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DEPARTMENT OF MICROELECTRONICS

CHARACTERIZATION OF DEPOSITION FURNACE SVG VTR-7000

CHARAKTERIZACE DEPOZIČNÍ PECE SVG VTR-7000

BAKALÁŘSKÁ PRÁCE

BACHELOR´S THESIS

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Abstract

This bachelor’s thesis deals with the problem of adjusting of a CVD (chemical vapor deposition) reactor for operations in a given plant. The problem is that precise machines such as a CVD reactor have to be adjusted for function in the place, where they will be operated. This can be done by using statistical tools such as the DOE (design of experiment). There is a range of inputs that can affect the results of the deposition process. From these some will have to be selected as constants and some will become variables in the DOE. The target of this project is to introduce the reader to the topic of CVD, then, from previous DOE done on such machine in the COM1, design an experiment to adjust the machine in CZ4 WFAB for production, evaluate the acquired data and obtain the ideal setting for the reactor.

The reader will be indirectly introduced also to DMAIC process since the DMAIC was used to evaluate the actual experiment in ON Semiconductor, Rožnov pod Radhoštěm, CZ4 WFAB.

1. Introduction

1.1. What is CVD?

Chemical vapor deposition (CVD) is a process in which solid material is deposited from chemical vapors. It is a material of high purity. The process is used also in semiconductor industry. The substrate, typically a wafer, is exposed to one or more precursors which react or decompose on the substrate surface to produce a layer of the deposit. By-products of this reaction are afterward carried away by the gas flow.

1.2. Types of CVD

According to used pressure of the gasses:

- ***Atmospheric pressure CVD (APCVD*****)** done at atmospheric pressures.
- ***Low pressure CVD (LPCVD)*** where better uniformity can be achieved for unwanted gas-phase reactions are reduced.
- ***Ultra high vacuum CVD (UHVCVD)*** processes are done at very low pressures.

By physical characteristics of the vapor:

- ***Aerosol assisted CVD (AACVD*****)** - A CVD process in which the precursors are transported by means of ultrasonically generated aerosol. AACVD is suitable for involatile precursors.
- ***Direct liquid injection CVD (DLICVD)*** - The precursors are in liquid form. It is also possible to use solid dissolved precursors solid dissolved. Liquid solutions then flow to vaporization chambers and then to injectors.

Plasma processing:

- ***Microwave plasma-assisted CVD (MPCVD)***
- ***Plasma-Enhanced CVD (PECVD)*** - CVD processes that use plasma to enhance chemical reaction rates of the precursors. PECVD processing makes deposition at lower temperatures possible.
- ***Remote plasma-enhanced CVD (RPECVD)*** - The wafer substrate is not in the plasma discharge region. Placing the wafer away from the plasma region allows processing temperatures down to room temperature.

1.3. Commonly deposited materials

- ***Polysilicon*** **–** polycrystalline silicon is deposited from silane (SiH_4). The silane used in this process is either pure or in solution with nitrogen or hydrogen. The polysilicon can be doped during the process by dopants such as phosphine (PH_3) and arsine (AsH_3) for N-type layers and boron trichloride (BCL_3) for P-type layers.

  $SiH_4 \rightarrow Si + 2H$

- ***Silicon dioxide (SiO_2)*** **–** also known simply as oxide in the semiconductor industry. Commonly deposited from dichlorosilane ($SiCl_2H_2$) and nitrous oxide (N_2O), or tetraethylorthosilicate (TEOS; $Si(OC_2H_5)_4$). The choice of gas for the reaction depends on the desired parameters of the deposited material.

  $SiCl_2H_2 + 2N_2O \rightarrow SiO_2 + 2N_2 + 2HCl$

  $Si(OC_2H_5)_4 \rightarrow SiO_2 + \text{byproducts}$

- ***Silicone nitride (Si_3N_4)*** **–** usually used as insulator or chemical barrier. According to desired parameters either LPCVD or PECVD process can be used.
  In LPCVD process silane (SiH_4) or dichlorosilane ($SiCl_2H_2$) and ammonia (NH_3) act as precursors.

  $3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12H_2$

  $3SiCl_2H_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2$

  In PECVD process the precursors are silane (SiH_4) and nitrogen (N_2) or ammonia (NH_3).

  $2SiH_4 + N_2 \rightarrow 2SiNH + 3H_2$

  $SiH_4 + NH_3 \rightarrow SiNH + 3H_2$

- ***Borophosphosilicate glass (BPSG)*** - used for passivation. It is a silicate glass containing boron and phosphorus. These materials undergo viscous temperatures around 850 °C. Stability in air can be difficult to achieve.

- ***Metals*** **–** metals such as copper or aluminium are seldom deposed by CVD. However molybdenum, tantalum, titanium, nickel, and tungsten often are.

2. Chemistry

2.1. Main goal

CVD means converting volatile chemicals by certain reactions of precursors into desired solid film. It depends on the availability of such chemicals.
First, let us discuss what makes the vapors (volatility that is). Second, gas phase reactions and reactions on the substrate surface have to be studied. Every CVD process requires a reaction path to convert vapor to solid. Designing and adjusting the reactor also has to consider the problem of where and when the reaction is to take place (on the substrate, not anywhere else.). Undesired reactions can worsen the result since the particles can fall onto the surface of the wafer. The process typically relies on four factors: temperature, time, pressure, and surface specificity.

4.2. Volatility

In order to deposit a layer a volatile precursor is needed. That means a gas or a liquid with modest boiling point.

"Most CVD precursors evaporate in molecular form from a molecular liquid or solid. The change in enthalpy upon evaporation is determined by the forces which hold the molecules together.

- ***Van der Waals force*** (or van der Waals interaction) - the attractive or repulsive force between molecules (or between parts of the same molecule) other than those due to covalent bonds or to the electrostatic interaction of ions with one another or with neutral molecules. Van der Waals forces are relatively weak compared to normal chemical bonds.

- ***Hydrogen bond*** - dipole-dipole force with a hydrogen atom bonded to nitrogen, oxygen or fluorine. The energy of a hydrogen bond (typically 5 to 30 kJ/mole) is comparable to that of weak covalent bonds (155 kJ/mol), and a typical covalent bond is only 20 times stronger than an intermolecular hydrogen bond.

- ***Covalent bond*** - a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms, or between atoms and other covalent bonds.

- ***Ionic bond*** - a type of chemical bond that can often form between metal and non-metal ions (or polyatomic ions such as ammonium) through electrostatic attraction. In short, it is a bond formed by the attraction between two oppositely charged ions."[1]

To form a volatile precursor, a substance has to be found, which forms molecules with minimal van der Waals forces (modest surface area). Also, formation of hydrogen or covalent bonds must be avoided.

2.3. Volatile precursors

- **Silane (SiH_4) –** Silicon-hydrogen compound. In silicon manufacturing, it is the most common precursor. It is a small molecule with small van der Waals attraction. It has a small dipole moment, no hydrogen bonding, covalent bonds are saturated. Highly volatile. Silane is a gas at room temperature even under pressure. Boiling point -112 C.

- **Disilane, Si_2H_6**, Another silicon-hydrogen compound. It is less volatile; its boiling point is -14 C. Can be liquefied under pressure at room temperature.

- **Dichlorosilane**, SiH_2Cl_2 is another common precursor. Chlorine atoms cause this molecule to be less volatile. Usually used for deposition of silicon nitride. Its boiling temperature is 8 C.

- Precursor molecules can be used, in which oxygen-silicon bonds already exist. As an example, TEOS (tetraethyl orthosilicate), $Si(OC_2H_5)_4$, can be mentioned. TEOS has a large surface area. Vapor pressure of TEOS is just around 5 Torr at 25 C. Its boiling point is 160 C.

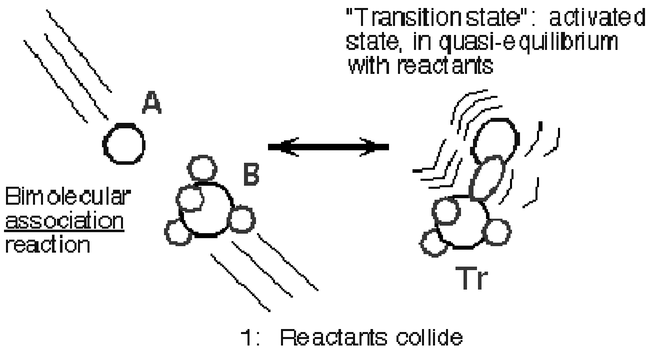
"It is not the mass of the molecule but the intermolecular forces that primarily determine volatility"[2]

2.4. Kinetics, reactions, mechanisms

Reaction has, in most cases, more than one step. Some of them are slower, so these are more dominant in determination of reaction rate. The rate expression (i.e. how the reaction depends on concentration of precursors and products) is, due to this fact, often quite non-obvious and complex.

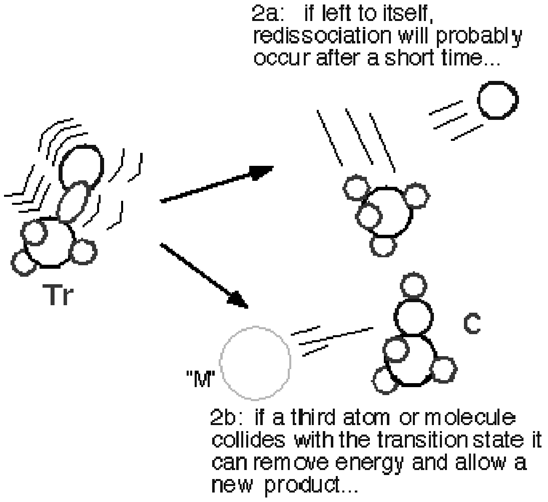
Generally, the mechanism of a chemical reaction can be determined by following all paths of all the atoms during the reaction. It seems, however, much simpler to see the reaction as relatively independent on the path, but taking in mind the passage through the transition stages.

In an association reaction, the molecules can collide in the gas phase, A + B => AB*:



Picture 2.1.: Transition stage

By conserving momentum, much of the kinetic energy is converted into internal energy of the transition state, therefore causing the dissociation of the reactants. This can be solved by a third atom or molecule (denoted usually as M), which will collide with the transition state and extract some energy. This would result in occurring of association: AB* + M => C.



Picture 2.2.: Deactivation by third species

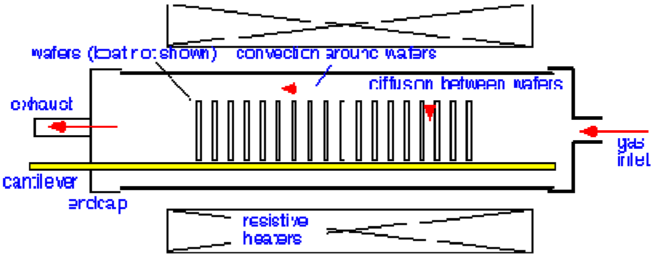
As a result, the association reactions usually depend on the de-activation by some third atom or molecule, therefore growth rate drops at low pressures. When the pressure in the reactor grows, reactions become “pseudo-first-order”, not depending on total pressure any more. The product may also fall down on the substrate surface in a form of powder or dust, thus negatively affecting the result of the CVD process. It can be concluded that APCVD process is, in general, “dustier” than LPCVD process for example.

3. Reactor

3.1. Tube reactor

The concept of vertical and horizontal tube furnaces is widely used in the industry because it makes mass production possible (with batches of up to 100-200 wafers). This concept, originally taken from annealing and oxidation furnaces, is simple and productive. The idea is to stack wafer into one of many slots in a quartz boat.

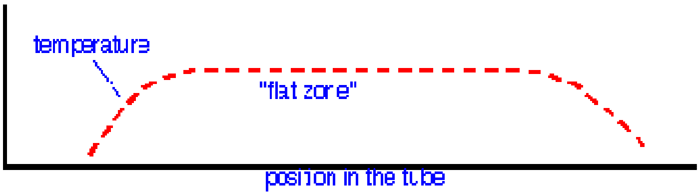
The basic function of a tube CVD reactor is, in a simplified form, shown below. The tube of the reactor is usually made of quartz with a diameter slightly higher than the wafer size so there is a gap between the wafers and the tube wall. . The tube is heated in a resistively heated box. There are typically two or more independent thermal zones in the reactor to enable control of axial temperature in the reactor. The example is of a horizontal configuration, but due to easier automated loading, smaller footprint and lower particle counts, recently, the vertical configuration is more popular. The principles are the same in both horizontal and vertical tube reactors since natural convection plays no role in the LPCVD conditions and temperature gradients are small.



3.1.:Tube reactor - schematic

Usually, wafers are loaded into slots in the quartz boat. The gap between wafers is small to increase the maximal number of wafers in the boat. In horizontal configuration, the boat s supported by a cantilever, thus in older reactors it could also rest on the bottom surface of the tube. The cantilever is simply a rod fixed at one end and it prevents scraping and formation of particles in the tube. The basic principle is that gas is supplied at on end of the tube and the other end acts as the exhaust. Also, other more elaborate arrangements can be used, like using a gas inlet and an extra injector at the other end of the tube. The tube is sealed on both ends by end-caps. These may be water-cooled. Also, dust-tolerant vacuum systems are used. More independent thermal zones are used in the reactor to maintain constant axial temperature and therefore to create the so called flat zone.

The flat zone is the area in a reactor where the wafers re located during the process. It is essential that the temperature in the flat zone must be controllable within better than one degree C. The dimensions of the flat zone directly affect the number of wafers that can be loaded in a single run, i.e. a batch.



3.2.: Flat zone

This type of reactors is so called hot wall reactor which means that everything is at the same temperature. The film is deposited on every exposed surface in the tube, i.e. on the walls, on the boat, cantilever and, most important, wafers.

The film from the tube, boat and cantilever has to be removed periodically to prevent particle formation (dust) and spalling. This cleaning procedure is usually done by etching the quartzware in aggressive acid baths. The wet procedure is costly, lengthy, quite dirty and complex. Large quantities of toxic acids have to be used.

Thermal decomposition of NF3 also known as in situ cleaning has been recenty reported as an alternative procedure. However, this is just the possibility for polysilicon or silicon nitride systems.

3.2. Along the Tube

In this part, the general findings on the topic of tube reactors will be summed up. These observations are the basic building stones in setting the machines.

- **"The tube is radially isothermal**. The thermal diffusion length is much larger than the radius of the tube: thus heat can easily travel by conduction from the walls of the tube to the central region. If the tube walls are held at a constant temperature, the radial temperature will be essentially constant. The axial temperature may vary and is somewhat influenced by convection (diffusion length comparable to the tube length), explaining the desirability of multi-zone heating.
- **Species concentrations are likely to be constant in the annular region**: the mass diffusion length is much larger than the distance between the wafer edge and the tube. Convection will have little influence on species concentration.
- **Gas phase reactions have a few seconds to proceed**: this allows one to choose which precursors can be used in such a system. Chemicals that will react in a few tens of milliseconds at the operating temperature will be consumed within a few cm of the hot zone; reactions that take more than 10 seconds won't contribute to deposition. "[3]

4. Design of Experiment

4.1. Our case

The SVG VTR-7000 deposition furnace is a vertical tube reactor with three thermal zones. This machine is to be characterized for production in CZ4 WFAB and is to produce phosphine doped polysilicon. Prior knowledge was obtained from experience with similar machine in COM1.

The input values for this machine are temperatures in three thermal zones, gas flow of nitrogen, silane and phosphine and pressure in the reactor. The goal is to achieve target value of resistivity and thickness and lowest possible wafer to wafer, site to site and run to run variability.

Since a deposition furnace ha to be adjusted and characterized before production, it is advisable to perform a series of experiments and start production after evaluation.

Also, please note that substance from this point onward referred to as phosphine is actually a mixture of phosphine with nitrogen. The concentration of phosphine is 1%.

4.2. What is DOE?

Design of experiment (DOE) is a statistical method used to determine behavior of outputs based on changes of variables. Measured data usually show differences both between repeated measurements and between replicated items or processes.

Blocking is the arrangement of experimental units into groups (blocks) that are similar to one another (i.e. same inputs, same trend). Blocking reduces known but irrelevant sources of variation. By this, greater precision in estimation can be maintained.

4.3. Prior knowledge

For the design we considered prior results of a similar experiment done in COM1 Phoenix, Arizona to determine the variables and constants for our design.

Experimental setup from COM1, Phoenix, Arizona
Screening Design: 6 Factors, 26-3 Fractional Factorial
Factors

Top PH3 (level = 5, 11, center point = 8)
Continuous
Bottom PH3 (level=5,9, center point=7)
Continuous
Top N2 (level=500, 0, center point =250)
Continuous
Bottom N2 (level=200, 0, center point= 100)
Continuous
Top SiH4 (level=400, 200, center point=300)
Continuous
Bottom SiH4 (level=400, 200, center point=300)
Continuous

Table 4.1.:Screening design - Factors

Response

Dep Rate	Maximize
Dep Rate Uniformity	Minimize
Rs	Match Target
Rs Uniformity	Minimize

Table 4.2.:Screening design - Responses

All flows in sccm
Pressure fixed at 500mTorr
Number of centre points: 2
Number of runs: 8+2

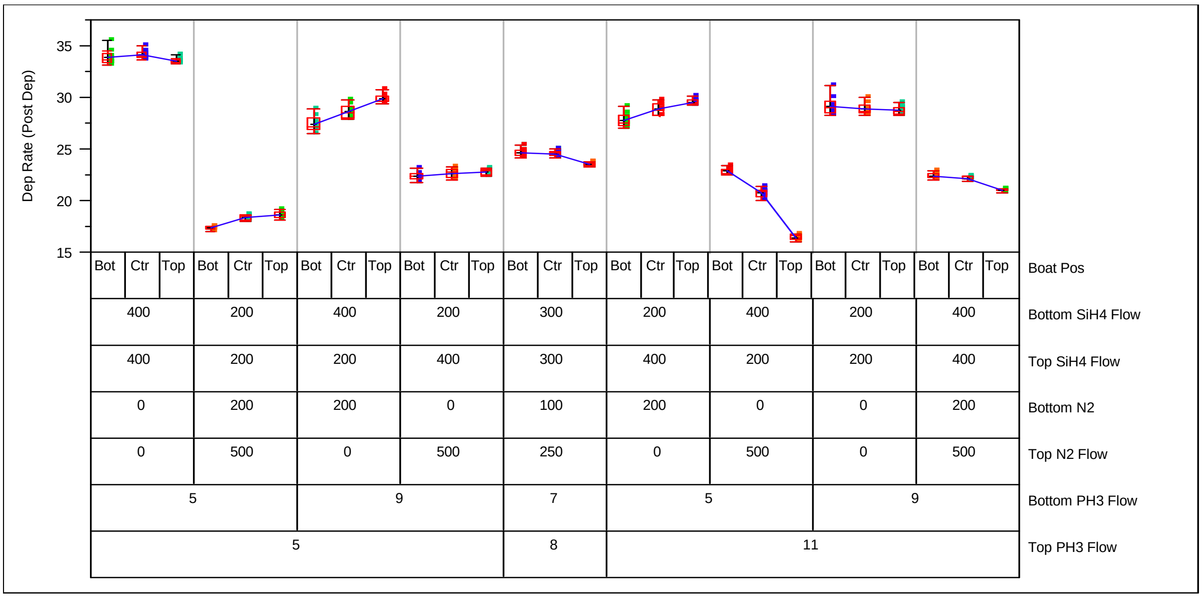


Table 4.2.: COM1 results - effects of variables

Response Mean Dep Rate (Post Deposition)

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept	Biased	24.99602	2.19798	11.37	0.0076
Top PH3 Flow	Biased	-0.152555	0.115611	-1.32	0.3178
Bottom PH3 Flow	Biased	0.0820216	0.173417	0.47	0.6828
Top N2 Flow	Biased	-0.018748	0.001387	-13.51	0.0054
Bottom N2	Biased	-0.010011	0.003468	-2.89	0.1020
Top SiH4 Flow	Biased	0.0142917	0.003468	4.12	0.0542
Bottom SiH4 Flow	Biased	0.0074336	0.003468	2.14	0.1653
(Top PH3 Flow-8)*(Bottom PH3 Flow-7)	Biased	0.0585134	0.057806	1.01	0.4180

Table 4.3.: Mean deposition rate

Response StDev Dep Rate (Post Deposition)

Intercept	Biased	1.0240357	0.753411	1.36	0.3071
Top PH3 Flow	Biased	0.0929279	0.039629	2.34	0.1437
Bottom PH3 Flow	Biased	-0.121945	0.059443	-2.05	0.1767
Top N2 Flow	Biased	0.0005645	0.000476	1.19	0.3571
Bottom N2	Biased	-0.001265	0.001189	-1.06	0.3989
Top SiH4 Flow	Biased	-0.003437	0.001189	-2.89	0.1017
Bottom SiH4 Flow	Biased	0.0032878	0.001189	2.77	0.1097
(Top PH3 Flow-8)*(Bottom PH3 Flow-7)	Biased	-0.057843	0.019814	-2.92	0.1000

Table 4.4.: Standard deviation of deposition rate

Response Mean Rs

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept	Biased	68.288122	10.94535	6.24	0.0247
Top PH3 Flow	Biased	-2.254707	0.575712	-3.92	0.0594
Bottom PH3 Flow	Biased	-3.40831	0.863568	-3.95	0.0586
Top N2 Flow	Biased	0.0321806	0.006909	4.66	0.0431
Bottom N2	Biased	0.0028801	0.017271	0.17	0.8829
Top SiH4 Flow	Biased	0.0050421	0.017271	0.29	0.7978
Bottom SiH4 Flow	Biased	0.0038412	0.017271	0.22	0.8446
(Top PH3 Flow-8)*(Bottom PH3 Flow-7)	Biased	0.5278627	0.287856	1.83	0.2081

Table 4.5.: Mean sheet resistivity

Response Std Dev Rs

Intercept	Biased	6.9640615	4.236627	1.64	0.2419
Top PH3 Flow	Biased	-0.411009	0.222842	-1.84	0.2064
Bottom PH3 Flow	Biased	-0.220439	0.334262	-0.66	0.5774
Top N2 Flow	Biased	0.0069406	0.002674	2.60	0.1219
Bottom N2	Biased	-0.012265	0.006685	-1.83	0.2080
Top SiH4 Flow	Biased	0.0068735	0.006685	1.03	0.4120
Bottom SiH4 Flow	Biased	-0.004145	0.006685	-0.62	0.5985
(Top PH3 Flow-8)*(Bottom PH3 Flow-7)	Biased	-0.09088	0.111421	-0.82	0.5004

Table 4.6.: Sheet resistivity standard deviation

Results for Second Order Model

1. The Top N2 Flow has the most significant impact on the Thickness after Deposition and Deposition Rate.
2. All other parameters were insignificant in the model. The second order model has insufficient degrees of freedom to resolve higher order effects.
3. A first order model would have to be analyzed to determine the significance and relative importance for the model parameters.

Output	Significant effect	Not significant
Sheet resistance, Rs	**Top PH3 Flow, most important** **Bottom PH3 Flow, most important** Top N2 Flow	Top SiH4 Flow Bottom SiH4 Flow Bottom N2 Flow
Stdev Rs	**Top N2 Flow, most important** **Top PH3 Flow, most important** Bottom N2 Flow	Top SiH4 Flow Bottom SiH4 Flow Bottom PH3 Flow
Thickness, deposition rate	**Top N2 Flow, most important** Bottom N2 Flow Top SiH4 Flow	Top PH3 Flow Bottom PH3 Flow Bottom SiH4 Flow
Stdev deposition rate	N/A	N/A

Table 4.7.: Effects - summary

Confirmation runs were completed and the final setting was determined from the experiment.

Result – COM1 DOE

Top PH3 Flow: 12 sccm
Bottom PH3 Flow: 12 sccm
Top N2 Flow: 200 sccm
Bottom N2 Flow: 200 sccm
Top SiH4 Flow: 400 sccm
Bottom SiH4 Flow: 400 sccm
Pressure: 500 mTorr

5. Our experiment design

For the DOE:

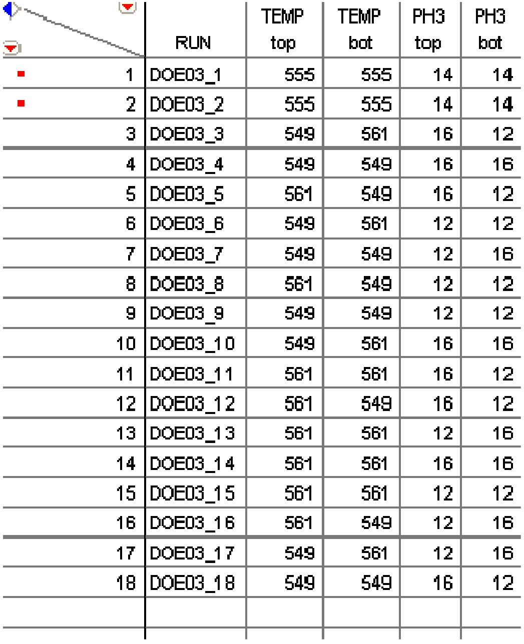
- N2 top and bottom flows fixed at 200sccm
- SiH4 top and bottom flows fixed at 400sccm
- Z1 and Z3 temperatures change
- Z2 temperature set to 555°C
- PH3 top and bottom flows change

Since five-zone furnace was used in COM1 and CZ4 uses a three-zone furnace, it is necessary to experiment also with the temperatures. Both phosphine flows have centre point at the COM1 final setting of phosphine flow. DOE variable selection is also determined by prior experience with the process and with elaborating such experiments.

JMP statistical software is used in this analysis.

Process target
THK = ± 10 nm
RES = ± 8 ohm/sq

Plan
Output parameters
THK target 180nm
RES target 80ohm/sq
stdev27 i.e. in lot minimal
FURNACE (thk1 - thk3), (res1-res3) in lot = 0



	RUN	TEMP top	TEMP bot	PH3 top	PH3 bot
■ 1	DOE03_1	555	555	14	14
■ 2	DOE03_2	555	555	14	14
3	DOE03_3	549	561	16	12
4	DOE03_4	549	549	16	16
5	DOE03_5	561	549	16	12
6	DOE03_6	549	561	12	12
7	DOE03_7	549	549	12	16
8	DOE03_8	561	549	12	12
9	DOE03_9	549	549	12	12
10	DOE03_10	549	561	16	16
11	DOE03_11	561	561	16	12
12	DOE03_12	561	549	16	12
13	DOE03_13	561	561	12	16
14	DOE03_14	561	561	16	16
15	DOE03_15	561	561	12	12
16	DOE03_16	561	549	12	16
17	DOE03_17	549	561	12	16
18	DOE03_18	549	549	16	12

Picture 4.8.: DOE Variables – experimental run settings

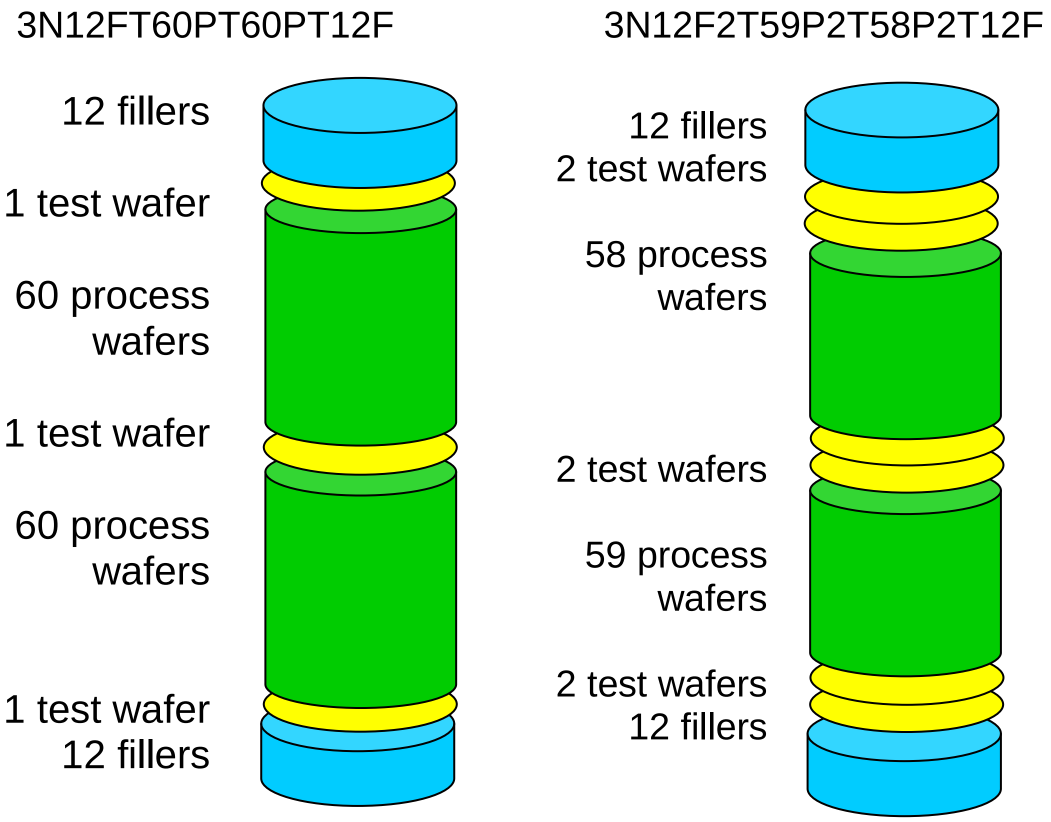
The DOE constants:
N2 top = 200sccm
N2 bottom = 200sccm
SiH4 top = 400sccm
SiH4 bottom = 400sccm
Z2 temp = 555°C
p=500mTorr

5.1. Loading pattern

These loading patters show how test wafers, filler wafers (dummy wafers) and process wafers were loaded onto the boat during the test. Since there are three thermal zones in the tube (it is possible to “tilt” temperature by setting top and bottom temperatures) it is convenient to use three measurement places (three test wafers) to determine the temperature tilt in the reactor.

For some of the following calculations the difference between two wafers from the same run and practically same place will be necessary. Therefore four runs of the DOE use the second loading pattern with two test wafers in each position. Position of wafer can also act as another variable.

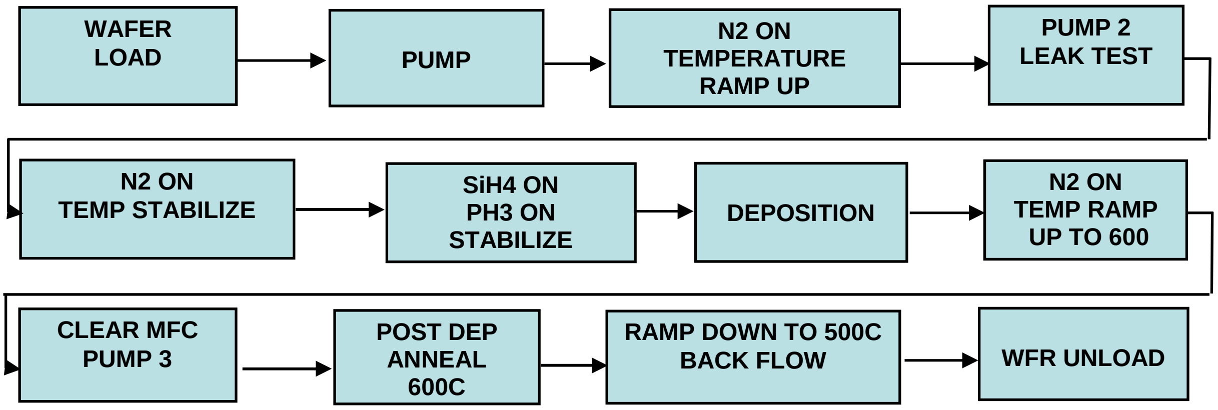
Loading is done by the operator.



Picture 5.1..: Loading patterns

5.2. Process map

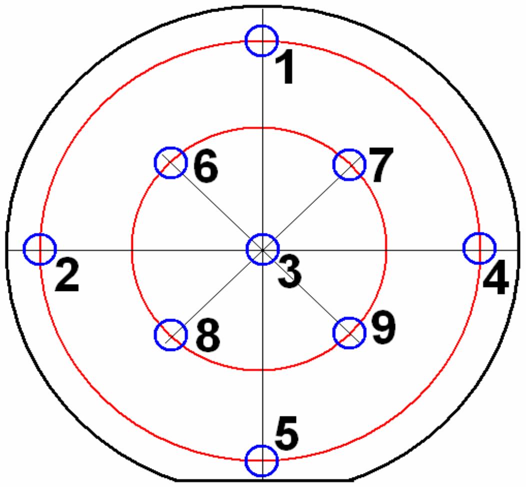
It is advisable to include a process map into the set of data for DOE evaluation. In case of CVD furnace there is a possibility of damaging the wafer by temperature. From the process map the experimenter can for example clearly see that the set temperature is not the highest temperature the wafer undergoes in the process. The highest temperature in case of this process is 600C during the post deposition annealing.



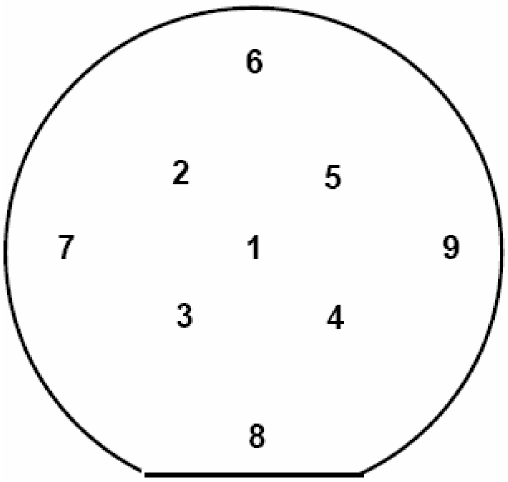
Picture 5.2..: Process map of Poly-Si phosphine doped deposition

5.3. Measurement

The measurement of thickness and resistivity of wafers is done on two machines separately.



Picture 5.3..: UV-1050 measurement pattern



Picture 5.4.: VP-10 measurement pattern

Thickness measurement is executed on Prometrix UV-1050 measurement equipment.

Based on proprietary advanced reflective optics, the UV-1050 system's broadband UV technology provides measurements on a wide range of applications including oxide on polysilicon, ultraviolet (UV) reflectivity, etch-to-clear, and simultaneous oxide and TiN thickness for CMP applications.

Resistivity measurement is executed on Prometrix VP-10. Prometrix VP-10 Versa Probe is an automated four-point probe. Measures doped films, metal films, and other conductive layers.

It is also advisable to include measurement patterns to see clearly that in our case the data from UV-1050 do not copy data from VP-10 in numbering, i.e. one machine measures in different order than the other.

5.4. Output variables

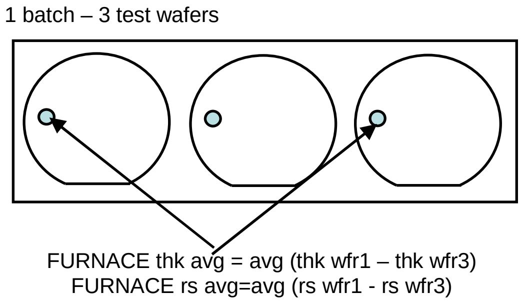
It is clear that the main output variables are thickness and resistivity. Also uniformity of the film is an issue. Uniformity describes the “flatness” of the wafer surface.

Due to character of the process it is necessary to introduce also other output variables to describe not only the target values but also the distribution of values in the furnace and differences between runs.

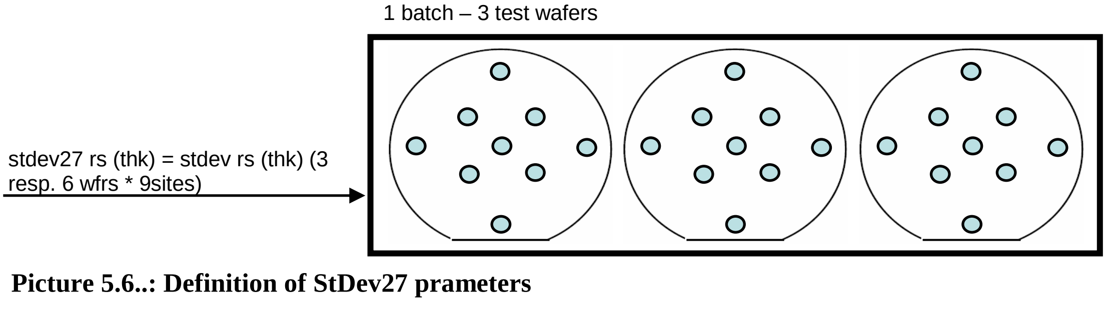
5.5. Run to run

FURNACE thk avg and FURNACE rs avg are introduced to compare results throughout runs. FURNACE parameter shows the average difference of thickness and resistivity on sites of wafers from the top and bottom thermal zone. It is a parameter defined as average of differences between sites in the top thermal zone and bottom thermal zone. These parameters make comparison concerning thermal tilt of the furnace possible as well as impact of thermal tilt on target values and overall performance of the process.

Stdev27 thk and stdev27 rs enable comparison of runs regarding standard deviation. This is done to determine the uniformity of the film. The parameter is defined as standard deviation of all measured sites in the run, i.e. twenty-seven in case of three test wafers and fifty-four in case of six test wafers in run.



Picture 5.5.: Definition of FURNACE parameters

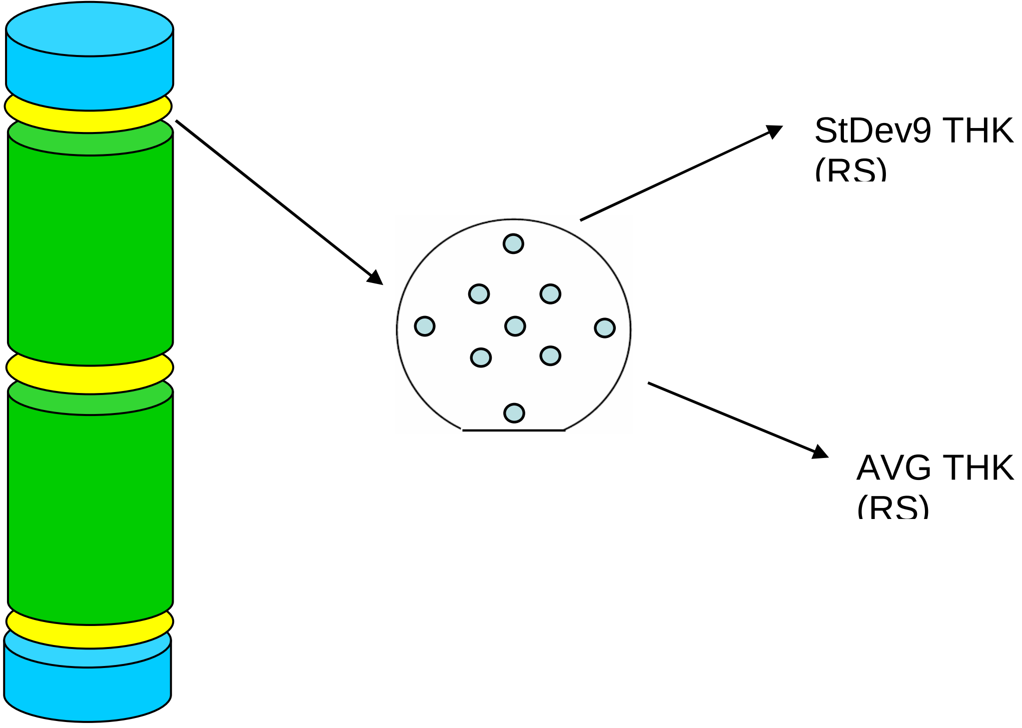


Picture 5.6..: Definition of StDev27 prameters

5.6. *Wafer to wafer*

Four variables are introduced in the wafer to wafer part. These are standard deviation of thickness and resistivity in nine sites on one test wafer (StDev9 THK and StDev9 RS) and average thickness and resistivity of nine sites on one test wafer (AVG THK and AVG RS).

These variables specify to greater depth uniformity characteristics and achieving the target values. In run to run calculations the comparison of runs is done. In the wafer to wafer calculations, the wafers of one run are compared.

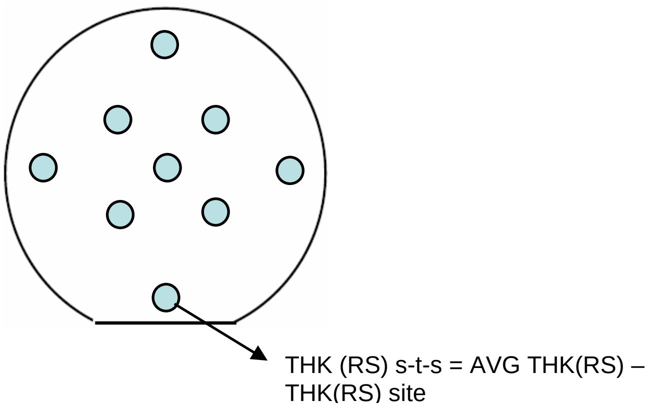


Picture 5.7.: Definition of StDev9 and AVG parameters

4.7. *Site to site*

Site to site calculations give out the outputs denominated THK s-t-s and RS s-t-s. These two parameters further deepen findings of uniformity of the layer. Nine values are acquired from each test wafer as difference between the average value of wafer and the specific value in given site.

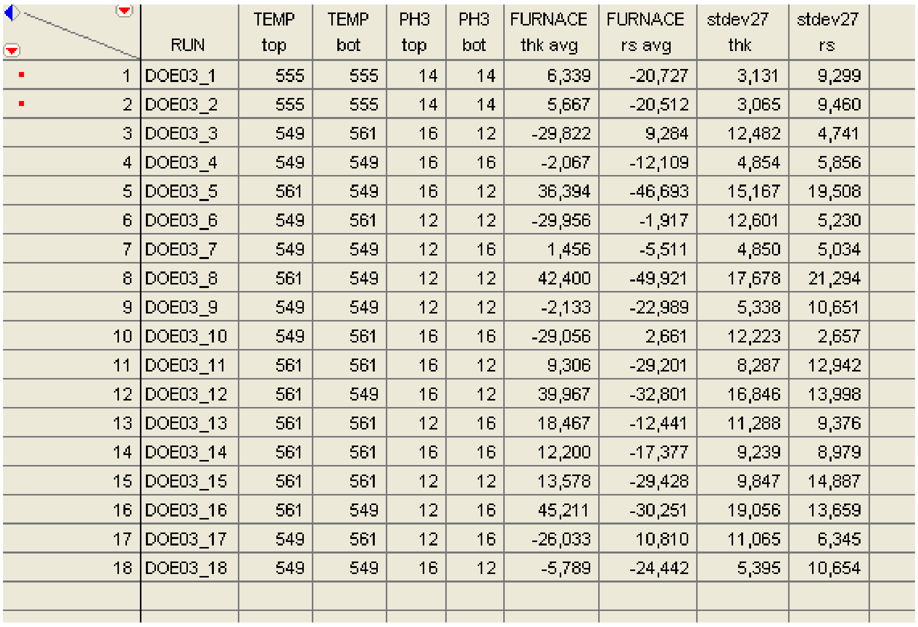
From evaluation of s-t-s results it can be determined that the process settings do or do not affect the uniformity (i.e. the process is on this level dependent on settings or the process at this level is determined by physical characteristics of the reactor for example).



Picture 5.8.: Definition of s-t-s parameters

6. Evaluation

6.1. Evaluation – run to run



	RUN	TEMP top	TEMP bot	PH3 top	PH3 bot	FURNACE thk avg	FURNACE rs avg	stdev27 thk	stdev27 rs
1	DOE03_1	555	555	14	14	6,339	-20,727	3,131	9,299
2	DOE03_2	555	555	14	14	5,667	-20,512	3,065	9,460
3	DOE03_3	549	561	16	12	-29,822	9,284	12,482	4,741
4	DOE03_4	549	549	16	16	-2,067	-12,109	4,854	5,856
5	DOE03_5	561	549	16	12	36,394	-46,693	15,167	19,508
6	DOE03_6	549	561	12	12	-29,956	-1,917	12,601	5,230
7	DOE03_7	549	549	12	16	1,456	-5,511	4,850	5,034
8	DOE03_8	561	549	12	12	42,400	-49,921	17,678	21,294
9	DOE03_9	549	549	12	12	-2,133	-22,989	5,338	10,651
10	DOE03_10	549	561	16	16	-29,056	2,661	12,223	2,657
11	DOE03_11	561	561	16	12	9,306	-29,201	8,287	12,942
12	DOE03_12	561	549	16	12	39,967	-32,801	16,846	13,998
13	DOE03_13	561	561	12	16	18,467	-12,441	11,288	9,376
14	DOE03_14	561	561	16	16	12,200	-17,377	9,239	8,979
15	DOE03_15	561	561	12	12	13,578	-29,428	9,847	14,887
16	DOE03_16	561	549	12	16	45,211	-30,251	19,056	13,659
17	DOE03_17	549	561	12	16	-26,033	10,810	11,065	6,345
18	DOE03_18	549	549	16	12	-5,789	-24,442	5,395	10,654

Picture 6.1.: Run to run – data set

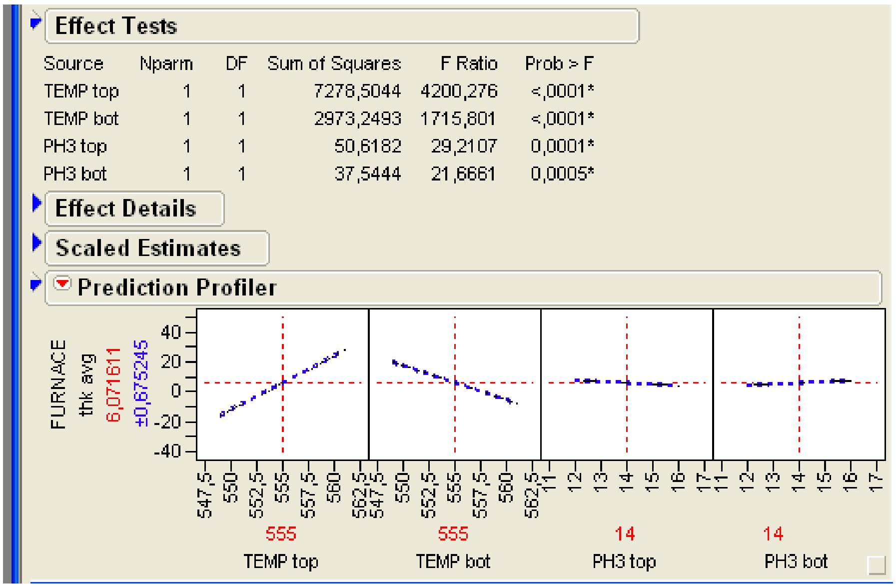
Output parameter = FURNACE thk avg

Hypothesis:

The THK profile along the furnace can be set only using TEMP (top & bot), without significant effect of PH3 (top, bot). This is because the deposition rate is dependent on temperature and concentration of precursors, but silane flow is fixed and phosphine flow and phosphorus deposition plays a minor role due to relatively low volume of deposited phosphorus.

FURNACE thk avg

Interactions are not significant. According to the analysis of model without interactions temperatures TEMP top and TEMP bot are significant factors while in this case PH3 top and bot are less significant.



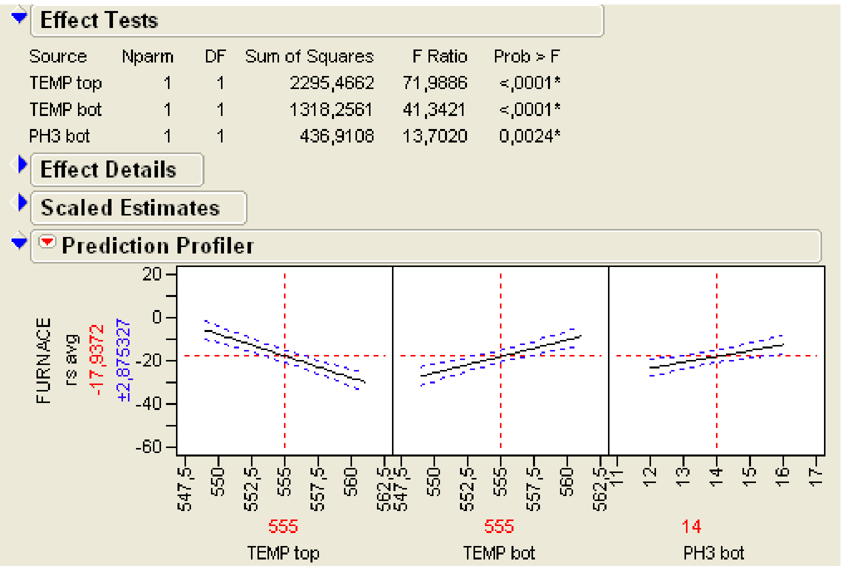
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
TEMP top	1	1	7278,5044	4200,276	<,0001*
TEMP bot	1	1	2973,2493	1715,801	<,0001*
PH3 top	1	1	50,6182	29,2107	0,0001*
PH3 bot	1	1	37,5444	21,6661	0,0005*

Picture 6.2.:FURNACE thk avg without interactions

Conclusion:

FURNACE thk avg can be set only by TEMP and is not significantly dependent on the PH3 setting (the thk profile is not dependent on the PH3 top and PH3 bot setting).

Output parameter = FURNACE rs avg



Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
TEMP top	1	1	2295,4662	71,9886	<,0001*
TEMP bot	1	1	1318,2561	41,3421	<,0001*
PH3 bot	1	1	436,9108	13,7020	0,0024*

Picture 6.3.:FURNACE rs avg - Temp top, Temp bot and PH3bot

Hypothesis:

Interactions are not significant. Resistivity is determined by phosphine flow and temperature. Temperatures determine deposition rate. Phosphine flow affects concentration of phosphorus in the film.

Conclusion:

According to the analysis of model without interactions temperatures TEMP top and TEMP bot are significant factors while in this case PH3 bot is less significant.

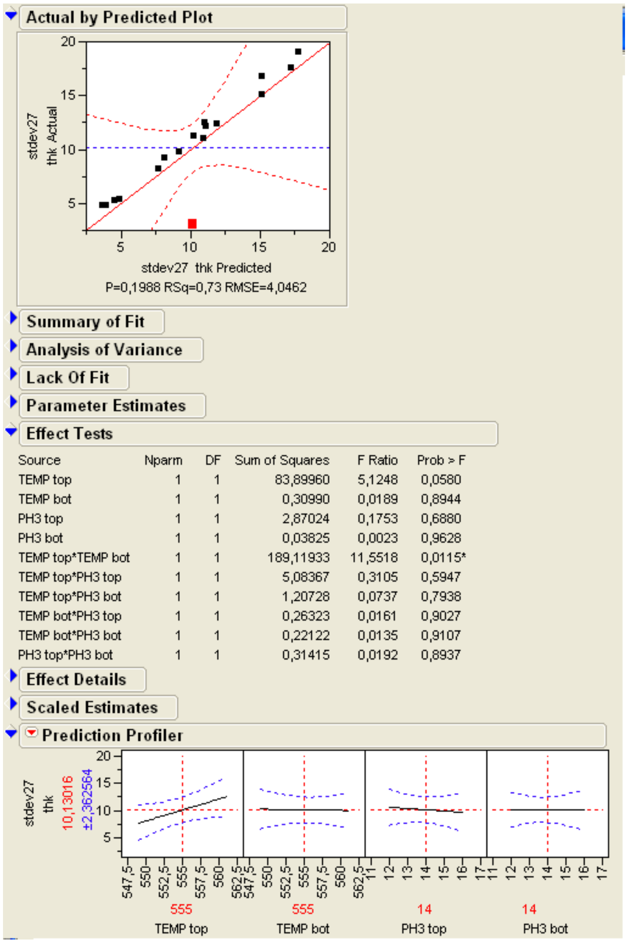
PH3 also affects growth rate and mainly phosphorus concentration in the deposited layer. The reason why only bottom phosphine flow is affecting the parameter is probably the physical characteristic of the tube and the gas inlets (one inlet is through injector and one by the flange).

Output parameter = STDEV27 THK

Hypothesis:

Standard deviation of THK in batch is not affected by values of set parameters (constant and smallest possible).

According to the STDEV27 thk model, interactions *TEMP bot*PH3 top*, *TEMP bot*PH3 bot a PH3 bot*PH3top* and factors *TEMP bot* a PH3 bot are not significant. Further, from the STDEV27 thk analysis, it can be seen, that the center point (marked red) is different from the predicted values and widens the confidence interval. This points to non-linearity of the model.



Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
TEMP top	1	1	83,89960	5,1248	0,0580
TEMP bot	1	1	0,30990	0,0189	0,8944
PH3 top	1	1	2,87024	0,1753	0,6880
PH3 bot	1	1	0,03825	0,0023	0,9628
TEMP top*TEMP bot	1	1	189,11933	11,5518	0,0115*
TEMP top*PH3 top	1	1	5,08367	0,3105	0,5947
TEMP top*PH3 bot	1	1	1,20728	0,0737	0,7938
TEMP bot*PH3 top	1	1	0,26323	0,0161	0,9027
TEMP bot*PH3 bot	1	1	0,22122	0,0135	0,9107
PH3 top*PH3 bot	1	1	0,31415	0,0192	0,8937

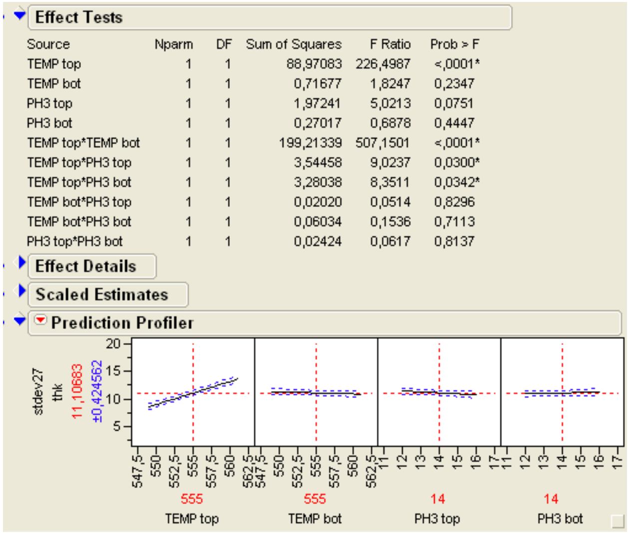
Picture 6.4.: StDev27 thk with interactions and center point

Test model without interactions and non-significant factors. Exclude center point.

After exclusion of non-significant factors and interactions and center point it is obvious, that the value of stdev27 THK is most dependent on value of TEMP top. Values of TEMP bot and PH3 bot are set as constants in the profiler.

Conclusion:

a) Model is non-linear
b) TEMP top has a significant effect on the THK variability in batch (lowest setting of TEMP top preferred)



Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
TEMP top	1	1	88,97083	226,4987	<,0001*
TEMP bot	1	1	0,71677	1,8247	0,2347
PH3 top	1	1	1,97241	5,0213	0,0751
PH3 bot	1	1	0,27017	0,6878	0,4447
TEMP top*TEMP bot	1	1	199,21339	507,1501	<,0001*
TEMP top*PH3 top	1	1	3,54458	9,0237	0,0300*
TEMP top*PH3 bot	1	1	3,28038	8,3511	0,0342*
TEMP bot*PH3 top	1	1	0,02020	0,0514	0,8296
TEMP bot*PH3 bot	1	1	0,06034	0,1536	0,7113
PH3 top*PH3 bot	1	1	0,02424	0,0617	0,8137

Picture 6.5.: StDev27 thk without center point – narrower confidence intervls

Output parameter = STDEV27 rs

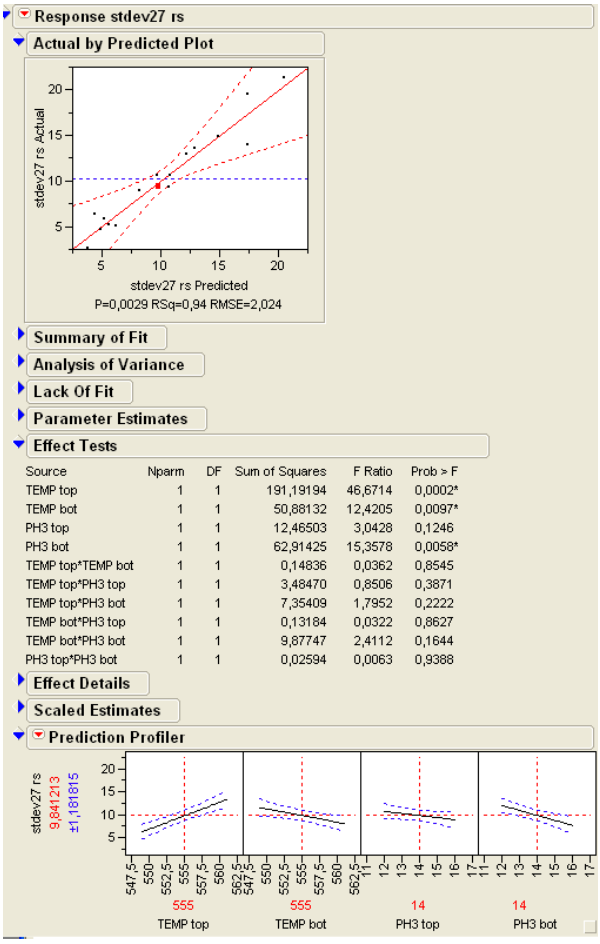
Hypothesis:

Standard deviation of RS in batch is not affected by values of set parameters (constant and smallest possible).

Interactions are not significant. Also the PH3 factor seemed not significant. Full model with center point is easy to evaluate.

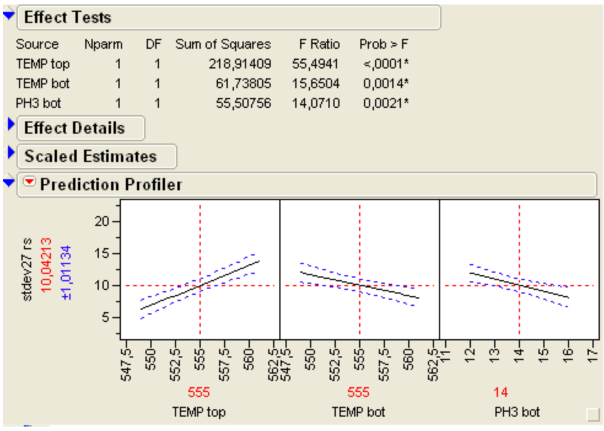
Conclusion:

According to the reduced model, the remaining factors are approximately equally significant. TEMP top has a significant effect on the Rs variability in batch (lowest possible TEMP top preferred).



Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
TEMP top	1	1	191,19194	46,6714	0,0002*
TEMP bot	1	1	50,88132	12,4205	0,0097*
PH3 top	1	1	12,46503	3,0428	0,1246
PH3 bot	1	1	62,91425	15,3578	0,0058*
TEMP top*TEMP bot	1	1	0,14836	0,0362	0,8545
TEMP top*PH3 top	1	1	3,48470	0,8506	0,3871
TEMP top*PH3 bot	1	1	7,35409	1,7952	0,2222
TEMP bot*PH3 top	1	1	0,13184	0,0322	0,8627
TEMP bot*PH3 bot	1	1	9,87747	2,4112	0,1644
PH3 top*PH3 bot	1	1	0,02594	0,0063	0,9388

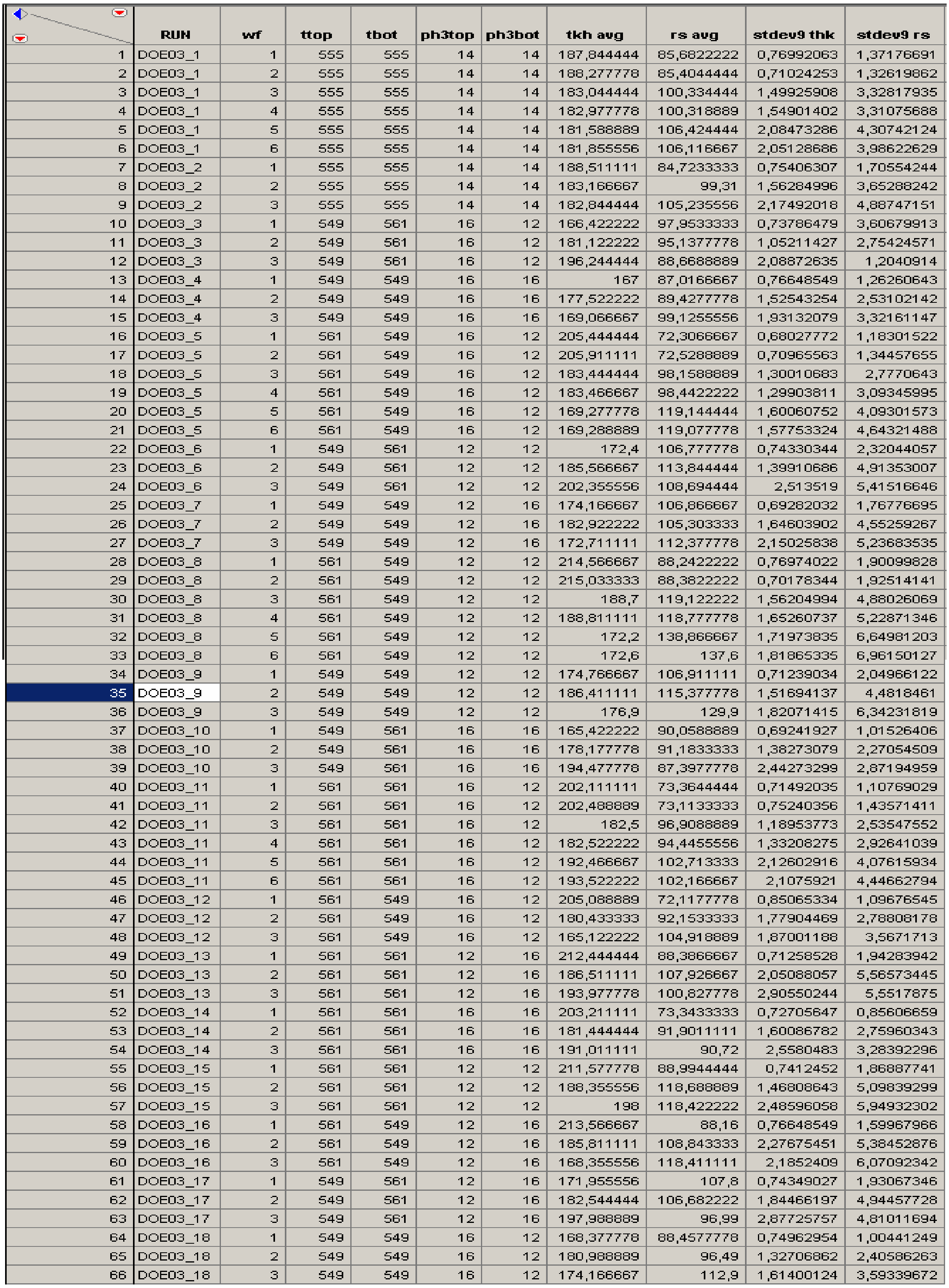
Picture 6.6.: StDev27 rs with interactions



Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
TEMP top	1	1	218,91409	55,4941	<,0001*
TEMP bot	1	1	61,73805	15,6504	0,0014*
PH3 bot	1	1	55,50756	14,0710	0,0021*

Picture 6.7.: StDev27 rs – Temp top, temp bot and PH3 bot factors only

6.2. Evaluation – wafer to wafer



	RUN	wf	ttop	tbot	ph3top	ph3bot	tkh avg	rs avg	stdev9 thk	stdev9 rs
1	DOE03_1	1	555	555	14	14	187,844444	85,6822222	0,76992063	1,37176691
2	DOE03_1	2	555	555	14	14	188,277778	85,4044444	0,71024253	1,32619862
3	DOE03_1	3	555	555	14	14	183,044444	100,334444	1,49925908	3,32817935
4	DOE03_1	4	555	555	14	14	182,977778	100,318889	1,54901402	3,31075688
5	DOE03_1	5	555	555	14	14	181,588889	106,424444	2,08473286	4,30742124
6	DOE03_1	6	555	555	14	14	181,855556	106,116667	2,05128686	3,98622629
7	DOE03_2	1	555	555	14	14	188,511111	84,7233333	0,75406307	1,70554244
8	DOE03_2	2	555	555	14	14	183,166667	99,31	1,56284996	3,65288242
9	DOE03_2	3	555	555	14	14	182,844444	105,235556	2,17492018	4,88747151
10	DOE03_3	1	549	561	16	12	166,422222	97,9533333	0,73786479	3,60679913
11	DOE03_3	2	549	561	16	12	181,122222	95,1377778	1,05211427	2,75424571
12	DOE03_3	3	549	561	16	12	196,244444	88,6688889	2,08872635	1,2040914
13	DOE03_4	1	549	549	16	16	167	87,0166667	0,76648549	1,26260643
14	DOE03_4	2	549	549	16	16	177,522222	89,4277778	1,52543254	2,53102142
15	DOE03_4	3	549	549	16	16	169,066667	99,1255556	1,93132079	3,32161147
16	DOE03_5	1	561	549	16	12	205,444444	72,3066667	0,68027772	1,18301522
17	DOE03_5	2	561	549	16	12	205,911111	72,5288889	0,70965563	1,34457655
18	DOE03_5	3	561	549	16	12	183,444444	98,1588889	1,30010683	2,7770643
19	DOE03_5	4	561	549	16	12	183,466667	98,4422222	1,29903811	3,09345995
20	DOE03_5	5	561	549	16	12	169,277778	119,144444	1,60060752	4,09301573
21	DOE03_5	6	561	549	16	12	169,288889	119,077778	1,57753324	4,64321488
22	DOE03_6	1	549	561	12	12	172,4	106,777778	0,74330344	2,32044057
23	DOE03_6	2	549	561	12	12	185,566667	113,844444	1,39910686	4,91353007
24	DOE03_6	3	549	561	12	12	202,355556	108,694444	2,513519	5,41516646
25	DOE03_7	1	549	549	12	16	174,166667	106,866667	0,69282032	1,76776695
26	DOE03_7	2	549	549	12	16	182,922222	105,303333	1,64603902	4,55259267
27	DOE03_7	3	549	549	12	16	172,711111	112,377778	2,15025838	5,23683535
28	DOE03_8	1	561	549	12	12	214,566667	88,2422222	0,76974022	1,90099828
29	DOE03_8	2	561	549	12	12	215,033333	88,3822222	0,70178344	1,92514141
30	DOE03_8	3	561	549	12	12	188,7	119,122222	1,56204994	4,88026069
31	DOE03_8	4	561	549	12	12	188,811111	118,777778	1,65260737	5,22871346
32	DOE03_8	5	561	549	12	12	172,2	138,866667	1,71973835	6,64981203
33	DOE03_8	6	561	549	12	12	172,6	137,6	1,81865335	6,96150127
34	DOE03_9	1	549	549	12	12	174,766667	106,911111	0,71239034	2,04966122
35	DOE03_9	2	549	549	12	12	186,411111	115,377778	1,51694137	4,4818461
36	DOE03_9	3	549	549	12	12	176,9	129,9	1,82071415	6,34231819
37	DOE03_10	1	549	561	16	16	165,422222	90,0588889	0,69241927	1,01526406
38	DOE03_10	2	549	561	16	16	178,177778	91,1833333	1,38273079	2,27054509
39	DOE03_10	3	549	561	16	16	194,477778	87,3977778	2,44273299	2,87194959
40	DOE03_11	1	561	561	16	12	202,111111	73,3644444	0,71492035	1,10769029
41	DOE03_11	2	561	561	16	12	202,488889	73,1133333	0,75240356	1,43571411
42	DOE03_11	3	561	561	16	12	182,5	96,9088889	1,18953773	2,53547552
43	DOE03_11	4	561	561	16	12	182,522222	94,4455556	1,33208275	2,92641039
44	DOE03_11	5	561	561	16	12	192,466667	102,713333	2,12602916	4,07615934
45	DOE03_11	6	561	561	16	12	193,522222	102,166667	2,1075921	4,44662794
46	DOE03_12	1	561	549	16	12	205,088889	72,1177778	0,85065334	1,09676545
47	DOE03_12	2	561	549	16	12	180,433333	92,1533333	1,77904469	2,78808178
48	DOE03_12	3	561	549	16	12	165,122222	104,918889	1,87001188	3,5671713
49	DOE03_13	1	561	561	12	16	212,444444	88,3866667	0,71258528	1,94283942
50	DOE03_13	2	561	561	12	16	186,511111	107,926667	2,05088057	5,56573445
51	DOE03_13	3	561	561	12	16	193,977778	100,827778	2,90550244	5,5517875
52	DOE03_14	1	561	561	16	16	203,211111	73,3433333	0,72705647	0,85606659
53	DOE03_14	2	561	561	16	16	181,444444	91,9011111	1,60086782	2,75960343
54	DOE03_14	3	561	561	16	16	191,011111	90,72	2,5580483	3,28392296
55	DOE03_15	1	561	561	12	12	211,577778	88,9944444	0,7412452	1,86887741
56	DOE03_15	2	561	561	12	12	188,355556	118,688889	1,46808643	5,09839299
57	DOE03_15	3	561	561	12	12	198	118,422222	2,48596058	5,94932302
58	DOE03_16	1	561	549	12	16	213,566667	88,16	0,76648549	1,59967966
59	DOE03_16	2	561	549	12	16	185,811111	108,843333	2,27675451	5,38452876
60	DOE03_16	3	561	549	12	16	168,355556	118,411111	2,1852409	6,07092342
61	DOE03_17	1	549	561	12	16	171,955556	107,8	0,74349027	1,93067346
62	DOE03_17	2	549	561	12	16	182,544444	106,682222	1,84466197	4,94457728
63	DOE03_17	3	549	561	12	16	197,988889	96,99	2,87725757	4,81011694
64	DOE03_18	1	549	549	16	12	168,377778	88,4577778	0,74962954	1,00441249
65	DOE03_18	2	549	549	16	12	180,988889	96,49	1,32706862	2,40586263
66	DOE03_18	3	549	549	16	12	174,166667	112,9	1,61400124	3,59339672

Picture 6.8.: Wafer to wafer evaluation data set

Output parameter = thk avg

Hypothesis:

Interactions are not significant. Temperature affects the deposition rate the most.

Most significant factors are TEMP top and TEMP bot. PH3 top is less significant.

Conclusion:

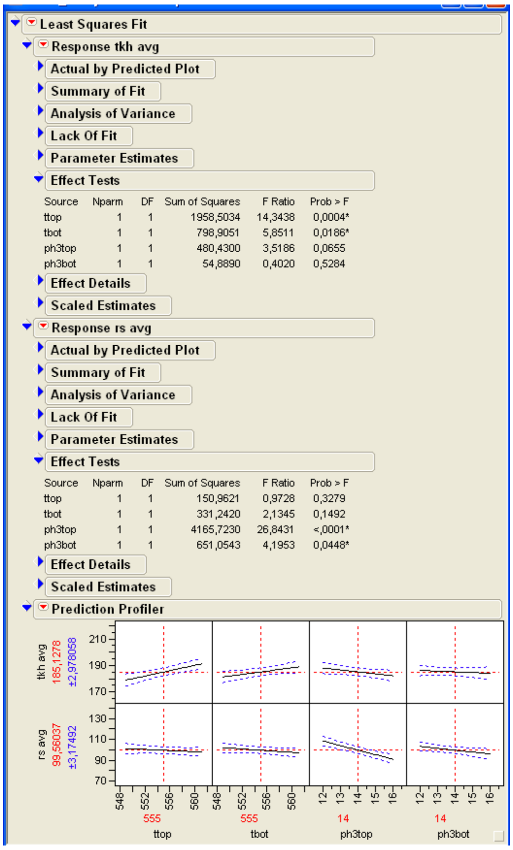
THK is mostly affected by temperature. The PH3 top flow affects growth rate less than temperature. PH3 top flow affects the thk avg due to physical characteristics of the tube.

Output parameter = rs avg

Hypothesis:

Interactions are not significant.
PH3 top and bot are most significant.

PH3 top is the most significant factor. PH3 bot is less significant.



```
Response tkh avg
Effect Tests
Source    Nparm   DF   Sum of Squares    F Ratio    Prob > F
ttop          1    1        1958,5034    14,3438     0,0004*
tbot          1    1         798,9051     5,8511     0,0186*
ph3top        1    1         480,4300     3,5186     0,0655
ph3bot        1    1          54,8890     0,4020     0,5284

Response rs avg
Effect Tests
Source    Nparm   DF   Sum of Squares    F Ratio    Prob > F
ttop          1    1         150,9621     0,9728     0,3279
tbot          1    1         331,2420     2,1345     0,1492
ph3top        1    1        4165,7230    26,8431     <,0001*
ph3bot        1    1         651,0543     4,1953     0,0448*
```

Picture 6.9.:Thk and rs avg-no interactions

Conclusion:

PH3 top flow affects Rs the most. Again, like in thk avg, this is due to characteristics of reactor tube (top phosphine inlet – injector, bottom by flange).

6.3. Evaluation – site to site

Hypothesis:

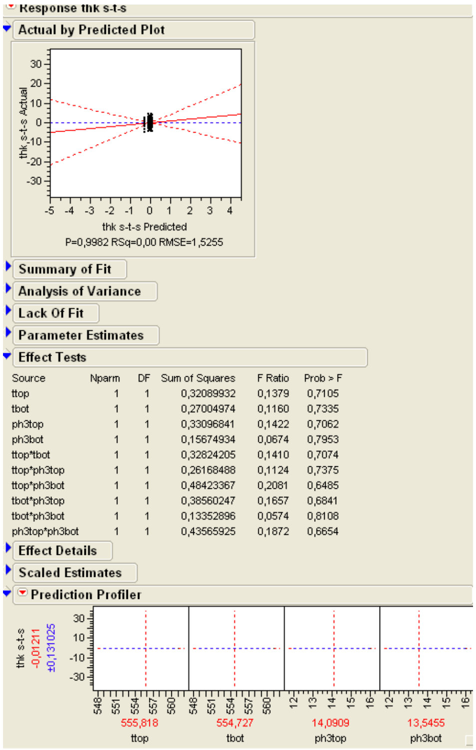
Interactions are not significant.
None of the factors is significant.

All factors have approximately same low significance.

Conclusion:

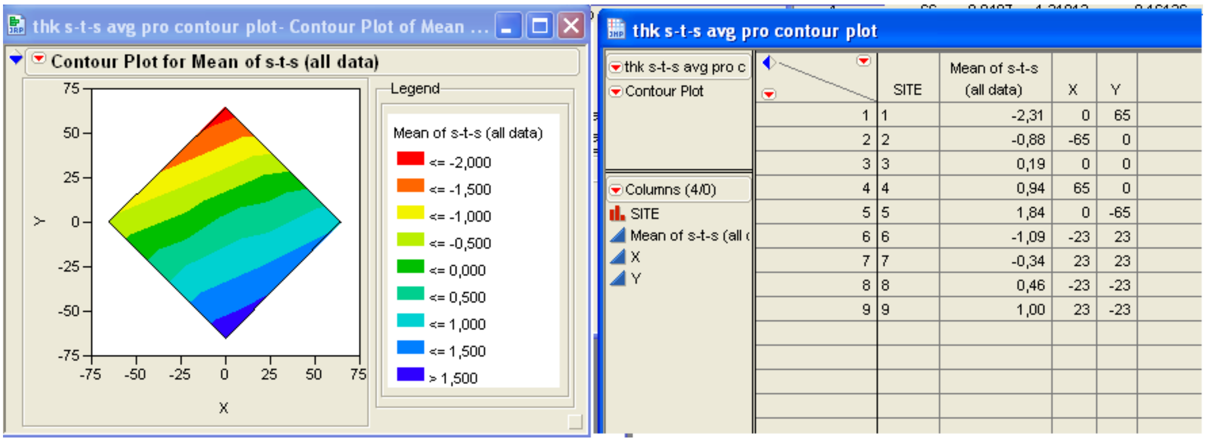
Profile across the wafer is not affected by factors. It is affected by the character of reactor. Since the profile of values across the wafer is not affected by the input variables (as seen in Prediction profiler) it is possible to determine the approximate character of the wafer surface.

As seen on the picture below a table was created binding together the location of site on wafer (x and y axis) and mean of site to site measurement.



```
Effect Tests
Source          Nparm   DF   Sum of Squares   F Ratio   Prob > F
ttop                1    1       0,32089932    0,1379     0,7105
tbot                1    1       0,27004974    0,1160     0,7335
ph3top              1    1       0,33096841    0,1422     0,7062
ph3bot              1    1       0,15674934    0,0674     0,7953
ttop*tbot           1    1       0,32824205    0,1410     0,7074
ttop*ph3top         1    1       0,26168488    0,1124     0,7375
ttop*ph3bot         1    1       0,48423367    0,2081     0,6485
tbot*ph3top         1    1       0,38560247    0,1657     0,6841
tbot*ph3bot         1    1       0,13352896    0,0574     0,8108
ph3top*ph3bot       1    1       0,43565925    0,1872     0,6654
```

Picture 6.10.: Thk s-t-s – all interactions



	SITE	Mean of s-t-s (all data)	X	Y
1	1	-2,31	0	65
2	2	-0,88	-65	0
3	3	0,19	0	0
4	4	0,94	65	0
5	5	1,84	0	-65
6	6	-1,09	-23	23
7	7	-0,34	23	23
8	8	0,46	-23	-23
9	9	1,00	23	-23

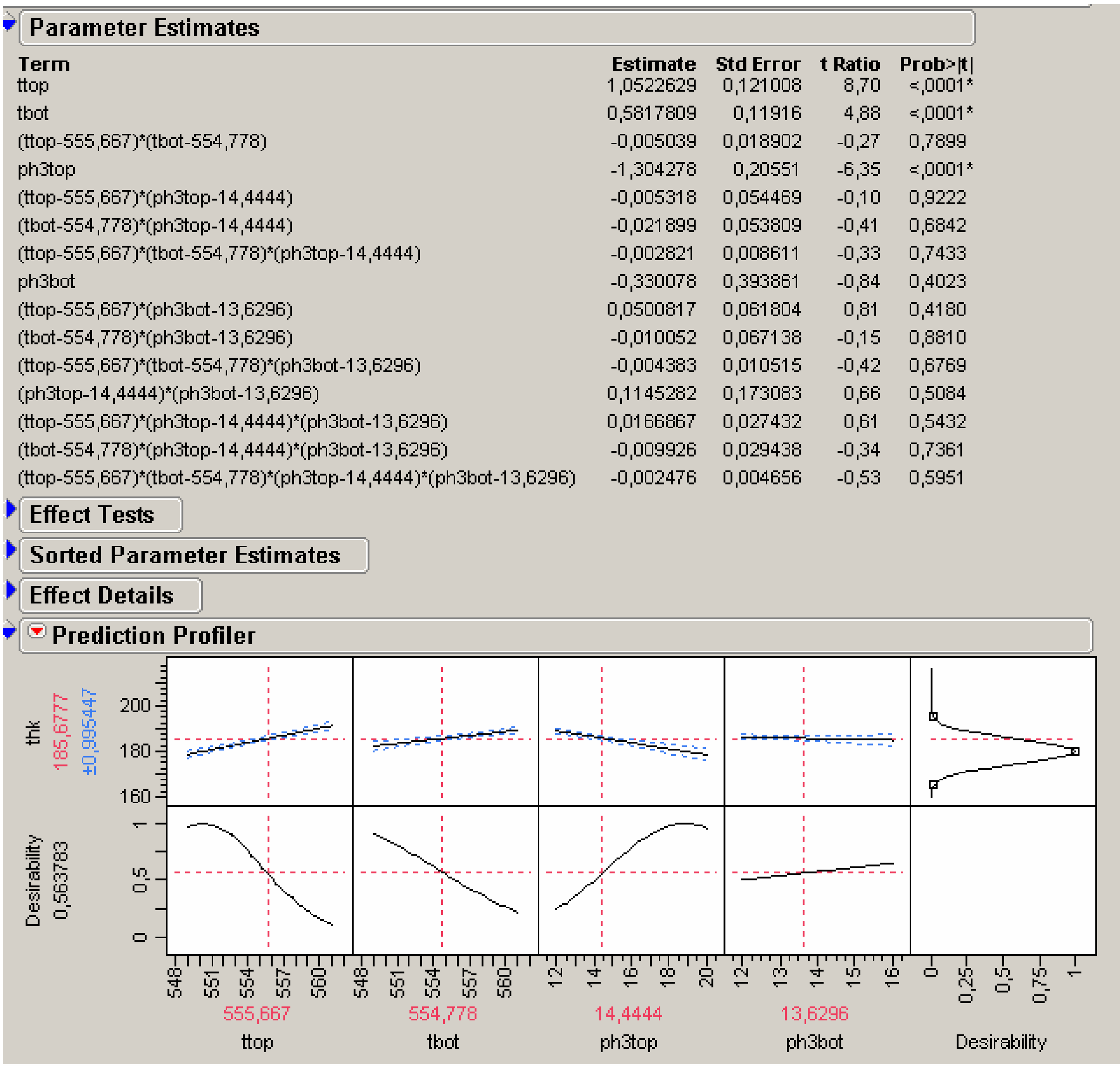
Picture 6.11.: Distribution of thickness across the wafer surface

The gas flows from the injector towards the tube wall where it splits into two flows circling the tube therefore the amount of phosphine in the area of the tube is distributed unevenly more to one side of the tube. From the contour plot above we see, that the hypothesis is correct. This hypothesis is just small piece o knowledge to further understand the process and all possible details that can affect such processes.

6.4. Overview

Plan
Output parameters
THK target 180nm
RES target 80ohm/sq
stdev27 THK, RS i.e. in lot minimal
FURNACE (thk1 - thk3), (res1-res3) in lot = 0

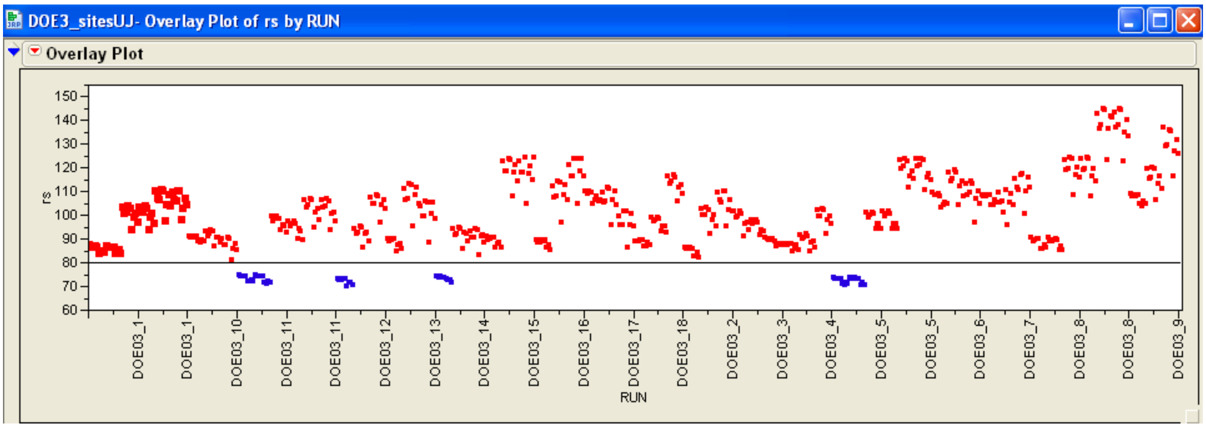
The first output parameter to be evaluated is thickness. Robust target can be set for thickness as seen below. Thickness is determined mainly by temperatures. Also silane flow has a strong effect on thickness but this value is fixed. Using the desirability function of the prediction profiler the ideal setting for target value can be found. See below the demonstration of desirability function of prediction profiler.



Term	Estimate	Std Error	t Ratio	Prob>|t|
ttop	1,0522629	0,121008	8,70	<,0001*
tbot	0,5817809	0,11916	4,88	<,0001*
(ttop-555,667)*(tbot-554,778)	-0,005039	0,018902	-0,27	0,7899
ph3top	-1,304278	0,20551	-6,35	<,0001*
(ttop-555,667)*(ph3top-14,4444)	-0,005318	0,054469	-0,10	0,9222
(tbot-554,778)*(ph3top-14,4444)	-0,021899	0,053809	-0,41	0,6842
(ttop-555,667)*(tbot-554,778)*(ph3top-14,4444)	-0,002821	0,008611	-0,33	0,7433
ph3bot	-0,330078	0,393861	-0,84	0,4023
(ttop-555,667)*(ph3bot-13,6296)	0,0500817	0,061804	0,81	0,4180
(tbot-554,778)*(ph3bot-13,6296)	-0,010052	0,067138	-0,15	0,8810
(ttop-555,667)*(tbot-554,778)*(ph3bot-13,6296)	-0,004383	0,010515	-0,42	0,6769
(ph3top-14,4444)*(ph3bot-13,6296)	0,1145282	0,173083	0,66	0,5084
(ttop-555,667)*(ph3top-14,4444)*(ph3bot-13,6296)	0,0166867	0,027432	0,61	0,5432
(tbot-554,778)*(ph3top-14,4444)*(ph3bot-13,6296)	-0,009926	0,029438	-0,34	0,7361
(ttop-555,667)*(tbot-554,778)*(ph3top-14,4444)*(ph3bot-13,6296)	-0,002476	0,004656	-0,53	0,5951

Picture 6.12.: Desirability function demonstration

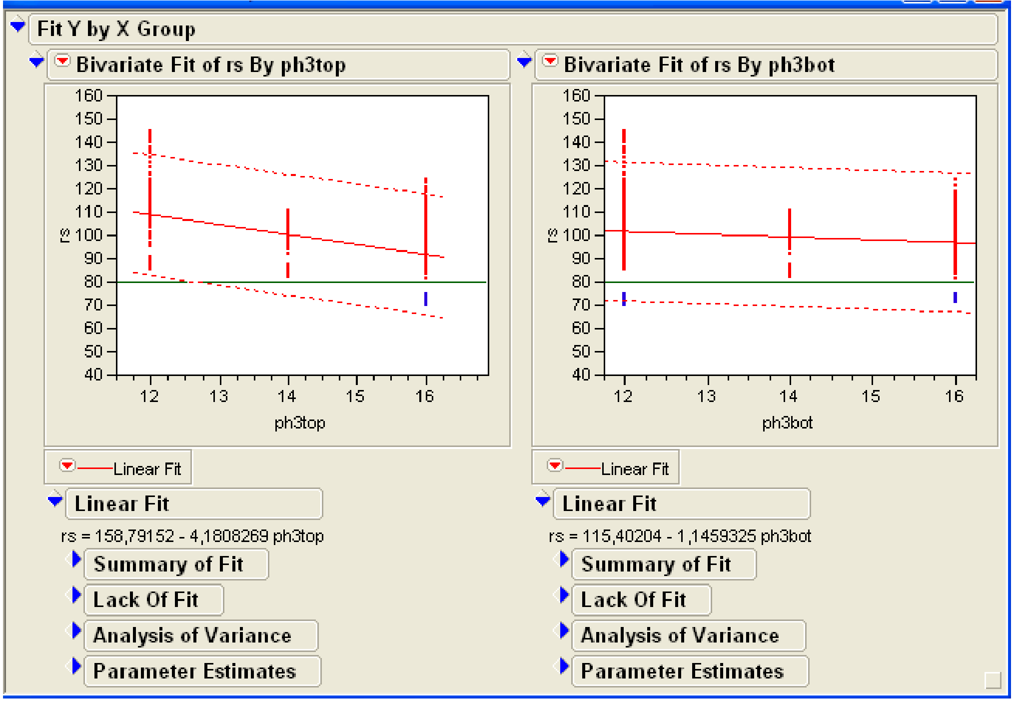
From what has already been shown above it is evident that setting the thickness to the target value is not a problem. But once resistivity values are more closely inspected a problem arises.



Picture 6.13.: Robust target of rs can not be set

Robust target of Rs can not be obtained from this experiment. From this graph it is obvious, that too little wafers are under target in Rs. These are, as can be seen from next graph, only wafers from the bottom position. This makes DOE conclusion with only these values impossible, therefore there are to be executed other experiments described below.

It can be seen from this graph, that the optimal setting of PH3top should have been set higher.



rs = 158,79152 - 4,1808269 ph3top

rs = 115,40204 - 1,1459325 ph3bot

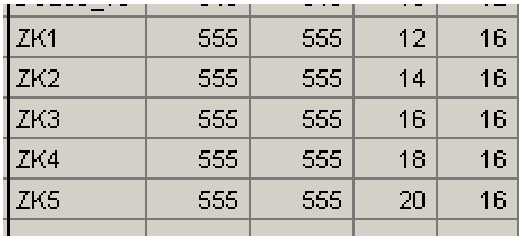
Picture 6.14.: Dependency of rs on PH3bot

6.5. Evaluation –conclusion

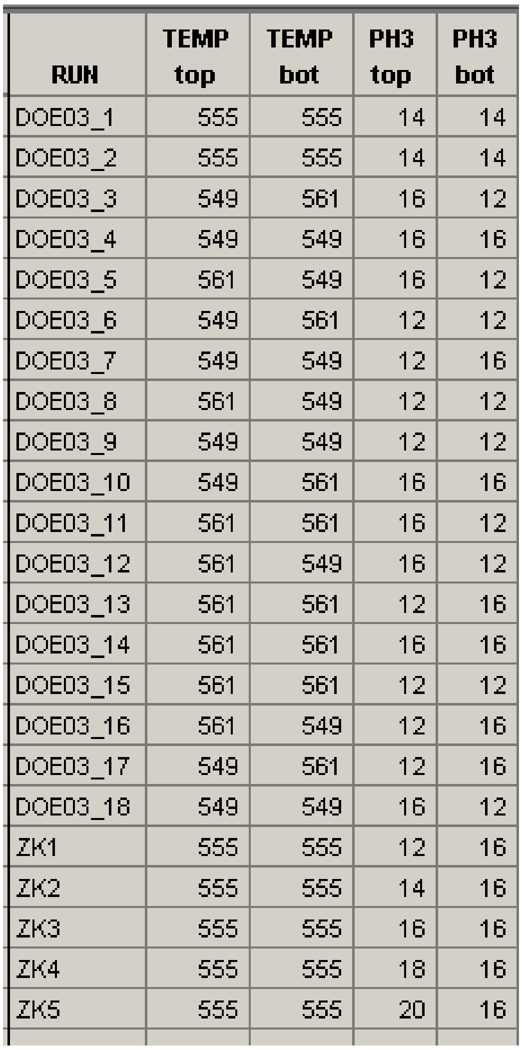
The PH3top values are selected too low to set robust target value of resistivity. Nevertheless information about the process have been gathered and now it is much easier to determine the range of values for PH3top. Since the other variables are well chosen and the robust target can be accomplished by only changing the PH3top setting, the easiest possibility to continue the experiment in order to acquire ideal settings and on the other hand not waste time and material with a new DOE is to execute an OFAT test (one factor at time).

6.6. One factor at time

To acquire a robust target in resistivity it is necessary to choose higher values for PH3top factor. Five additional tests are planned to execute the OFAT analysis. The PH3top flow is set at 12,14,16,18 and 20 sccm. Also the output target for resistivity is changed. Technology engineer lets the DOE team know that new, less strict target is to be accomplished. The new target is between 70 and 100 ohm/sq. Even so it is necessary to execute the OFAT since the resistivity has to meet the target in the whole batch. During the prior DOE the RS values sometimes touched the 150 ohm/sq border.



ZK1	555	555	12	16
ZK2	555	555	14	16
ZK3	555	555	16	16
ZK4	555	555	18	16
ZK5	555	555	20	16



RUN	TEMP top	TEMP bot	PH3 top	PH3 bot
DOE03_1	555	555	14	14
DOE03_2	555	555	14	14
DOE03_3	549	561	16	12
DOE03_4	549	549	16	16
DOE03_5	561	549	16	12
DOE03_6	549	561	12	12
DOE03_7	549	549	12	16
DOE03_8	561	549	12	12
DOE03_9	549	549	12	12
DOE03_10	549	561	16	16
DOE03_11	561	561	16	12
DOE03_12	561	549	16	12
DOE03_13	561	561	12	16
DOE03_14	561	561	16	16
DOE03_15	561	561	12	12
DOE03_16	561	549	12	16
DOE03_17	549	561	12	16
DOE03_18	549	549	16	12
ZK1	555	555	12	16
ZK2	555	555	14	16
ZK3	555	555	16	16
ZK4	555	555	18	16
ZK5	555	555	20	16

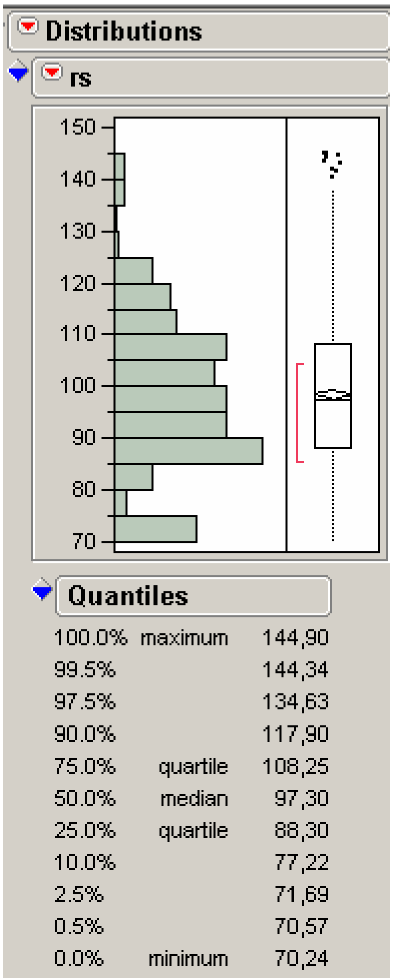
Picture 6.16.: DOE + OFAT data set

Plan
Output parameters
THK target 180nm
RES between 70 and 100 ohm/sq
stdev27 THK, RS i.e. in lot minimal
FURNACE (thk1 - thk3), (res1-res3) in lot = 0

The new data set for evaluation is added to the old DOE data set. New values are shown in picture.

Next thing to do is to test the possibility of setting robust target for resistivity.

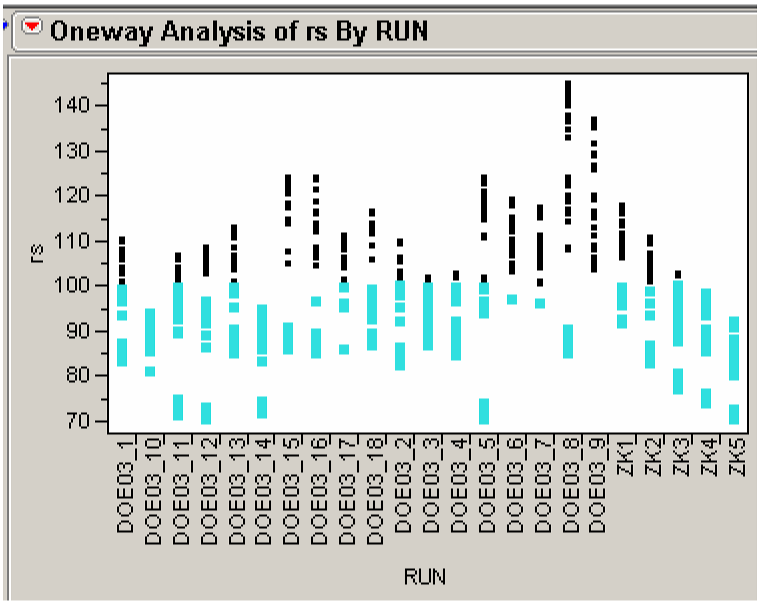
For this reason the distribution of RS values can be inspected. The fact must be kept in mind that the old data is still present in the data set. This shifts the median of distribution to higher values.



100.0%	maximum	144,90
99.5%		144,34
97.5%		134,63
90.0%		117,90
75.0%	quartile	108,25
50.0%	median	97,30
25.0%	quartile	88,30
10.0%		77,22
2.5%		71,69
0.5%		70,57
0.0%	minimum	70,24

Picture 6.17.: DOE + OFAT rs distribution

After one way analysis is done it can be said that target can be set. This is just an approximation. More details come out of the prediction profiler.

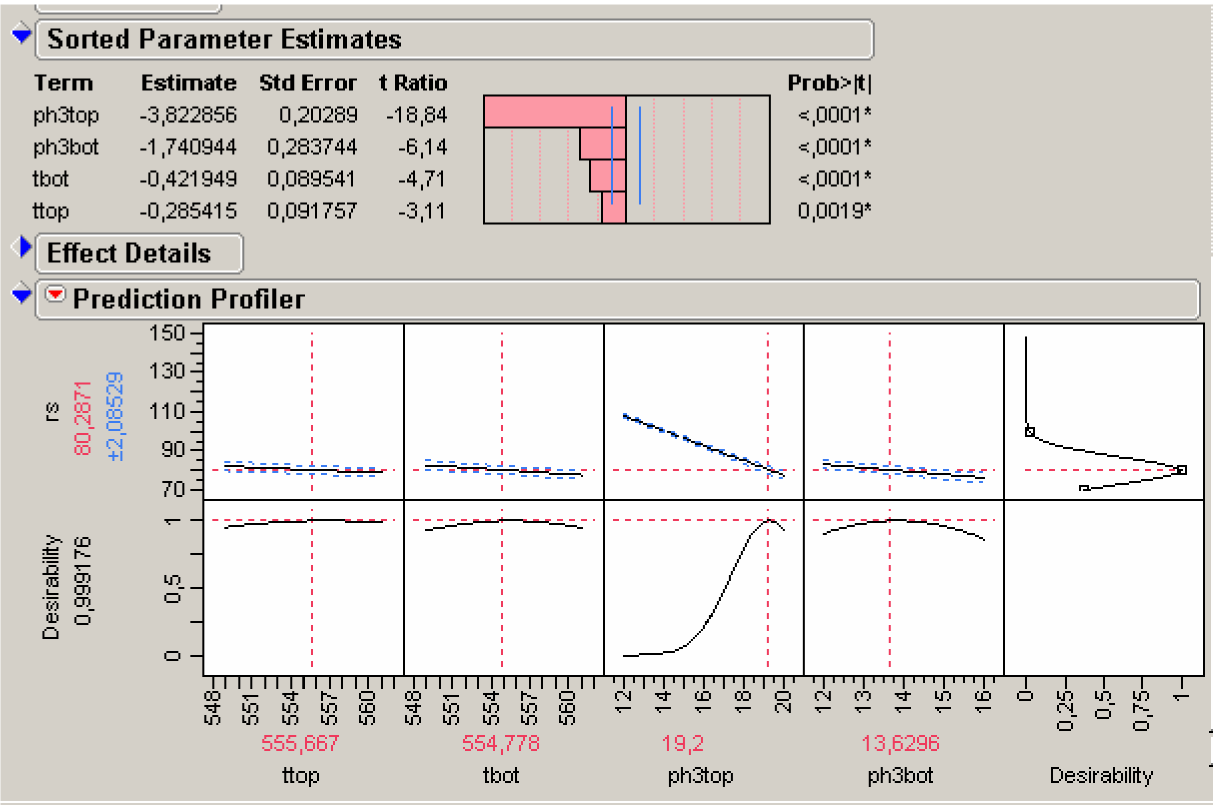


Picture 6.18.: Oneway analysis

6.7. Setting the optimal values

To finally acquire some results from this effort it is necessary to have some output. In this case the output is the final setting of a machine so it can be qualified and start production. At this point all the work is practically done. Large data sets are measured, collected and sorted.

The process is described to a point where the prediction profiler is precise enough to determine very well the input parameters in order to maintain good output from the process. Here the desirability function is put to work. On the picture below the usage of desirability function is shown. Target value of 80 ohm/sq was selected from prior target.



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
ph3top	-3,822856	0,20289	-18,84	<,0001*
ph3bot	-1,740944	0,283744	-6,14	<,0001*
tbot	-0,421949	0,089541	-4,71	<,0001*
ttop	-0,285415	0,091757	-3,11	0,0019*

Effect Details

Prediction Profiler

Picture 6.19.: Determining the PH3 flows to determine ideal settings for rs target

Other such desirability estimations were executed for optimal setting of thickness and uniformity. From this profiler recommended values were acquired and then used for verification runs. Three settings were tested in this case and one came out as ideal for the process.

The final setting is:
Top zone temperature 555,6 C
Bottom zone temperature 554,8 C
Top phosphine flow 19,5 sccm
Bottom phosphine flow 13,6 sccm
N2 top and bottom flows 200sccm
SiH4 top and bottom flows 400 sccm
Middle zone temperature 555 C

Table 6.20.: Verification runs

		THK	RS		THK	RS		THK	RS	
OV_RUN1	T50-12	179,9	74,75	T50-11	176,7	86,8	T50-10	175,3	96,23	ttop 555,7
		181,7	74,49		176,6	87,27		177	94,02	tbot 555,9
		181,7	74,24		178,6	88,33		178,7	94,05	ph3top 19,55
		180,7	74,83		179,6	87,9		180,6	96,41	ph3bot 14,9
		181,8	74,91		180,4	81,74		181,7	96,27	
		181,2	72,26		177,1	84,64		176,8	87,3	
		181	72,56		178,3	85,36		178,1	91,37	
		182,1	73,77		178,6	85,88		179	92,91	
		181,5	73,12		179,5	82,8		180,3	90,62	
OV_RUN2	T50-15	170,2	76,89	T50-14	174,1	86,13	T50-13	184,4	88,25	ttop 553,4
		171,9	76,89		174	84,87		186,5	86,35	tbot560
		171,8	76,52		175,8	85,39		188,1	86,51	ph3 top 19,5
		170,8	76,99		176,5	85,86		189,9	88,2	ph3bot 14,75
		171,8	77,03		177,3	85,43		191,5	87,67	
		171,4	74,77		174,5	81,51		186,1	80,7	
		171,2	74,78		175,5	82,76		187,3	83,82	
		172,2	76,29		175,8	82,76		188,6	84,41	
		171,7	75,46		176,6	80,73		189,8	82,43	
OV_RUN3	T50-19	174	72,96	T50-20	175,8	87,29	T50-21	178	98,74	ttop 555,6
		175,8	72,77		175,8	86,04		179,8	96,7	tbot 554,8
		177,2	72,52		177,4	86,53		179,7	96,9	ph3top 19,5
		178,6	72,95		178,1	86,84		178,7	98,45	ph3bot 13,6
		179,7	72,99		178,9	86,34		179,8	90,09	
		175,6	70,94		176,2	82,54		179,3	98,18	
		176,5	71,49		177,1	83,77		179	95,07	
		177,5	72,16		177,4	83,36		180,1	94,33	
		178,5	71,58		178,2	81,63		179,5	91,97	
OV_RUN3B	T80-9	177	72,75	T80-8	174,9	86,15	T80-7	174,3	96,57	ttop 555,6
		179,1	72,76		175,4	85,23		176,7	96,62	tbot 554,8
		178,9	72,54		176,8	85,8		177,9	64,62	ph3top 19,5
		177,8	72,91		177,3	85,7		179,1	94,86	ph3bot 13,6
		178,8	73,01		178	85,36		180,3	96,39	
		178,5	71,12		175,7	82,15		176,3	96,19	
		178,1	71,59		176,4	83,26		177	88,71	
		179,3	72,64		176,9	82,83		178,3	92,09	
		178,7	71,78		177,5	80,87		179,2	92,98	

Verification on 1800nm Poly-Si film, RG40406 production lot

The reason why the target value is 180 nm and the production wafers are deposited with 1800nm layer is purely economical. Behavior of deposition of 180nm thick film is similar to that of 1800nm film.

7. Conclusion

The first part of this project informs the reader about the CVD fundamentals in general. The basic classification of CVD processes is mentioned as well as basic physics and chemistry essential for understanding of the process. Also the most common precursors in the CVD process are introduced to the reader as well s the basics of tube reactors or furnaces.

In the second part there is introduction to the design of experiments, a complex tool for statistical analysis. By means of DOE the process running in COM1 is analyzed. From the analysis the DOE for CZ4 WFAB is designed.

Our DOE plan:

- N2 top and bottom flows fixed at 200sccm
- SiH4 top and bottom flows fixed at 400sccm
- Z2 temperature set to 555°C
- Z1 and Z3 temperatures change
- PH3 top and bottom flows change

Process target

- THK = ± 10 nm
- RES = ± 8 ohm/sq

Output parameters

- THK target 180nm
- RES target 80ohm/sq
- stdev27 i.e. in lot minimal
- FURNACE (thk1 - thk3), (res1-res3) in lot = 0

In the chapter named “Our experiment design” the reader can find information on actually designing own experiment. Wide range of information is included in this chapter including loading and measurement patterns etc. Other variables are introduced to assist us in deeper understanding of the process.

Evaluation part of the thesis deals with the data gained from the prior experiment. Also the reader is introduced to the concept of “one factor at time” analysis. At the end of this part the ideal setting for the SVG VTR-7000 in case of production of polycrystalline phosphine-doped silicon.

The final setting is:

- Top zone temperature 555,6 C
- Bottom zone temperature 554,8 C
- Top phosphine flow 19,5 sccm

- Bottom phosphine flow 13,6 sccm
- N2 top and bottom flows 200sccm
- SiH4 top and bottom flows 400 sccm
- Middle zone temperature 555 C

In this thesis we have undergone the process that has a new machine in the fabrication line in the beginning and a qualified producing machine at the end of the process. Since, as stated above, precise machines such as a deposition furnace always have to be tuned and tweaked on the site where these are to produce later on.

8. Acknowledgements

I would like to thank my supervisor Ing. Vlastimil Hanáček for helping me with the CVD fundamentals and experiment design as well as the data gathering and handling.

Also, I would like to thank Ing. Jan Ulrych for help regarding the DMAIC process and the DOE execution and evaluation as well as for help with the JMP statistical software.

My thanks also go to Ing. Edita Hejátková for pedagogic guidance and help with formal matters.

9. Sources of information

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