Productivity Enhancements in Recipe Creation for Overlay Metrology Measurements

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ABSTRACT

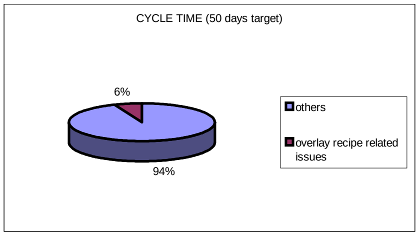
As the number of varied devices produced by a fab increases, coupled with an increased complexity in those devices which call for an ever increasing number of process layers, in-line process control via metrology can become an impossible task, unless metrology recipe management schemes are implemented. Logic fabs are now introducing more than 1 new device per day, which can result in the writing and management of thousands of recipes, which in turn can lead to the costly consumption of tool and personnel resources and a general loss in productivity.

In this paper we present the productivity gains to be made in the recipe creation process through off-line recipe generation, as well as a method of decreasing the recipe optimization time. We will also outline the concept of Just In Time (JIT) recipe creation, its contribution to productivity gains, and its generalized implementation with respect to Overlay Metrology recipes.

Keywords: Overlay, Metrology, Alignment, Photolithography, Recipes, Automation, Just-in-Time

1. INTRODUCTION

Metrology in general, and overlay metrology specifically can help accelerate yield improvements in both new and mature processes. As such, the time required to obtain information from the metrology measurement system about the disposition status of a lot should be as short as possible[1]. One significant means of reducing the 'time to knowledge' is to reduce the time required to generate the optimum recipes that govern the measurement process. Additionally as fab productivity is gauged, among other things, by wafer cycle times, metrology operations should strive to minimize the Work in Process (WIP) time between the process and the metrology tool. A typical Logic fab introduces more than 1new product per day, with up to 40 measurement steps per device for most advanced technology nodes (0.12um and below). This can lead to the creation of several thousand recipes per year. This recipe creation work leads to loss of production time from the metrology system, consumes resources both in the form of personnel and equipment, and lowers the fab productivity by increasing WIP times. Figure 1a and 1b provide an example of wafer cycle times associated with a prototype device, and the proportion of the cycle time that can be lost to recipe related issues.



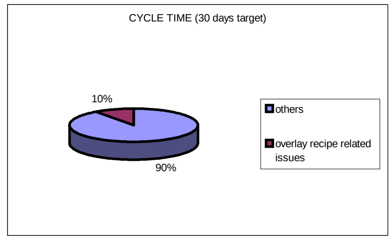


Figure 1a. **Figure 1b.**

The charts above show a cycle time analysis of a prototype, exhibiting recipe overlay related issues. Fully 6% of the 50 day targetted cycle time was lost as a result of either overlay recipe non-availability or failure. As overall cycle time targeted for 300mm will be more aggressive (almost 1.5 mask level/day), if everything remains constant, the impact of recipe related matters will be even stronger (up to 10% in this case).

2. EXPERIMENTAL METHODOLOGY

2.1 Overlay recipe creation

The recipe creation and the subsequent optimization process were performed on a Schlumberger IVS 135 Overlay and CD Metrology system. The recipes, that we will call "golden" recipes later on, were created on the measurement tool with a wafer.
Creating a recipe for a metrology tool, specifically for overlay measurements, essentially entails acquiring and storing reference images of the wafer alignment points and measurement targets. This initial step allows wafer alignment and navigation to the target sites to take place automatically and accurately. The stored images (reference) can be either specific to the wafers to be measured ("product dependent") or specific to a family to which the wafers belong ("non-product" dependent). The second phase in recipe creation entails setting the measurement parameters to optimize the measurement performance (precision, target acquisition success rate) and recipe reliability. This then is the 'Golden' recipe

2.2 Off-line recipe creation

If standard wafer alignment and overlay measurement (targets) features exist in the scribe line of the wafer, then the reference images of these features will be non-product dependent and optically identical at one layer and technology (same process) for all devices [2]. Therefore from the golden recipe, one can very quickly generate other recipes for all devices, as only the coordinates of images to be found will change within the wafer. In other words, recipes for new devices can be generated by melding the Golden recipe with the wafer map and measurement location information of the new device. This software capability is termed as off-line recipe creation, in the sense that the user does not need to be in front of the tool, with a wafer to "teach" the recipes, but rather can accomplish this task on an offline computer.[3,4]

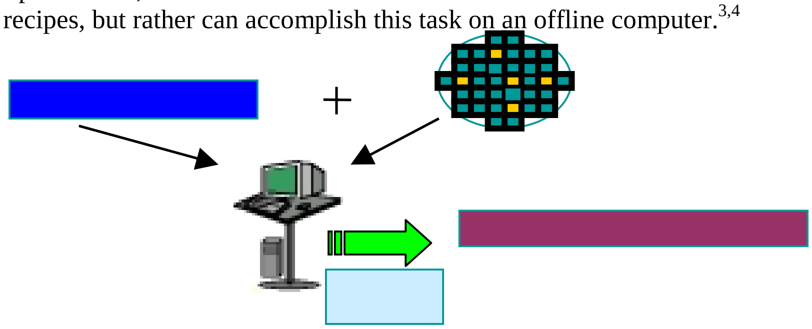


Figure 2. RJG (Remote Job Generator) Offline recipe creation software combines the Golden recipe with the wafer geometry and measurement information

A typical view of the relationship between the Process Step, Product, and Lot is shown in Figure 3.

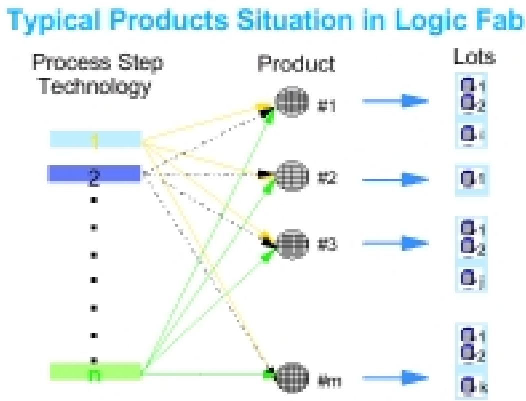


Figure 3.

This permits the metrology environment to reduce the number of recipes to be created dramatically, to principally the "golden recipes" or "master recipes" and therefore saves significant working time. Moreover, as off-line created recipes are not generated on the measurement instrument itself, WIP time will be significantly reduced and equipment time will not be needed, therefore improving tool availability for production. In this study offline recipe creation was accomplished through the Remote Job Generator software package[5].

Nevertheless, there are some practical some limitations to this strategy. The principle of off-line recipe creation relies on the fact that reference images are not device-dependent. This requires the pattern-recognition to be powerful, so that it will deal with "site-to-site", "wafer-to-wafer", "lot-to-lot" or even "device-to-device" process variation (contrast changes due to thickness non-uniformity or material properties, edges are more or less smooth due to CMP process or antireflective coating…). An example of this is shown in Fig 4

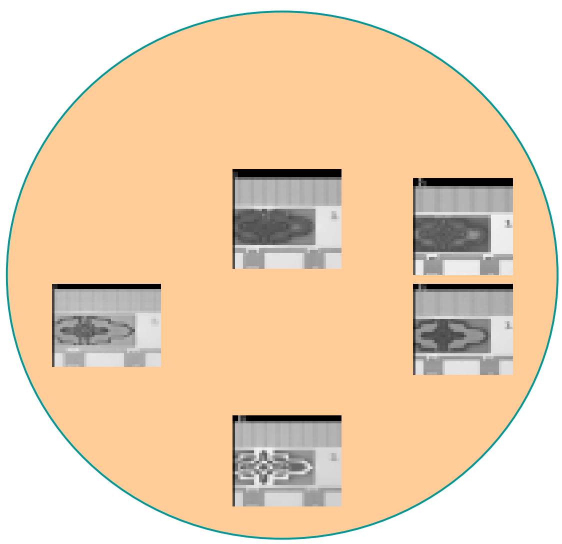


Figure 4. An example of site to site image contrast variation of the alignment points resulting from process variations. The burden of maintaining strong precision results across the process window, by aligning and measuring successfully, despite the contrast variation, is placed on the pattern recognition function and the intrinsic capabilities of the measurement system. In this study recipes were optimized to produce nearly flawless measurement success rates.

2.3 Just in Time Recipe Creation

A further improvement to the Offline Recipe creation in terms of recipe generation efficiency leads to the concept of Just in Time (JIT) Recipes. The goal of JIT recipe creation is to create the wafer specific recipe just at the time of measurement. Following the measurement the JIT recipe is discarded and all that remains is the Golden recipe. In other words the Offline recipe creation function (where the Golden recipe and the Wafer Map and measurement location sites are merged) is automated. Therefore a user scenario might be as follows:

- Wafers to measured are placed on the measurement tool by the user
- User scans/types an alphanumeric identifier into the system
- This triggers the customer's database to send the relevant product specific geometry information to the system
- System interacts with offline recipe creation function to generate the required recipe
- System runs the recipe
- System discards recipe following end of measurement

2.4 Recipe feedback

As a general rule the greater the number of people involved in the recipe creation process, the greater the risk of recipe variation. This typically results in recipe under-performance, which could ultimately lead to passing bad lots, inappropriate rework, and lost cycle time. Therefore network related recipe management such as Offline and JIT offer a means of reducing the human interaction with the recipe creation and improves the recipe consistency. Nevertheless, underpinning any measure of a recipe's success rate, whether it is a Golden recipe or whether it is created offline, or Just in Time, is the recipe's performance over the lifetime of the device. It is at this point that recipe feedback becomes crucial.

Golden or Master recipes at times require re-optimization. There can be many reasons for this. The Golden recipe may have been created on a device from a lot that is not representative of the further lots. Further lots may show stronger process variations that the recipe accommodates, or the intrinsic tool capability may not be sufficient to cope with process variations from device to device. Independent of the reasons for the re-optimization, recipe feedback needs to begin with the ability to check the recipe parameters frequently and easily. This will be referred to as the **"Recipe Verification"** step. Once recipe contents have been verified, software is required to analyze recipe performance on a frequent basis, so that engineers can react and adjust the golden recipes to maintain recipe performance, before the resulting problems of decreased recipe performance is realized on the process control charts. This process will be referred to as **"Recipe Performance Status"**.

The image below show a description of this global approach for recipe management:

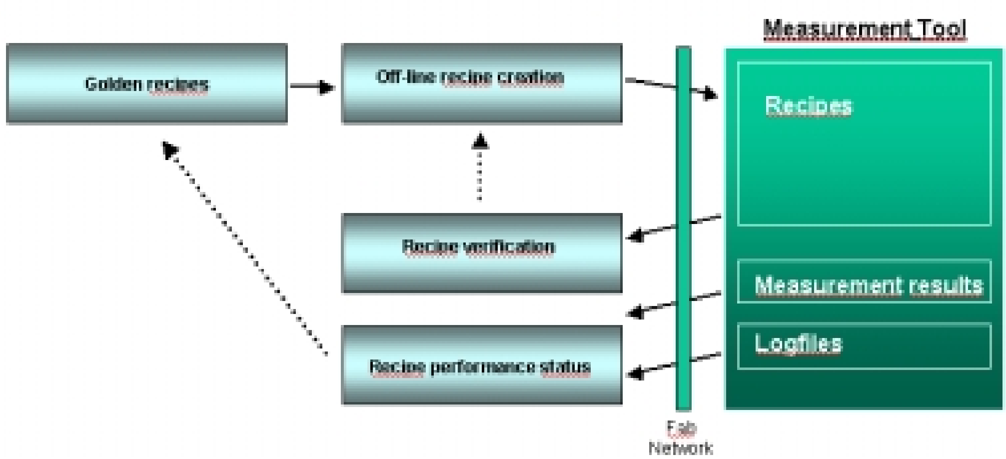


Figure 5. The Global Approach to recipe management integrates Golden Recipes, Offline Recipe creation, and JIT recipe creation, with a Recipe feedback mechanism for a maintaining optimum overlay recipe performance.

For this study, two special software packages were used. The first of these, the Recipe Documentation software, is designed to work in conjunction with the measurement tool to generate a comprehensive file containing the recipe parameters of all existing recipes, which allows easy and frequent verification of the recipes. The software is a key to the first phase of the feedback process. The second software package - Recipe Performance Status (RPS), is designed to scan, track, and analyze all of the generated measurement files and logfiles, so that recipe performance can be gauged over time. Additionally the RPS software provides information on the causes of recipe performance degradation . Taken together, the RPS and Recipe Documentation packages provide an effective means of implementing a recipe feedback program Recipe feedback involves the tracking of metrics that gauge the recipe performance. However, depending on the fab setting, the metrology engineer will need to decide which parameters will be followed. In general, the parameters to be followed should coincide with the measurement strategy adopted for that setting. For example, it is not likely that large amounts of statistical data on recipe precision would be followed in production as no repetitive measurements are generally taken in normal production settings. However other sensitive indicators may be followed which might include:

- The wafer alignment success rate. This has a major impact on cycle time of the lot, as the measurement will not be performed if the wafer is not aligned successfully.
- The target acquisition success rate with its root causes for failure (illumination, focus, pattern recognition,..). Fewer than the expected number of measurements on a wafer could result in poor overlay stepper/scanner correction information
- Max value on a wafer (for flyer detection). This has an impact on the cycle time of the lot, as the flyer is hiding the real maximum overlay value of the lot.
- Number of lots re-measured. This can show non-detected errors that force the users to re-measure the lot

These metrics can be sorted by recipe name, measurement step, and product, and consequently they can be used as a powerful diagnostic tool in determining if an overlay measurement failure is a result of either a process related issues, a tool related issue or a recipe related issue.

2.5 Samples

In an effort to gauge the effectiveness of these software tools in determining when recipes were not optimized and required optimization, a broad variety of samples spanning different technology nodes (0.18um and 0.12um), and devices (1A00A, 1A03A, 3A1BA,….) were used. “Back-end” process layers (metal, via), were specifically chosen as they represent typical challenges of mature and new technologies. Precision required for these technologies was achieved on every golden recipe[6]..

3. RESULTS AND DISCUSSION

3.1 Recipes Performances

Below in Figure 6 are examples of the type of information which can be extracted from the RPS software. In this instance, Figure 6b shows that the recipe performance for device 9A03A is weak. Figure 6c corroborates this by showing a high re-measurement rate for 9A03A. Figure 6d narrows down the problem further to the Line 1 (Metal 1) recipe. Upon examining this recipe through the Recipe Documentation function it was evident that the target image had changed significantly from that which was used in Golden recipe. The Golden recipe was subsequently modified to accommodate the change in the target image. Figure 6f shows the maximum overlay values per lot over a 1-month measurement period. Considering a typical process window (0-200nm), high values are generally representative of lots exhibiting one or more flyers. Such filters help in removing known data excursions from skewing recipe performance information

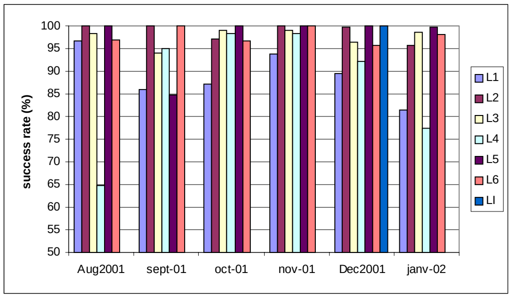


Figure 6a. Long Term Metal level recipe success rate

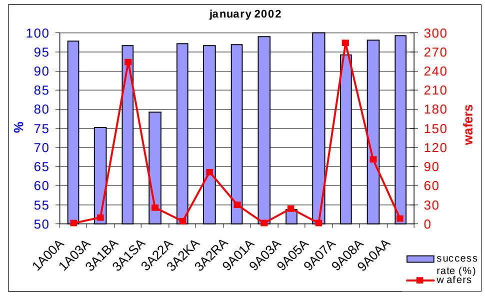


Figure 6b. Recipe success rate and number of wafers measured as a function of device type (for 1 month)

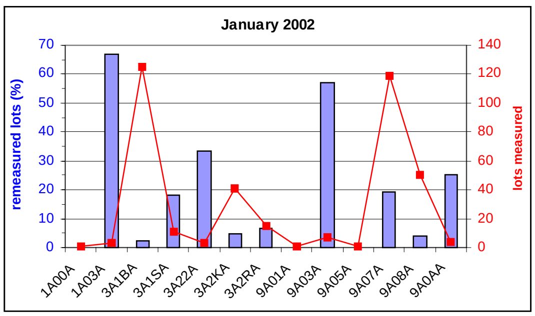


Figure 6c. Re-measurement rate and number of lots measured as a function of device type (for 1 month).

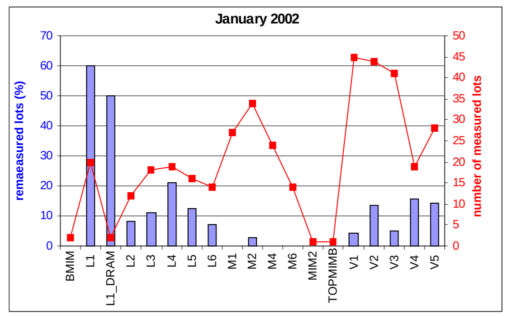


Figure 6d. Re-measurement rate as a function of layer

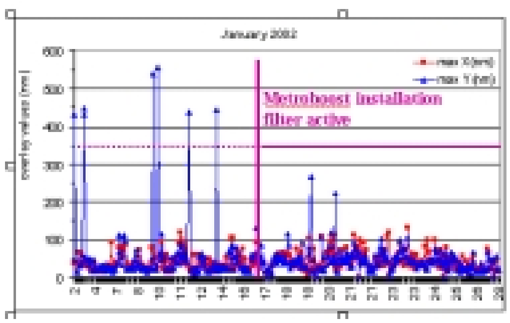


Figure 6f. Data filtering used to discriminate known data excursions from skewing Stepper correction information and recipe performance information.

3.2 Productivity gains

3.2.1 Recipe availability in the measurement sequence

One particular aim of this study in proposing a global approach to recipe management was to minimize the WIP time associated with metrology operations. Therefore it is important to quantify the impact of the various components that constitute this approach (Golden recipes, Offline recipes, JIT). To do this one needs to evaluate what portion of the recipe creation process affects the execution of a measurement. In this work we have concluded that the lack of 'recipe availability' is one of the key elements in influencing WIP time negatively. The lack of recipe availability is defined as either a recipe which been written or a recipe which hasn't been optimized at the time of need.

The following operational permutations are typical.

1. Recipe availability (four cases are possible).
   - The golden recipe is not available and need to be created. With no prior information and with the degree of process variability seen in this study an average of 120 minutes was required to produce a Golden recipe with 100% measurement success
   - The off-line recipe is not available and needs to be created. It takes ~ 5min with RJG software
   - The recipe is available and requires re-optimization. As the starting point is known, it will take less time to re-optimize the golden recipe than to create it. Given the difficulty of the sample variability in this study re-optimization required 60min on average.
   - The recipe is available and optimized.

2. Recipe selection. This is typically performed automatically, and takes on average 1 min. The Operator simply places the lot on the tool and enters the identification number of the lot. Then measurement begins automatically.

3. The measurement is performed. The throughput of the tool will depend on several factors: handling time, wafer alignment time, measurement time. In practice the leading influence on throughput is the measurement time, which in turn is a strong function of the sampling plan. Optimized recipes used in this study have minimum measurement times and maximum success rates

4. Data collection. This is usually done by the automation, and takes approximately 1min.

Figure 7 shows a breakdown of measurement sequence:

Avg. time (min)	A golden recipe is not available and need to be created	B off-line recipe is not available and need to be created	C recipe is available but need to be reoptimized	D recipe is available and optimized
recipe availability	120	5	60	0
recipe selection	1	1	1	1
Measurement	10	10	10	10
data upload	1	1	1	1

Figure 7.

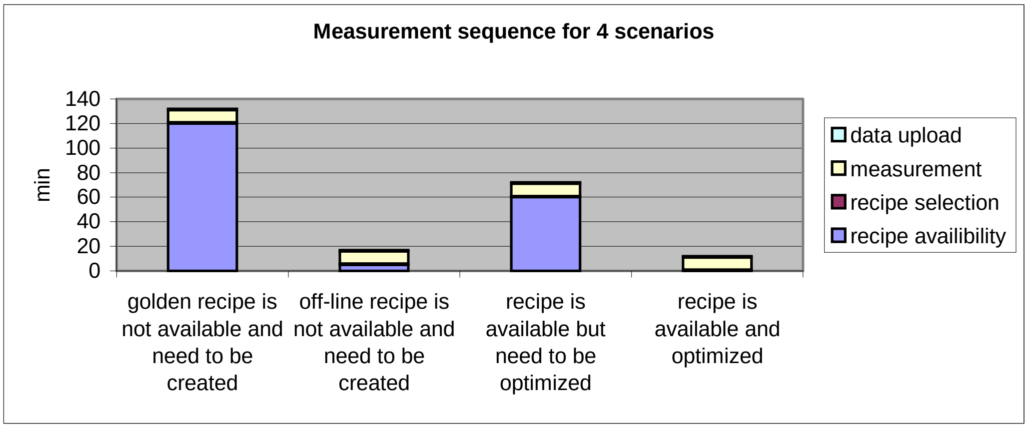


Figure 8. Graphical representation of measurement execution times

It is clear that recipe creation and optimization are time-consuming components of a single measurement sequence and in the case of prototypes, work on its reduction will lead to important benefits in cycle time.

3.2.2 Overall cycle time gains

Next, to gauge the gains offered by this type of global approach, it is important to consider under which conditions the 4 scenarios have been constructed. Scenarios 1and 3, which we will refer to as the Technology Learning Curve is representative of the first engineering phase in an R&D plant – characterized by few devices, low volume, and an abundance of process changes (changes to materials, design, stacks, thickness). Scenarios 2 and 4, which will referred be to as the Volume ramp-up/Mature phase is characterized by more or less fixed processes, accompanied by an increase in production volume. The impact of all of the recipe related issues can then be estimated in terms of WIP Time Lost, (which is directly related to cycle time), tool downtime and working time. Therefore we have tried to estimate the productivity gain between a situation where no special recipe management scheme exists and where offline recipe creation, JIT, recipe verification, and recipe status software coexist. The underlying assumptions in the model to be presented are based on the actual experience in the fab setting, calculated over a period of 1 year, and are described below for the two cases
Without any recipe management capability, WIP time lost due to recipe issues will be dominated by the overall time to create recipes for all layers, devices and technologies involved, plus the time to optimize the recipes that need to be re-engineered (% of overall recipes) , where causes for re-engineering are either process changes ("re-engineering due to fab") or normal recipe performance enhancement ("re-engineering due to the measurement system"). Downtime percentage for recipe creation on the tool is calculated by dividing the WIP Time lost to recipe issues (in days) by 365. Total Working Time is the sum of the time to create recipes plus the time to optimize recipes for all layers devices and technologies (product families).

However with the whole software package for recipe management in place, the situation is different, as time needed to create off-line recipes is hidden for the tool and the lots. And time needed to re-engineer recipes, (caused by measurement tool), will decrease as well. We estimate that re-engineering rate is 10% during the Technology Learning Curve scenario, as fewer recipes are easier to manage than the larger number found in the Volume ramp/Mature technology scenario, where we estimate the re-engineering rate to be (15%). Using the software package for recipe feedback, based on monthly results, we estimate that the re-engineering rate to go down to 5% for both scenarios, due to better control on recipe parameters and performance. Therefore, the WIP time lost corresponds to the time to create and optimize golden recipes, (i.e. only for 1 device). The tool down time is still directly calculated from it. However the working time will take into account the time to create and optimize the golden recipes (1 device), plus the time to create all other recipes with the off-line recipe creator. It has to be noted that, in our case, the time to create 1 off-line recipe or all the recipes for every layer is the same.

Figure 9 encapsulates in a simple model the quantitative gains in time and savings that result from the Global recipe management approach. The model definition precedes the results.

<u>Model Definitions:</u>
The following give the definitions for the model parameters which have been used.
Input : Nb = Number

- Nb of Product Families – This refers to the number of general process governing the product family (CMOS, BiPolar, etc…)
- Overall Nb of Devices - This refers to the number of types of devices (Disk Drive Accelerometers, Memory Chip A, etc…)
- Nb of measurement steps – This is a reference to the numbers of measured layers
- Layer – Via 1-n, Metal 1-n, Poly, Implant, etc…
- RJG – Remote Job Generator (the offline recipe creation software package)
- JPD - Job Plan Documentation software (also referred to as the Recipe Documentation software)
- JPP – Job Plan Performance Status software (also referred to as the RPS software)

[1 year basis]				SCENARIOS							
				technology learning curve			mature technology, volume ramp-up				
INPUT	FAB	nb of product families		2			10			412	devices overall
		overall nb of devices for 1 technology		6			40				
		nb of measurement steps for 1 device		40			20				
		re-engineering rate per golden recipe (process improvement)	[%]	100			10				
	IVS135	averaged time to create a golden recipe	[min]	120			120				
		averaged time to re-optimize a golden recipe	[min]	60			30				
		time to create off-line recipes for 1 device (all measurement steps)	[min]	5			5				
		re-engineering rate per golden recipe (recipe enhancement)	[%]	10	5	5	15	5	10		
				without RJG, JPD, JPP *	with RJG, JPD, JPP*	gains	without RJG, JPD, JPP *	with RJG, JPD, JPP*	gains		
OUTPUT		**WIP time lost due to recipe issues**	[day]	62	10	**52**	708	17	**691**		
		Single TOOL DOWN TIME due to recipe issues	[%]	17	3	**14**	194	5	**189**		
		WORKING TIME due to recipe issues	[working day]	213	10	**202**	2429	19	**2410**		
		COST*	[k$]	52	2	**50**	595	5	**590**		

* RJG = Remote Job Generator
JPD = Job Plan Documentation
JPP = Job Plan Performance status
** averaged engineering cost at a rate of $35 / h

Figure 9. Input and output of the recipe creation productivity gains model

We can see from the WIP time lost in the technology learning curve scenario that a 52 day gain can be made. Additionally the Working Time due to recipe issue is decreased by over 200 days (assumes a 7 hour work day) Furthermore, if we apply that gain to first devices, it represents ~4 days/device gain (52days/12devices). Finally, considering the combined gains for both scenarios, time savings amounting to a tool availability corresponding to ~2 tools is seen, along with a cost saving of 600k$ annually associated with the working time.

The situation can be can be improved further: Off-line recipe creation can be made automatic (ie: JIT recipes), therefore saving the 5min needed per device to generate the recipes as well as avoiding some human input errors that can lead to re-engineering time. The ultimate goal will be to automate the golden recipe creation . This could save the 120min estimated for every layer and product family, however this would mean the tool capability will need to be perfect (pattern recognition, measurement capability,…), so that it will not increase re-engineering time to a point where it would hide the benefit of the feature.
In addition to the absolute numbers calculated in the ‘gain’ section of the model output, which is of practical importance, the study also brings out the relative effects of having and not having a recipe management package, within the fab context.

We clearly see that without the package and with big volumes, it is not possible to create all recipes needed, as time (2429 working days) and tools (1.9 tools) are obviously insufficient (limited resources and toolset). As a consequence, the measurement methodology in this fab context was to do a limited sampling of devices to be measured, and to concentrate on the “big runners” (those devices expected to be produced in large volumes).
While this may be sufficient to get some qualitative yield information this method is not well suited to a site where processes are dynamic, and where every substantive verification action (i.e. which can lead to significant rework) needs to be done on prototypes, in order to get the best process

4. CONCLUSIONS

We have been able to show that offline recipe creation, when used in conjunction with the Recipe Documentation and Recipe Performance Status software can lead to a faster means of arriving at the optimized Golden recipes, and diagnosing recipe failures. These recipes in turn can be used to generate wafer specific recipes in an automated fashion resulting in significant WIP Time reductions and cost savings, thereby enhancing the fab’s productivity. Such productivity gains will be all the more significant at 300mm. Finally the global approach can be extended to every “in-line” metrology tool, where there is need to be able to measure at several well-defined positions on a wafer.

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5. RJG Software is the Schlumberger trademark name for its offline recipe creation software.

6. 2001 ITRS Roadmap

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