OPTIMIZING SPRAY COATER PROCESS PARAMETERS

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Published in the SUSS report 01/2014

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Spray coating technology is known for being affected by many different process parameters that, combined together in an ensemble, would lead to a variety of different coating outcomes. In the present article, a systematic analysis on how to optimize spray coating processes, based on the chemical and physical origin of the behaviour of the resist over high topography structures will be discussed.

From the set of measurements shown, it will become clear that two stronger players would be the **resist surface tension** and the **complex dynamics of the resist particles inside the spray cone.** In the following, the effect of those parameters and the ways to control them within the SUSS Altaspray technology will be clarified.

NEW SUSS TEST WAFERS FOR EVALUATING CONFORMAL COATING PROCESSES

Since such an important effect on the coating results is given by the topography of the substrates, an ad-hoc design for the test wafers was optimized, in order to allow a systematic study of the spray coating properties. Figure 1a depicts the layout of the 9-inch test wafer masks. It contains a total of 36 test dice, each having a size of 28 mm x 22.5 mm. The dark lines in the image indicate deep etched areas. Figure 1b shows more details of the die layout of the test dice. The test dice offers a variety of square cavities and trenches of different sizes for evaluating and optimizing conformal coating processes. The data discussed in the present article refers to KOH etched wafers (typical etch angle of 54.7°), with an etching depth of 100 µm.

In each die there are:

1. 5 large cavities (1 mm x 1 mm, 2 mm x 2 mm, 3 mm x 3 mm, 4 mm x 4 mm, 5 mm x 5 mm)
2. 8 trenches, each of them 5 mm long (width: 25 µm, 50 µm, 100 µm, 200 µm, 400 µm, 600 µm, 800 µm, 1000 µm), and
3. 8 sets of smaller square vias (25 µm, 50 µm, 100 µm, 200 µm, 400 µm, 600 µm, 800 µm, 1000 µm)

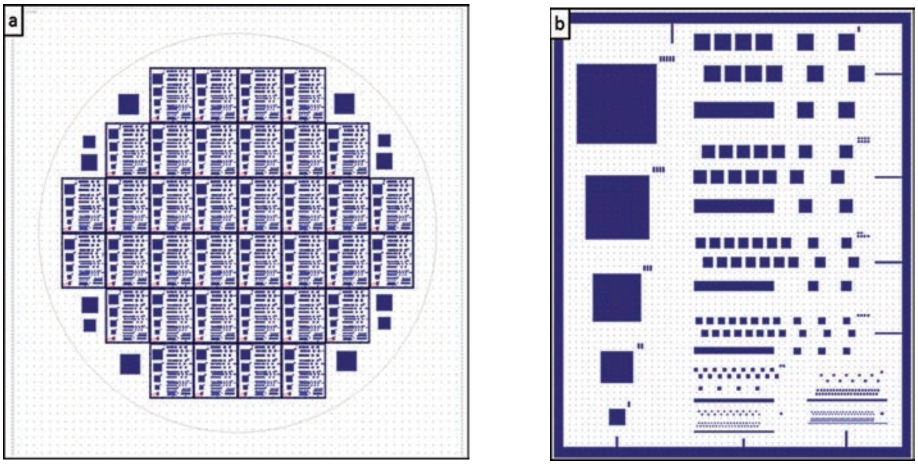

Figure 1.
a) Layout of test wafer with 36 dices per 200 mm wafer
b) Design of individual test dice. Dark lines indicate the KOH etched areas.

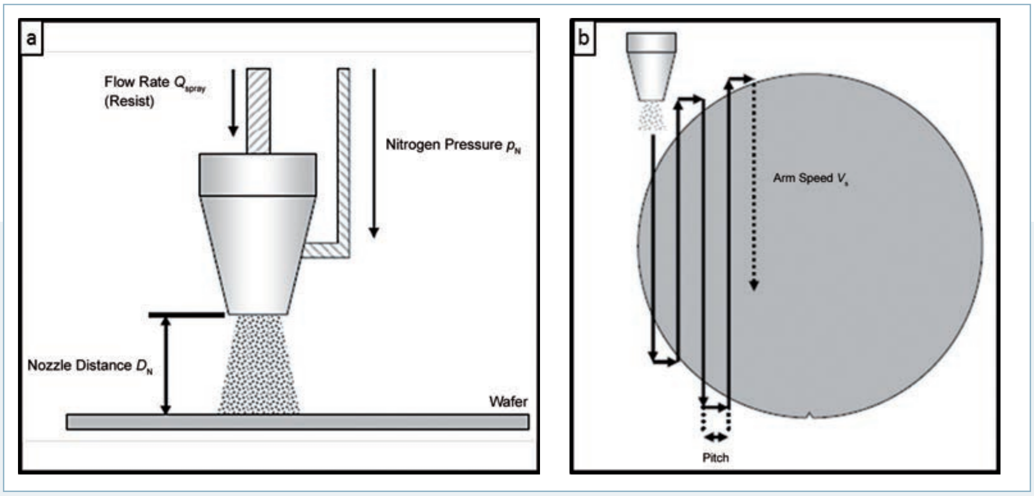

Figure 2: a) The nozzle setup parameters, defining the shape and the intensity of the resist spray cone.
b) The meander setup, defining the movement of the nozzle relative to the substrate.

GENERAL PROCESS SETUP

SUSS MicroTec‘s spray coating technology uses binary spray nozzles that atomize the photoresist by pressurized nitrogen. Figure 2a depicts the parameters that control the operation of the spray nozzle. The spray nozzle scans across the wafer area, as shown in Figure 2b. The spray arm scans the wafer by a succession of linear scans with constant pitch. During this scan the wafer chuck remains stationary.

There are seven important process parameters that can be adjusted for best performance of the spray coater: The **flow rate Q_{spray}** controls the total amount of resist that is sprayed onto the wafer within a certain period of time. The **nitrogen pressure p_N**: The nitrogen atomizes the resist to form the spray cone. The **nozzle distance D_N** gives additional means to tune the air flow inside topographic structures. The **pitch *D*** defines the distance of adjacent scanning lines. The **speed v_s** of the spray arm, together with the flow rate Q_{spray}, defines the amount of resist deposited locally during one scan. The number ***N*** of full wafer scans defines how often the full wafer scan is repeated and thus how many resist layers are deposited. By setting **temperature T_c of the wafer chuck** the user has means to stabilize the resist film immediately after droplet deposition.

For all the data shown in the following, a positive-tone DNQ/Novolak based resist has been sprayed, the AZ4999, developed by AZ Electronic Materials specifically for the SUSS spray coating technology.

Even though each specific process might have different coverage requirements, depending on the whole lithographic process, for the sake of simplicity here we will focus mostly on the resist conformality, defined as the ratio between the minimum and the maximum resist thickness across the substrate topography. The resist coverage across each pattern will be measured by optical microscopy of its cross-section, typically at five distinct locations: The top plateau (*T1*), the top corner (*T2*), the side wall (*T3*, eventually split in $T3_{min}$ and $T3_{max}$), the bottom corner (*T4*) and the bottom plateau (*T5*).

OPTIMIZATION OF THE COATING PARAMETERS SET

Starting from the SUSS standard baseline coating recipe, several parameters can be singularly tuned, in order to extract which physical and chemical resist properties have the stronger effect on the coating results and how to control them. Two aspects would arise as particularly significant: The **resist surface tension** and the **complex dynamics of the resist particles inside the spray cone**.

By increasing the temperature, the resist mixture becomes more liquid and the resist film is allowed to minimize its surface energy by pulling the resist away from the top corners. Simultaneously, the solvent component of the resist mixture evaporates and the coated layer hardens in the shape, defined by the minimized surface energy.

An example of this behaviour is shown in Figure 3: (a) is a cross section of a sample coated at a chuck temperature of 60°C; one can notice that the resist easily covers the whole profile, giving a

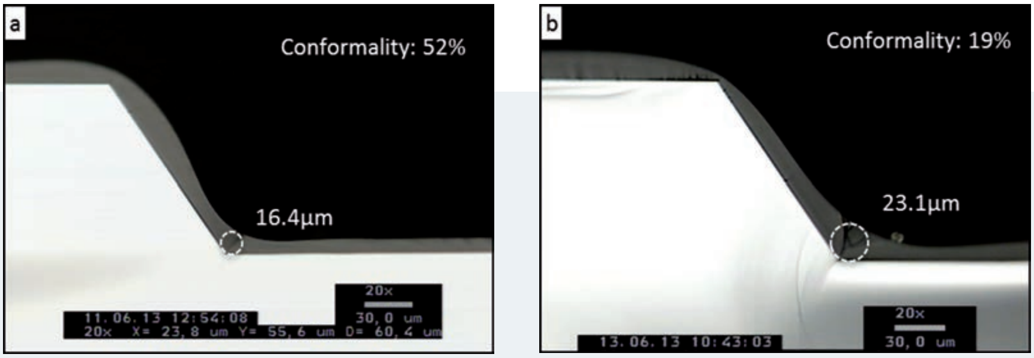

Figure 3. Cross sectional views of spray coated samples (Tc: 60°C) before (a) and after (b) the soft bake step at 90°C for 90s

conformality as high as 52 %.
When a sample coated with the same recipe as (a) undergoes the soft bake step (90 seconds at 90°C), the resist starts flowing again and the result is shown in (b): The conformality is now down to 19 %.
Spraying a *drier resist mixture*, i.e. a less liquid material, significantly minimizes the surface tension effect.

The high tuneability of process parameters offered by the SUSS Altaspray technology allows for several different methods to achieve a dry resist coating; most effective have been proven to be:

1. using a chuck temperature, during the coating, as close as possible to the soft bake temperature, as shown in the left side of Figure 4, where conformality is plotted as a function of the chuck temperature for different cavity sizes, and
2. decreasing the volume of the dispensed resist, while increasing the number of full wafer scans (right side of Figure 4, where the points corresponding to the 16-scans recipe lie at a higher position as the ones from the 8-scans recipe, that, in their turn, are higher than the ones from the 4-scans recipe).

The first method accelerates thermally the solvent evaporation, while the second one achieves its aim by slowing down the overall process and therefore leaving more time to the solvent to evaporate between consecutively coated layers. Depending on the specific process requirements (soft bake temperature, overall throughput, resist chemistry,…) either one, the other, or both methods could be selected.
A second important player in the spray coating technology is the dynamic of the resist particle inside the spray cone: The turbulent motion of those particles would in fact define where the resist will accumulate over the substrate topography. Process parameters that can be

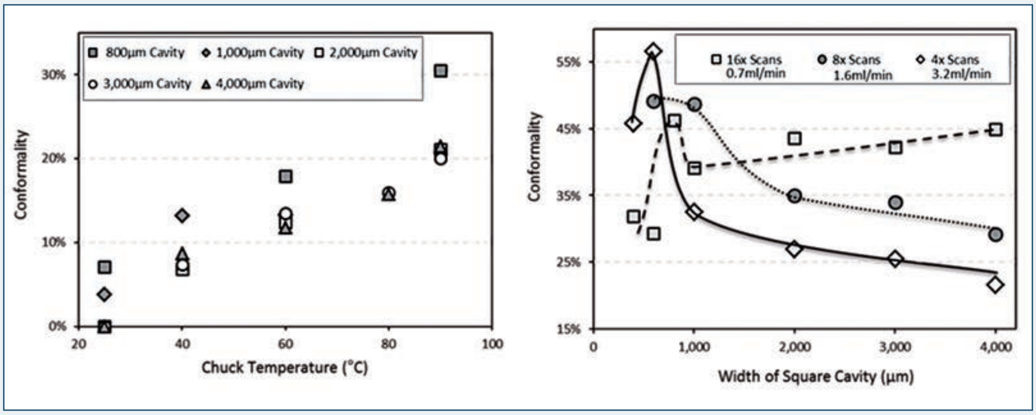

Figure 4. Left: Conformality of spray coated AZ4999 resist film for various 100 µm deep etched square cavities as a function of chuck temperature. After spray deposition the wafers were softbaked for 90 s at 90°C.
Right: Conformality of resist film versus cavity size (100 µm deep KOH etched) for three different resist flow rates: 0.7 ml/min (16 x scan), 1.6 ml/min (8 x scan) and 3.2 ml/min (4 x scan).

utilized to tune the aerodynamic of the spray cone are:

1. The nitrogen flow, that atomizes the resist into a spray, gives higher kinetic force to the particles and affects the solvent content of the resist - acetone mixture, and
2. The nozzle height that regulates the area of the cone cross section and the strength of the spray.

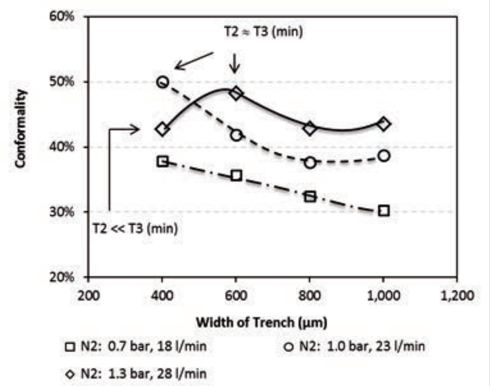

Figure 5. Conformality of resist films spray coated across 100µm deep KOH trenches as a function of structure size and nitrogen pressure. For large structures best conformality is achieved with high nitrogen pressure settings.

A typical case is reported in Figure 5, where the resist conformality is plotted as a function of the trenches width for different nitrogen flows: higher nitrogen pressure, by adding kinetic energy to the resist particles, increases the turbulence within the spray cone. The resist, therefore, is scattered around within the topography cavity and, instead of depositing on the bottom, accumulates on the upper part, namely the top corner and the upper portion of the side wall. Since the conformality is, in most cases, a ratio between the resist thickness at the top corner and the one at the bottom of the cavity, the overall conformality is then increased.

The aerodynamics of the resist particles is also affected by *topological effects*, i.e. the shape, the size and the depth of the substrate structures will contribute to the achievable conformality. When the spray cone, for example, moves across a narrow and deep cavity, a large amount of the resist will not succeed in reaching the very bottom of the topography, because there it will find an air cushion that will make it scatter back upwards. On the contrary, shallower and wider features will accumulate a large amount of the resist on the bottom corner, since the spray cone can fill the whole area and push the resist particles towards the (lower regions of the) side walls.

CONCLUSIONS

In spray coating many different aspects will affect the resist coverage and a process recipe has to take all of them into account by tuning the set of parameters as in an ensemble. For this reason it is then crucial to understand the chemical and physical reasons underlying the general coating results, to be able to constructively combine the several recipe parameters into an effective set.

From results as the ones shown in the present article, we can clearly define that particularly important are the resist surface tension and the aerodynamic of the particles in the spray cone and we can systematically outline how those could be controlled via the SUSS Altaspray technology.

THE AUTHORS

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