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229196

Project acronym:
piezoVolume

Project full title:
High volume piezoelectric thin film production process for microsystems

Collaborative Project targeted to a special group (such as SMEs)
Grant Agreement No.:

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Duration: 3 years

D 2.11
Final CSD cluster coater tool

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Actual delivery date: 2012-12-21

Organisation name of lead contractor for this deliverable: SOS

Project co-funded by the European Commission within the Seventh Framework Programme (2008-2011)		
Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential , only for members of the consortium (including the Commission Services)	

Deliverable number:	D 2.11
Deliverable name:	Final CSD cluster coater tool
Work package:	WP 2 Tool development
Lead contractor:	SOS

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Abstract

In the course of the piezoVolume project SOS has developed an automated tool for the production of PZT thin films on wafers. It consists of :

- a spincoater for the homogeneous deposition of liquid chemicals,
- hotplates to perform pyrolysis,
- a RTP furnace featuring two lamp arrays for heating,
- robotics for automated wafer transport,
- all required infrastructure like pumps, reagent reservoirs, waste etc.
- and a hermetically closed cabin to permit operation under clean room conditions and to prevent operators from coming into contact with toxic vapors

The cluster tool incorporates improvements derived from the experience with a prototype and is currently investigated experimentally. This report describes the integration of the RTP furnace at SOS and the installation at SINTEF. The difficulties encountered in the course of the project are summarized.

Public introduction[1]

[1] According to Deliverables list in Annex I, all restricted (RE) deliverables will contain an introduction that will be made public through the project WEBsite

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1 TOOL DESIGN

The starting point for the development of the Final CSD cluster coater tool was the prototype installed at SINTEF, which was reported in D2.6. It required manual operation and crystallisation had to be performed in a separate furnace, yet some valuable insights were derived from the results obtained with this tool.

Fig. 1: Prototype CSD coater tool without RTP

So the development of the final cluster tool mainly consisted of three tasks:

- Find and integrate a RTP furnace
- Add robotics for fully automated wafer handling and make it work
- Take into account the experiences with the prototype tool

At the beginning of the second half of the piezoVolume project the question of how to accomplish the crystallization step was still open. Budgetary constraints had revived the discussion whether to go for a Hot-Plate solution instead of a more expensive RTP-oven. Because of time running out and the need to provide a functioning automatic coating tool by the end of the project however it was decided to favour a lamp-array-heated furnace. On the basis of this decision three companies with proven expertise in the furnace market were contacted, two of which did not respond to the offer for cooperating in the development of an RTP according to the requirement specifications at all.

The remaining firm recently had finished a prototype of a new RTP with very promising key features. Especially the temperature uniformity, which is considered crucial for the PZT-process had been shown to be within < ±1% @ 400°C over a 300 x 300 mm area under steady state conditions. The manufacturer was confident to achieve this performance up to 700°C, yet without proof by experimental data by that time.

Fig. 2: Prototype of RTP furnace with cover opened and 300 mm wafer inside

Top-loading was another feature of this RTP, which made it quite attractive for the piezoVolume project as it provides good accessibility to the wafer and simplifies integration into a fully automated coating tool.

Fig. 3: Automated coating tool together with RTP-furnace during assembly at SOS

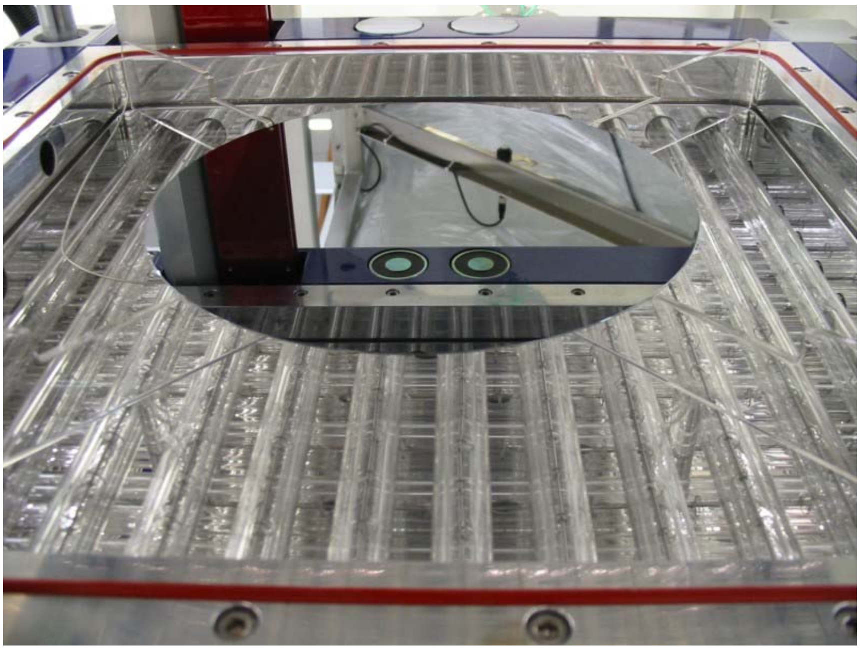


Fig. 4: RTP furnace - lower lamp array with 200 mm wafer

Key features of the RTP furnace

- Top loading ensures good accessibility of wafer and facilitates automatic wafer handling.
- Crossed lamp arrays 18 kW each below and on top of the wafer (36 kW in total).
- Individual control of lamps permits fine tuning for good temperature uniformity.
- Modular design ensures easy adaptation to changing requirements.
- Height of processing chamber can be adapted over a wide range up to a maximum of 100 mm.
- Maximum temperature 1000°C for 30s and heating rate > 40 Ks^{-1}

1.1 Temperature uniformity

After the 30M meeting the RTP was returned to the manufacturer for fine tuning and to validate the claimed performance with respect to temperature uniformity.

Expectations were high and it was noticed not without gladness when the first results indicated that temperature uniformity even at 700°C stayed well within the specified limits.

The excellent performance that can be achieved through individual block wise control of the lamps is demonstrated by the screenshot and the table below.

Location	Meas. #1	Meas. #2
0° / 50mm	691.9	699.8
90° / 50mm	694.3	701.0
180° / 50mm	693.8	700.4
270° / 50mm	696.2	702.4
45° / 95mm	687.7	695.6
135° / 95mm	685.8	694.4
225° / 95mm	687.1	694.5
315° / 95mm	692.8	698.6

	#1 T [°C]	#2 T [°C]
Max	696.2	702.4
Min	685.8	694.4
Average	691.2	698.3
Max-Min	10.4	8.0
Limit	14 (± 7)	14 (± 7)
Result	**OK**	**OK**

Table 1, Temperature uniformity of RTP furnace across 200 mm wafer

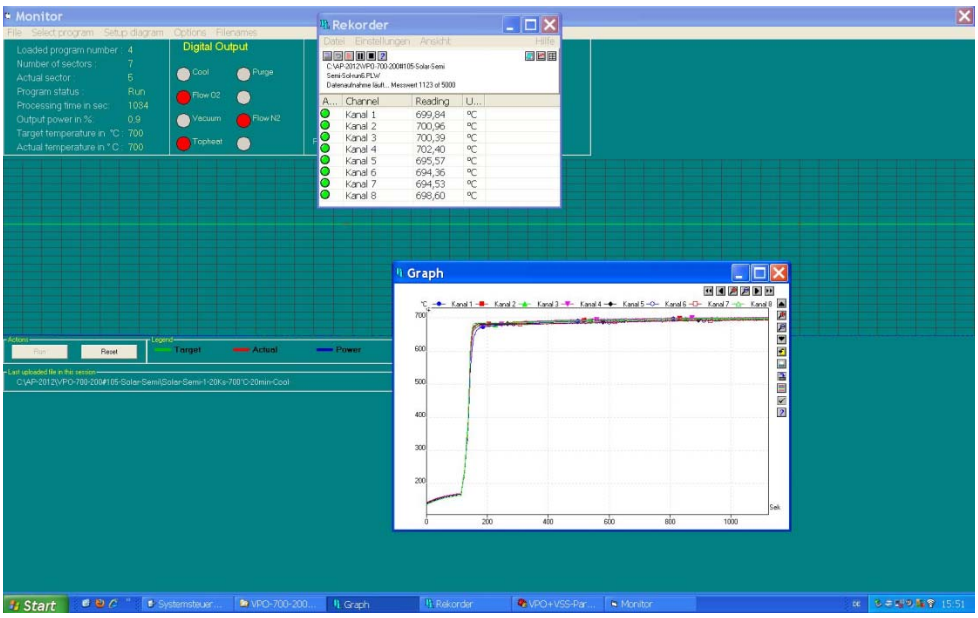


Fig. 5: Screenshot of RTP warm-up

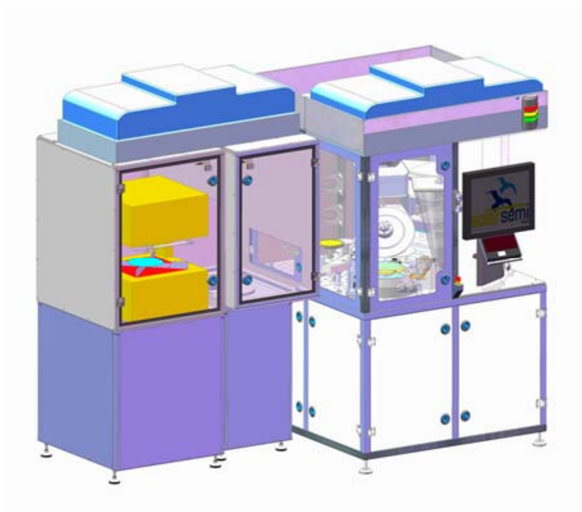


Fig. 6: 3D view of the final CSD tool with the RTP to the left

1.2 Highlights of the final CSD tool

- RTP integrated into coating tool facilitates PZT crystallisation
- Crossed lamp arrays with 18 kW each below and on top of the wafer (36 kW in total).
- Optimization of RTP heat radiation through independent control of upper lamp array
- Wafer handling at the edges only to minimize thermal non-uniformity on coated PZT layers
- Hermetically closed cabin permits operation under laminar flow conditions and prevents operators from coming into contact with toxic vapours
- High temperature Hotplates (max. 450 °C) for pyrolysis
- Electrically controlled lifting pins in the Hotplates permit arbitrary temperature profiles
- Three precision media pumps enable post mixing of single element precursors Coater featuring edge handling, Covered Chuck Technology and option for operation in open state
- Solvent saturated atmosphere in parking position prevents dispensing nozzles from drying and keeps PZT destroying vapour away from the PZT.
-

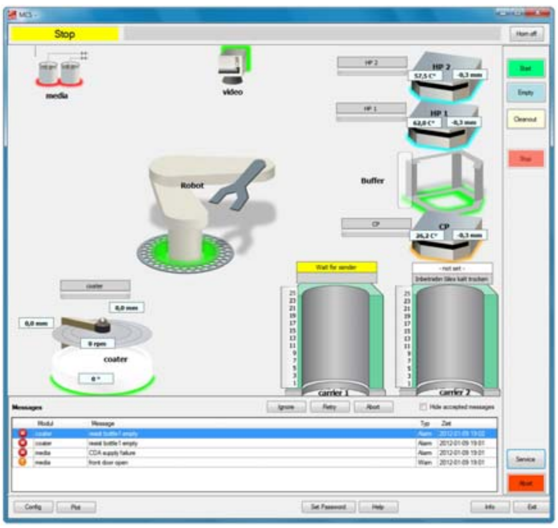


Fig. 7: Human Machine Interface

Operation of the Cluster Tool is greatly simplified through the ergonomically designed Human-Machine-Interface. Each module is represented by a self-explaining symbol and plain text messages guide the operator. The relevant parameters are displayed simultaneously giving excellent control over the running process.

1.3 Facility requirements

Both, the coating tool and the furnace put high requirements on the infrastructure at the installation site, e.g. two 3x32A/230V main supplies for the furnace alone are not available everywhere. All facility requirements are summarized in Appendix B.

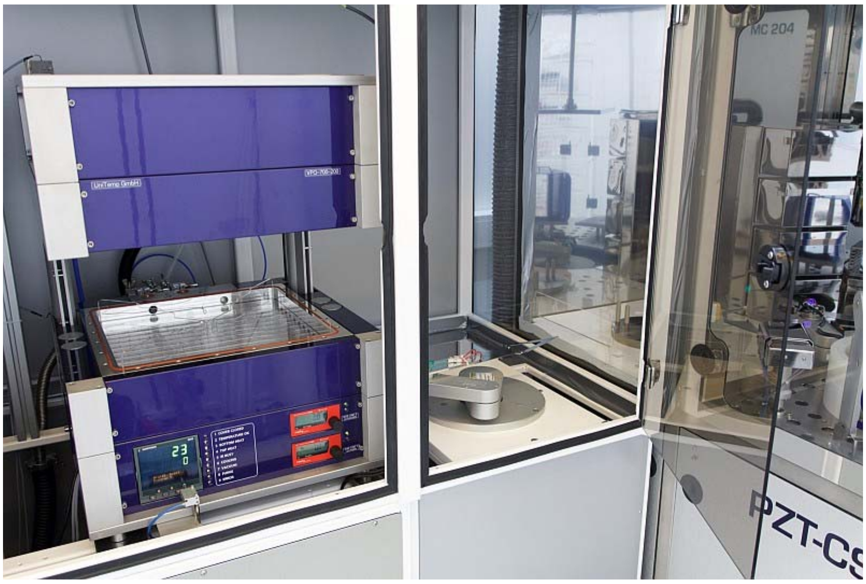


Fig. 8:, RTP, transfer robot and CSD coater (from left to right)

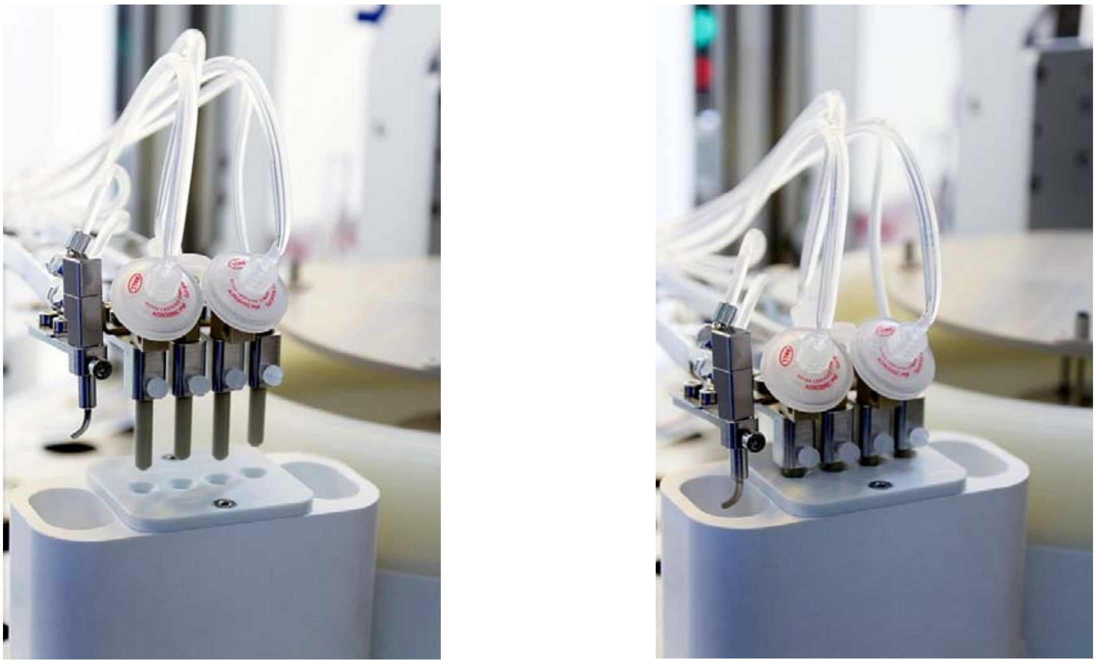


Fig. 9: Media arm with the nozzles lifted (left) and in the parking position (right)

Investigation of the prototype had identified point of use filtering to be a key factor for particle free coating. Consequently 0.45µm filters as close to the nozzles are used to keep dead volume at a minimum. The nozzles are kept in a solvent environment when not in use. This is done to prevent formation of particles from dried precursor solutions.

Fig. 10: Interior of the CSD cabinet

The picture to the left shows the inside of the CSD cabinet: coater, robot and hotplates (front to back). The original cover has been removed as it had been identified to be one cause for the particle problem experienced with the demo tool. Consequently the inner bowl was removed too, to lower the position of the wafer, which helps to avoid contamination of the cabinet by spun off fluid.

Fig. 11: Final CSD tool after installation at SINTEF

2 TOOL PERFORMANCE

2.1 Coating uniformity

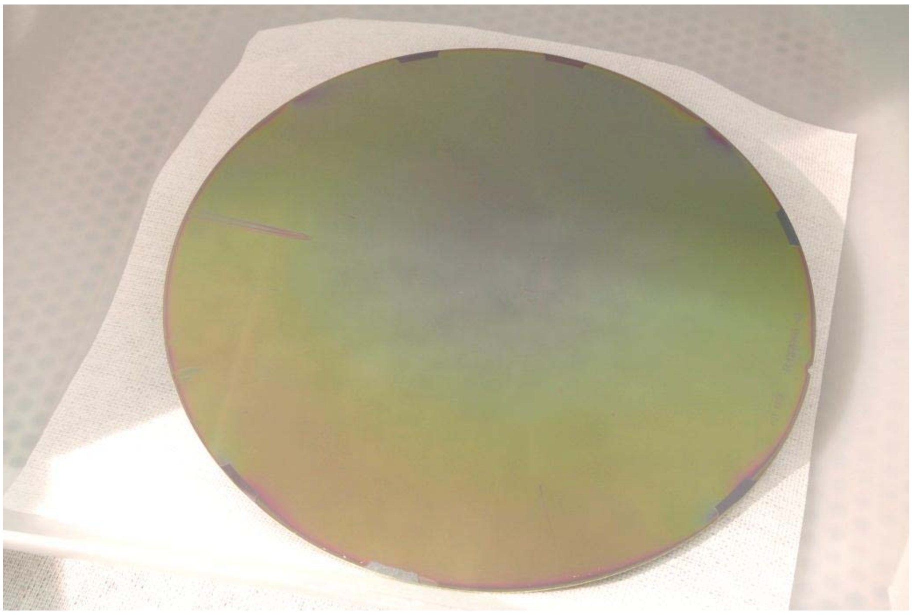


Fig. 12: A 200 mm wafer coated with 2 µm PZT using the final CSD tool

The uniformity was measured using ellipsometry as shown in Fig. 13 and Fig. 14. The data shows that the uniformity is very good with only +- 0.9 % thickness variation.

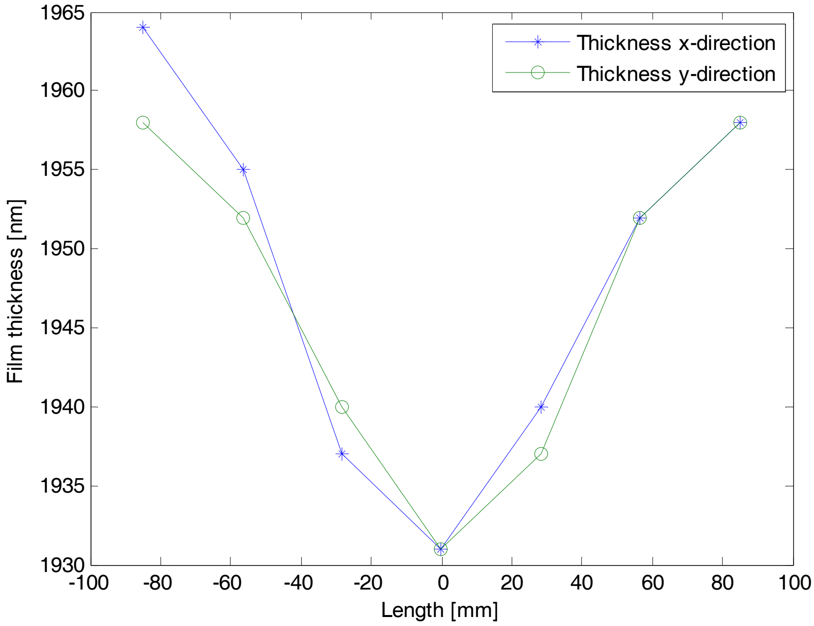


Fig. 13:, Thickness uniformity measured by ellipsometry

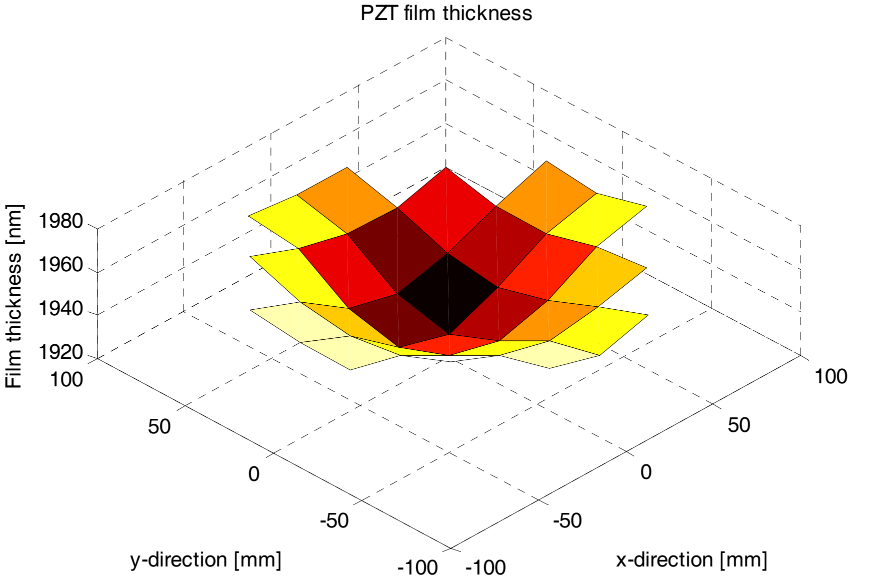


Fig. 14: Thickness uniformity map measured by ellipsometry

2.2 Crystallographic quality

The wafer was analysed using a Bruker AXS D8. The results in Fig. 15 show that the PZT is highly (001) oriented. Using a PZT powder as reference the film is 95,7 % (001) oriented which is very encouraging.

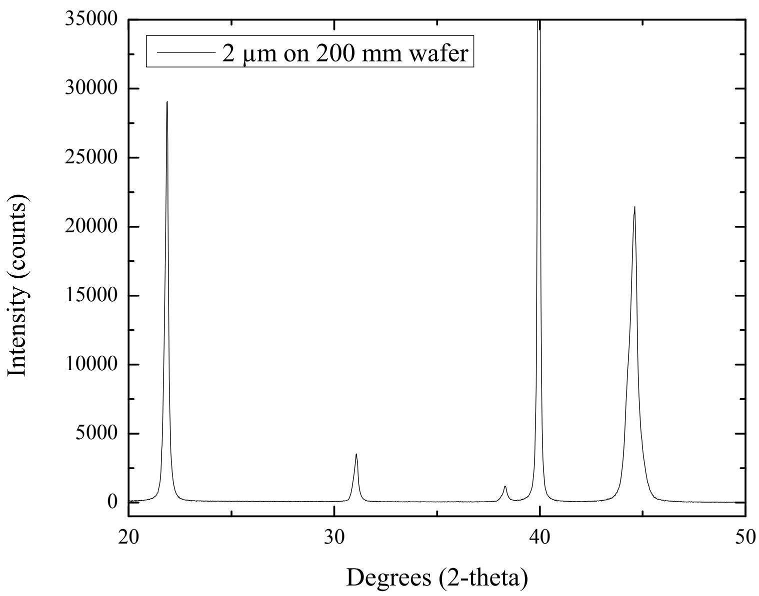


Fig. 15: X-ray diffractogram of the center area of the 200 mm wafer

2.3 Piezo and ferroelectric properties

The wafer was patterned at ISI (Fig. 16) and characterized at AIX using the automated testing tool. Some defects in the film could be seen in the upper part of the picture below. The reason for this unknown.

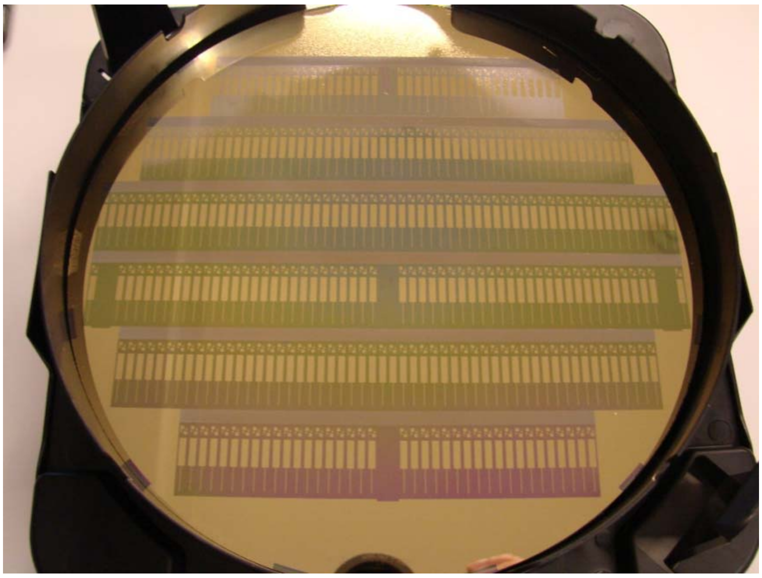


Fig. 16: Wafer patterned with Cr/Au top electrodes for testing.

The uniformity of $d_{33,av}^{+}$, $d_{33,av}^{-}$ and C_{av} using 16 measurement points are shown below in Fig. 17, Fig. 18 and Fig. 19.

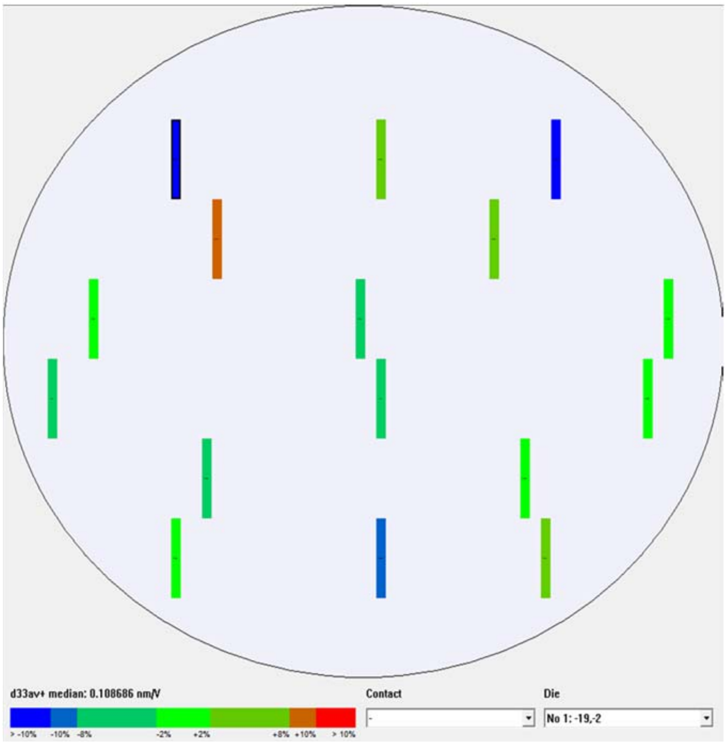


Fig. 17: Uniformity of $d_{33,av}^{+}$

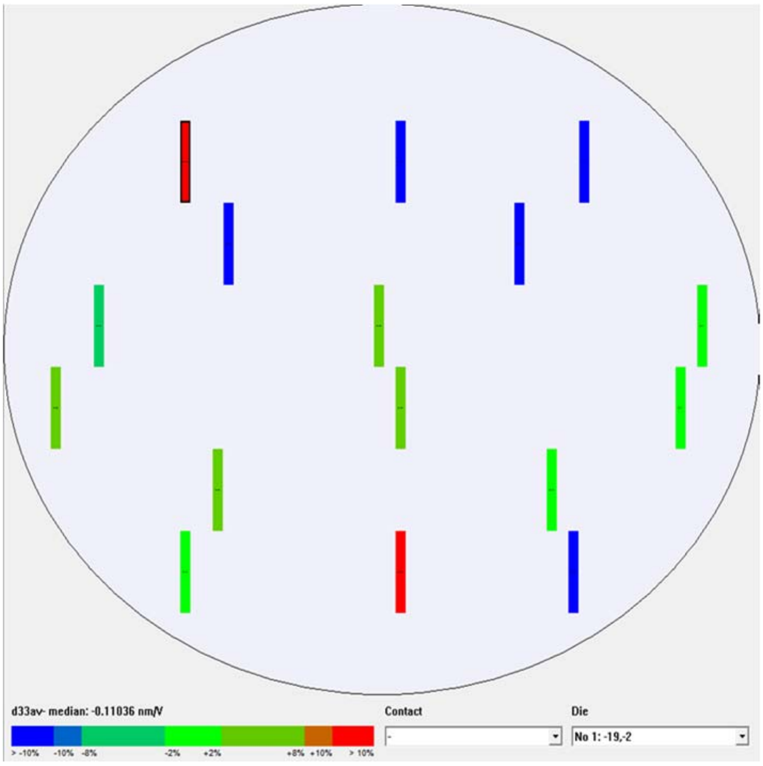


Fig. 18: Uniformity of $d_{33,av}^{-}$

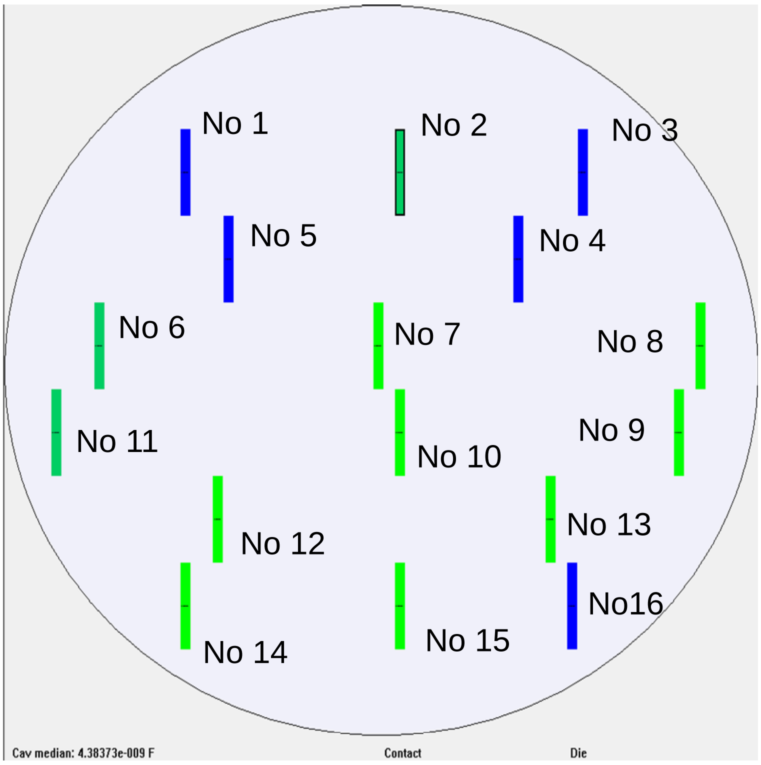


Fig. 19: Uniformity of C_{av}

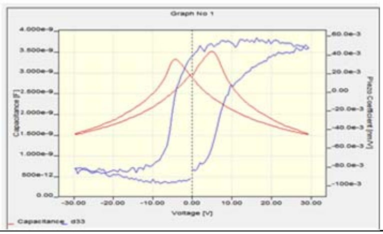
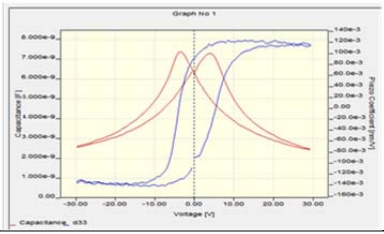
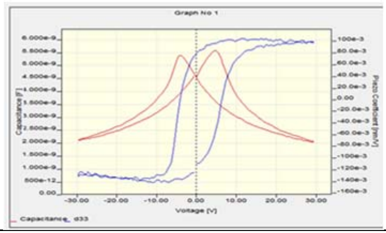
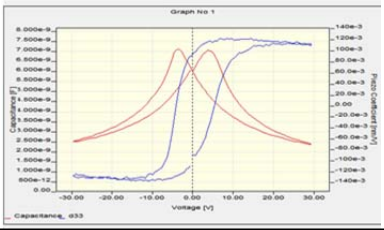
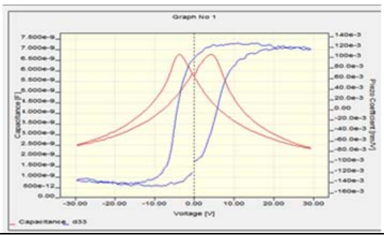
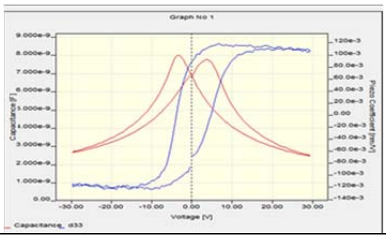
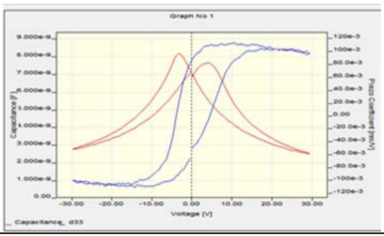
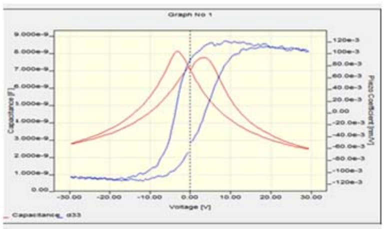
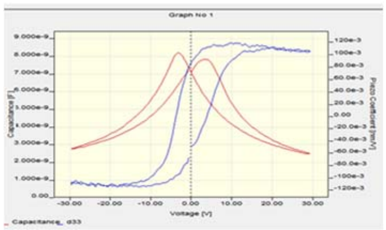
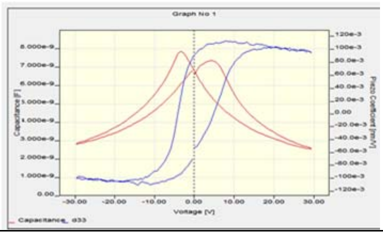
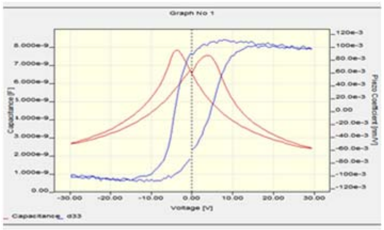
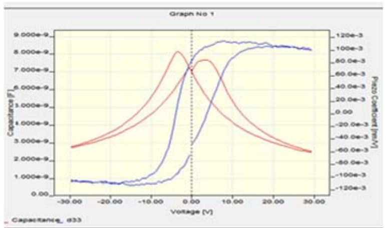
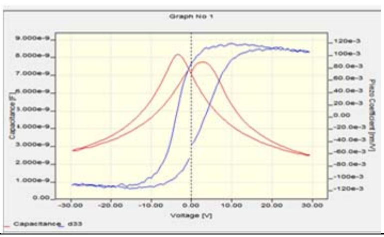
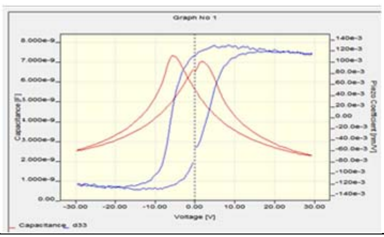
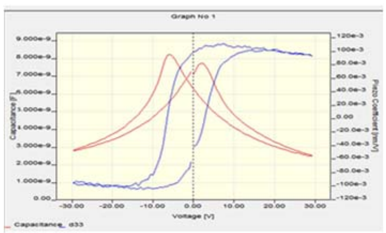
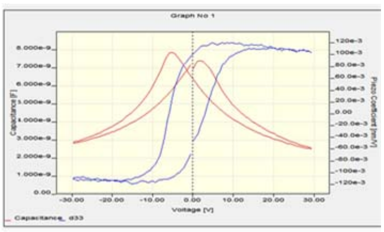
1 	2 	3 
4 	5 	6 
7 	8 	9 
10 	11 	12 
13 	14 	15 
16 		

Table 2: Cv and piezoelectric d33,f measurements for the capacitors shown in Fig. 19

The results above show that (001) oriented PZT films can be deposited with high thickness uniformity and high performance on 200 mm wafers by CSD. The non-uniformity in piezoelectric performance is higher than the industry specification of ± 2 %. However, the performance is overall high with around 120 pm/V large signal $d_{33,f}$ as shown in Table 2.

2.4 Throughput

At the beginning of the piezoVolume project the throughput goal for the final cluster coater tool was set to "at least 3 and ultimately 4 wafers/(h µm)". By that time (2010) the state of the art processes were capable to add a maximum layer thickness of about 60 – 65 nm per coating cycle. Hence 4 repetitions of four coating cycles each followed by an RTP resulting in a total of 16 coating cycles and 4 RTPs (4 [4CC+RTP]) were required for the deposition of a 1 µm layer.

After four coating cycles in sequence (4*113s, approx. 7.5 min) a RTP (approx. 3.5 min) must be performed. In serial production spin coating and crystallization in the RTP furnace can be run independently (on two wafers) at the same time and the time needed for the abovementioned 16 cycles can be calculated as 16 * 113s = 1808s, or approximately 30 minutes. In terms of throughput this amounts to 2.0 wafers/(h µm) which is well below the initial goal.

A closer inspection reveals that the bottleneck is the coating cycle as it takes 7.5 min, whilst the RTP only takes 3.5 min.

The coating process consists of:

1. Pre-wet wafer using solvent with puddle nozzle
2. Pre-dispense coating solution into solvent cup
3. Coat wafer using a continuous spiral dispense at a somewhat off-centre position.
4. Spin-off and accelerate to 3000 rpm for 20 s

The individual steps and their duration are listed below:

Coater			38
	Predispense	3	
	Prewet-wafer	5	
	Coating	5	
	Spinning	20	
	Deceleration	5	
Alignment			5
Hot plate			30
Cool plate			30
Other handling			10
Single cycle		Sum	113

(all times in seconds)

Table 3, Coating cycle timing

In order to accomplish the throughput goal defined at the beginning of the project the time needed for coating must be reduced. In principle there are two options:

1. keep all steps as short as possible, maximize parallel processing

The first approach makes use of the possibility to process several wafers in parallel, i.e. the scheduler will run coatings on one wafer while the others are on the hotplate/cool plate, yet this has not been demonstrated in practice due to problems with the automatic operation of the tool. Unfortunately to current knowledge the potential savings of the first option are limited unless one is willing to make substantial changes to the CSD tool.

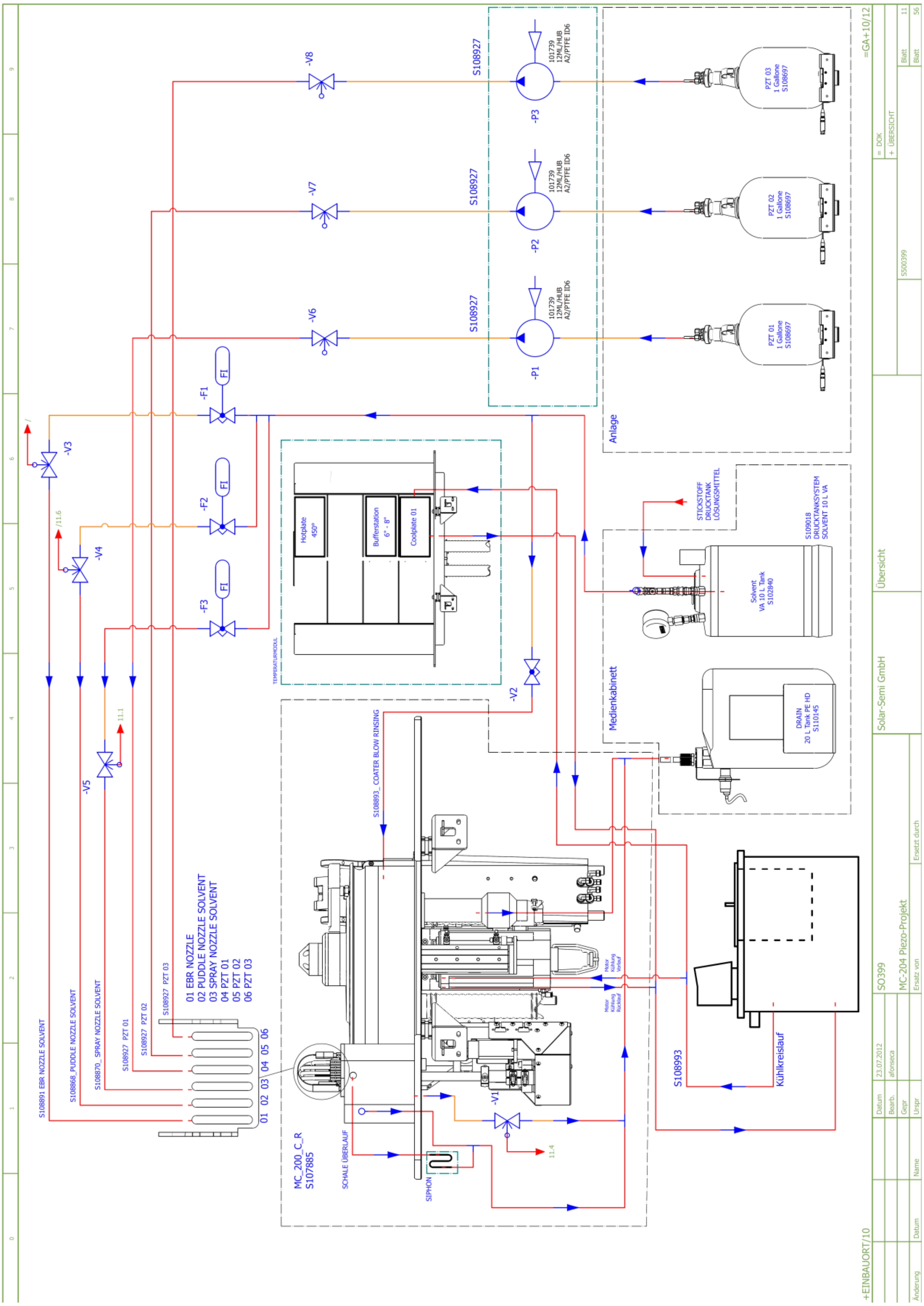
2. increase the layer thickness so as to decrease the number of coating cycles needed

This option was specifically addressed in WP1 "Process development and integration". As described in D1.6 "Report on CSD process development for high volume" the maximum layer thickness is limited by either occurrence of cracks or degraded crystallographic (001) orientation. Addition of precursor modifier resulted in well (001) oriented and crack free films of 100 nm thickness.

With this increased film thickness the number of coating cycles goes down to 10 cycles per micron and time needed for coating is reduced from 30 minutes to just 18.8.

As a consequence throughput is increased from 2.0 to 3.2 wafers/(h µm) and well within the targeted range.

3 APPENDIX A, CSD TOOL FLUIDICS



4 APPENDIX B, FACILITY REQUIREMENTS LIST AUTOMATED CSD TOOL

Requirement	***Description***	***SINTEF provides***	***SOS provides***
Total foot print Width x Depth x Height [mm]	**MC204:** approx. 1300 x 1300 x 2500 **VPO-700-200:** approx. 505 x 505 x 680 + 100 mm space on backside of RTP	-	-
Total weight [kg]	approx. 300 + 105		
Noise level of the unit	< 70db(A)	-	-
Power requirements	System power supply **MC204:** **VPO-700-200:** 2 x (3x32A, 230V/50Hz, 3P+N+PE, 18kW) CEE Socket '3P + N + E, 6h' (IEC 60309)	Voltage: 400VAC / STAR-Connection 1 x (3-phase 230V + N + PE / 50Hz Fuse current rating: 3 x 16 Amps) Type of plug: 16 Amps female CEE 5pin 2 x (3-phase 230V + N + PE / 50Hz Fuse current rating: 3 x 32 Amps) Type of plugs: male/female ?	
Power consumption	11,5 kW + 2 x 18 kW	-	-
Cooling water	**VPO-700-200:** Maximum inlet/outlet pressure: 5 bar/1 bar Differential pressure: 3 bar Flow rate (at 3 bar differential pressure): 5 l/min Inlet Temperature: 16 - 20 °C Inlet/Outlet connector: 10 mm outer diam. for PU		

Requirement	*Description*	*SINTEF provides*	*SOS provides*
	Hose (10x8x1) For continuous operation at > 1000 °C (duration max. 30s): Differential pressure: at least 3 bar Flow rate 5 l/min Max. inlet temperature: 15 °C Unitemp: please review and confirm		
Compressed air	**MC204:** Clean dry air (CDA) for Pneumatics **VPO-700-200:** CDA, 6-10 bar, 4mm outer diam. hose for Pneumatics	Tube (outside Ø 10mm, inside Ø 8mm) Pressure: 8 ± 2 bar Quality: 5 µm filtered, dry, oil free	Tube fitting SWAGELOK (outside Ø 10mm, inside Ø 8mm)
Nitrogen	For pressurizing the tank systems, spray nozzles and hotplates Nitrogen: high gas flow for fast cooling 6 mm Swagelok compression fitting Adaptor to 6 mm outer diam. PU hose (6x4x1) included Max. inlet pressure 4 bar; min.: 2 bar	PFA tube (outside Ø 10mm, inside Ø 8mm) Pressure: 4,0 ± 0,5 bar Standardization of gas connectors and tubings ??? !	Tube fitting SWAGELOK (outside Ø 10mm, inside Ø 8mm)
Vacuum	For chuck- and hotplate- vacuum Max. vacuum capability of RTP 10E-6 bar	Tube (outside Ø 10mm, inside Ø 8mm) Pressure: 0,2 ± 0,1 bar Vacuum pump	Tube fitting (outside Ø 10mm, inside Ø 8mm)
Media #1 PT-seed-layer-solution Coater1:	MSD55 (1 pc.) Motorized Syringe Dispense System Mediapump ?	Media requirements process dependent SINTEF's input required	MSD55 (1 pc.) Motorized Syringe Dispense System (Syringe-size up to 55ml)

Requirement	*Description*	*SINTEF provides*	*SOS provides*
Media #2 PZT-solution-1 Coater1:	MSD55 (1 pc.) Motorized Syringe Dispense System Mediapump ?	-	MSD55 (1 pc.) Motorized Syringe Dispense System (Syringe-size up to 55ml)
Media #3 PZT-solution-2 Coater1:	MSD55 (1 pc.) Motorized Syringe Dispense System Mediapump ?	-	MSD55 (1 pc.) Motorized Syringe Dispense System (Syringe-size up to 55ml)

Requirement	*Description*	*SINTEF provides*	*SOS provides*
Media #4 2-Methoxyethanol-solution Coater1:	MSD55 (1 pc.) Motorized Syringe Dispense System Mediapump ?	-	MSD55 (1 pc.) Motorized Syringe Dispense System (Syringe-size up to 55ml)
Media #5 Solvent	Solvent for puddle nozzle #1 for Coat Module 1	-	5ltr. Stainless steel pressure tank system with low level senor and quick connectors for tubes. Media and Nitrogen each: Tube fitting for PFA tube (outer Ø 6mm, inner Ø 4mm), sensor connection cable
Media #6 EBR (Edge Bead Remover)	Solvent for EBR nozzle #1 for Coat Module 1	-	5ltr. Stainless steel pressure tank system with low level senor and quick connectors for tubes. Media and Nitrogen each: Tube fitting for PFA tube (outer Ø 6mm,

Requirement	***Description***	***SINTEF provides***	***SOS provides***
			inner Ø 4mm), sensor connection cable
Drain	Process bowl drain coater	-	Connection for 5ltr. waste tank, with low level sensor inside the cabinet below the coating chamber
Exhaust #1	Exhaust for process bowl coater	Flexible chemical resistant tube, (inner Ø 110mm), max. flow rate: 100m³/h	Connection piece with manual adjustable throttle valve, outer Ø 110mm
Exhaust #2	Exhaust for hotplates	Flexible chemical resistant tube, (inner Ø 110mm), max. flow rate: 100m³/h	Connection piece with manual adjustable throttle valve, outer Ø 110mm
Exhaust #3	Exhaust for cabinet (electrical + complete)	Flexible chemical resistant tube, (inner Ø 110mm), max. flow rate: 100m³/h	Connection piece with manual adjustable throttle valve, outer Ø 110mm