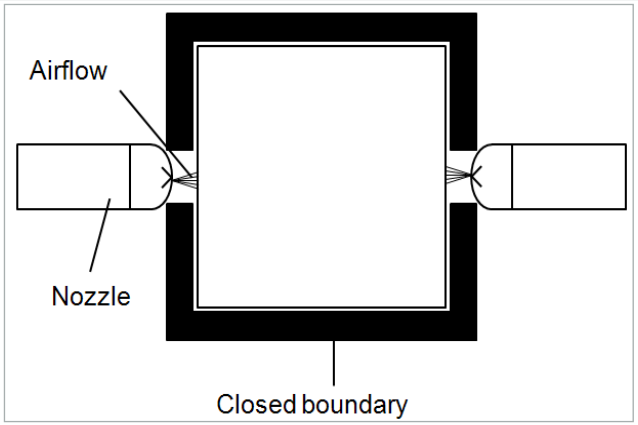
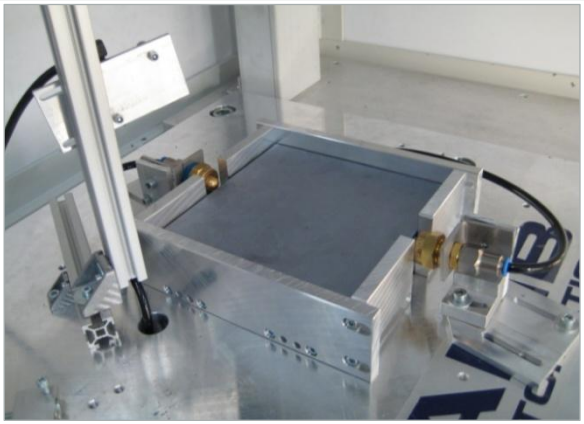
5. Closed side wall design

Goals:

- Research on consequences to picking process
- Reduction of air needed for pre-separation





- Picking not possible due to evacuated space under topmost wafer
- No improvement in pre-separation process

Not suitable

5. Summary and Outlook

Pre-separation:

- Analysis and determination of significant factors
- Specification of suitable settings for reliable pre-separation

Picking process:

- Characterization of suction force and influencing factors
- Investigation on methods for reliable separation process

Outlook:

- New nozzle type (e.g. flat jet)
- Damping with alternative medium (e.g.ultrasonic sound)