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Microelectronics Reliability 46 (2006) 1006–1012
MICROELECTRONICS RELIABILITY
www.elsevier.com/locate/microrel

Research note

Critical dimension control in photolithography based on the yield by a simulation program

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Received 11 April 2005; received in revised form 10 August 2005
Available online 29 September 2005

Abstract

The critical dimension (CD) of wafers in photolithography is the most important parameter that determines the final performance of devices. The sampling of CD's, as a result, is essential and must be taken with caution. Process yield is a common criterion used in the manufacturing industry for measuring process performance. A measurement index, called S_{pk}, has been proposed to calculate the yield for normal processes, and can be used to establish the relationship between the manufacturing specifications and the actual process performance, which provides an exact measure on process yield. In this paper, we solve the CD control problem based on the yield index S_{pk}. The critical values required for the hypothesis testing, using the standard simulation technique, for various commonly used performance requirements, are obtained. Extensive simulation results are provided and analyzed. The results indicate that a sample size greater than 145 is sufficient to ensure that the decisions made are insensitive to the process precision and the process accuracy. The investigation is useful to the practitioners for making reliable decisions in testing process performance of a stepper and quality of an engineering lot by CD control.

1. Introduction

A trend of semiconductor industry is to manufacture integrated circuits (ICs) with smaller devices and feature sizes on wafers of larger diameters. The progressively more demanding specifications and shrunken device size put a tremendous pressure on process control, especially the control of photolithography.

In photolithography, the pattern printed on a wafer is not an exact replica of the mask pattern in practice. "Critical-dimension," or just "CD," is defined as the linewidth of the photoresist (PR) line printed on a wafer and reflects whether the exposure and development are proper to produce geometries of the correct size [1]. Because of limited resources and more-stabilized advanced process system, the sample size of CDs is shrinking. Therefore, the goal of this paper is to find the most suitable number of chips that should be selected in each lot (25 pieces) of wafers for measuring CD's in such instance. The rest of the paper is organized as follows. Section 2 discusses the importance of CD control in photolithography. Process yield and yield measurement index, S_{pk}, are briefly introduced in Section 3. Section 4 presents the simulation for the critical values of S_{pk}.

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0026-2714/$ - see front matter
doi:10.1016/j.microrel.2005.08.003

Section 5 presents an application example and solves the number of samples required for checking the stability of a stepper or the quality of an engineering lot. Some conclusion remarks are made in the last section.

2. Control of the photolithography process by CD measurement

Photolithography, taking about 40–50% of the total wafer-processing time, is the core of the IC manufacturing process, which requires six to eight weeks to fabricate bare wafers into finished wafers [2]. Photolithography requires high resolution, high sensitivity, precise alignment and low defect density, and an advanced IC chip usually needs more than 30 patterning steps of which each one must align with the previous one precisely to successfully transfer the pattern of the chip design.

Three major steps of the photolithography are PR coating, alignment and exposure, and developing. The most critical step of the process is alignment and exposure, which determines the success of transforming the IC design pattern on the mask or reticle to the PR on the wafer surface [2]. The last step of the photolithography process is after-develop-inspection, which determines whether the steps up to this point have been performed correctly and within the specified tolerance and whether the photolithography produced a satisfactory pattern on the PR [3]. Pattern inspection is essential since the wafers that fail to pass the inspection can still be sent to strip the PR and to rework on the whole process again. However, after a wrong pattern is etched or implanted, it is almost impossible to rework a wafer then. As a result, the inspection process is very important to detect whether the pattern on the PR is misaligned, whether there are incorrect critical dimensions (CD's) and whether there are surface irregularities [2]. In advanced IC fabs, CD loss, caused mainly by overexposure or over-development, lead to the most photolithography reworks. Therefore, a successful CD control is essential for the final performance of the devices and the achievement of throughput and profit target of a firm.

To control the process effectively, CD measurements must be made on each layer in the manufacturing process, which typically contains 10–15 such layers [4]. The CD can be measured at the top, bottom or any height of the resist profile [1]. For the new generation of ICs which have submicron features made on step-and-repeat printers using die-by-die alignment, the measurement task is becoming more and more pressing and difficult [4].

CDs are usually measured from bar grating patterns, and the measurement is generated by comparing the bar diameter to the space between bars which should be equal [4]. The difficulty with this method is to determine where the edges of a bar are in the intensity profile especially when ringing from interference fringes is present. Generally, an arbitrary point on the curve that gives the most repeatable results is selected since process control in repeatability usually takes priority over absolute precision [4]. Automated systems for CD measurement are common nowadays, and the inspection data generated from the systems is further analyzed to determine the acceptability of wafers.

The distribution of CDs is referred to as across chip linewidth variation (ACLV), and the width of the distribution is represented by 3σ, where σ is the standard deviation of a normal or close to normal distribution [5]. Because the statistical sampling is often too small to examine the normality of the distribution, the distribution width is usually expressed by total indicated range (TIR), the difference between the maximum CD and minimum CD in a sample. Statistical methodologies like Shewhart-type control charts are usable tools in practice to check if CDs are in or out of statistical control [6]. However, more precise analysis with designed experimental datasets is often required to deal with CD variation because significant CD variation may need prompt decisions such as mask revisions and process conditions changes, and techniques, for example, the analysis of variance (ANOVA), are often utilized to investigate CD variation [6].

3. An overview of the process yield and yield measurement index S_{pk}

Process yield, the percentage of processed product unit passing the inspection, is a common and basic criterion used in the manufacturing industry as a numerical measure on process performance. For a product to pass the inspection, its product characteristic must fall within the manufacturing tolerance, and all passed product units are equally accepted by the producer. On the other hand, for a product that is rejected due to nonconformities, it may be scrapped, or additional cost is required to repair the product. The process yield, for a process with two-sided manufacturing specifications, can be expressed as $F(\mathrm{USL}) - F(\mathrm{LSL})$, where USL and LSL are the upper and the lower specification limits, respectively, and $F(\cdot)$ is the cumulative distribution function of the process characteristic [7]. For a process characteristic following a normal distribution, the process yield is $\Phi[(\mathrm{USL} - \mu)/\sigma] - \Phi[(\mu - \mathrm{LSL})/\sigma]$, where μ is the process mean, σ is the process standard deviation, and $\Phi(\cdot)$ is the cumulative distribution function of the standard normal distribution $N(0, 1)$ [7].

Process capability indices (PCIs) establish the relationship between the actual process performance and the manufacturing specifications. An abundant literature has focused on the establishment of indices, and some widely used basic indices include C_p, C_a and C_{pk} [8]. A review for the development of PCIs is presented by Kotz and Johnson [9].

A yield measurement index called S_{pk} is proposed by Boyles [10] to establish the relationship between the manufacturing specifications and the actual process performance for normal processes [10]:

$$S_{pk} = \frac{1}{3}\Phi^{-1}\left\{\frac{1}{2}\Phi\left(\frac{\mathrm{USL}-\mu}{\sigma}\right)+\frac{1}{2}\Phi\left(\frac{\mu-\mathrm{LSL}}{\sigma}\right)\right\}. \quad (1)$$

A one-to-one correspondence between S_{pk} and the process yield can be found. For instance, if $S_{pk} = k$, then the process yield is

$$\text{process yield} = 2\Phi(3k) - 1. \quad (2)$$

Therefore, S_{pk} provides an exact, rather than approximate, measure of the process yield [7,10].

$$\begin{aligned} S_{pk} &= \frac{1}{3}\Phi^{-1}\left\{\frac{1}{2}\Phi\left(\frac{\mathrm{USL}-\mu}{\sigma}\right)+\frac{1}{2}\Phi\left(\frac{\mu-\mathrm{LSL}}{\sigma}\right)\right\} \\ &= \frac{1}{3}\Phi^{-1}\left\{\frac{1}{2}\Phi\left(\frac{d-|\mu-m|}{\sigma}\right)+\frac{1}{2}\Phi\left(\frac{d+|\mu-m|}{\sigma}\right)\right\} \\ &= \frac{1}{3}\Phi^{-1}\left\{\frac{1}{2}\Phi\left(\frac{1-|\mu-m|/d}{\sigma/d}\right)+\frac{1}{2}\Phi\left(\frac{1+|\mu-m|/d}{\sigma/d}\right)\right\} \\ &= \frac{1}{3}\Phi^{-1}\left\{\frac{1}{2}\Phi[3C_pC_a]+\frac{1}{2}\Phi[3C_p(2-C_a)]\right\}. \end{aligned} \quad (3)$$

The index S_{pk} can be transformed into a function of two parameters, precision index C_p and the accuracy index C_a [11]. The parameter C_p is a function of the process standard deviation, and the overall process variation relative to the specification tolerance can be measured. C_p is defined as [12]:

$$C_p = (\mathrm{USL} - \mathrm{LSL})/66. \quad (4)$$

The parameter C_a is a function of the process mean, and the degree of process centering is measured. It is defined as [13]:

$$C_a = 1 - |\mu - m|/d, \quad (5)$$

where $m = (\mathrm{USL} + \mathrm{LSL})/2$, and $d = (\mathrm{USL} - \mathrm{LSL})/2$.

A mathematical relationship among the three measurements, S_{pk}, C_p and C_a can be established as [11,13]:

$$(3S_{pk}) = \{(3C_pC_a) + [3C_p(2 - C_a)]\}/2. \quad (6)$$

With given C_p and C_a, S_{pk} can be calculated by Eq. (3), and the corresponding yield can be obtained by Eq. (2). Table 1 summarizes various S_{pk} with $C_p = 1.00$, 1.25, 1.50, 1.75, 2.00, $C_a = 0.00$, 0.25, 0.50, 0.75, 1.00, and corresponding yield (shown in bottom rows). For example, if a process has $S_{pk} = 1.07$, then the corresponding yield is 0.99865 and the nonconformities is roughly 1350 ppm.

The natural estimator $\hat{S}_{pk}$ can be applied to estimate the yield measurement index S_{pk} from a stable process [7]:

$$\hat{S}_{pk} = \frac{1}{3}\Phi^{-1}\left\{\frac{1}{2}\Phi\left(\frac{\mathrm{USL}-\bar{X}}{S}\right)+\frac{1}{2}\Phi\left(\frac{\bar{X}-\mathrm{LSL}}{S}\right)\right\}, \quad (7)$$

where $\bar{X} = (\sum_{i=1}^{n} X_i)/n$ is the sample mean and the conventional estimator of μ.; and $S = [(n-1)^{-1}\sum_{i=1}^{n}(X_i - \bar{X})^2]^{1/2}$ is the sample standard deviation and the conventional estimator of σ.

However, the exact distribution of S_{pk} is analytically intractable, and the process performance cannot be tested [7]. Fortunately, Lee et al. [14] uses Taylor expansion technique to obtain a normal approximation to the distribution of $\hat{S}_{pk}$. The estimator can be expressed approximately by Taylor expansion as [7,14]:

$$\hat{S}_{pk} = S_{pk} + \frac{1}{6\sqrt{n}}\frac{W}{\phi(3S_{pk})} + \frac{O_p}{n}. \quad (8)$$

Table 1
S_{pk} values and the corresponding yield for some typical values of C_a and C_p

C_p	C_a				
	0.00	0.25	0.50	0.75	1.00
1.00	0.22 0.7499999995	0.40 0.7733725716	0.61 0.9331894011	0.83 0.9876871101	1.00 0.9973002039
1.25	0.22 0.750000000	0.45 0.9128746440	0.72 0.9848018145	1.01 0.9987703580	1.25 0.999915825
1.50	0.22 0.750000000	0.50 0.8697054829	0.84 0.9877755273	1.19 0.9996309123	1.50 0.9999932047
1.75	0.22 0.750000000	0.56 0.9526621285	0.95 0.9978337760	1.37 0.9999794165	1.75 0.9999999240
2.00	0.22 0.750000000	0.61 0.9331927987	1.07 0.9986501020	1.55 0.9999966023	2.00 0.9999999980

Note that $W = (\sqrt{n/2})[a(S^2-\sigma^2)/\sigma^2] - \sqrt{n}[b(\bar{X}-\mu)/\sigma]$ for $\mu < m$, $W = (\sqrt{n/2})[a(S^2-\sigma^2)/\sigma^2] + \sqrt{n}[b(\bar{X}-\mu)/\sigma]$ for $\mu > m$, ϕ is the probability density function of the standard normal distribution $N(0,1)$. The statistic W is distributed as a normal distribution with mean 0 and variance (a^2+b^2), where a and b are functions of μ and σ defined as follows [14]:

$$\begin{aligned} a &= \frac{1}{\sqrt{2}}\left\{\frac{\mathrm{USL}-\mu}{\sigma}\phi\left(\frac{\mathrm{USL}-\mu}{\sigma}\right)+\frac{\mu-\mathrm{LSL}}{\sigma}\phi\left(\frac{\mu-\mathrm{LSL}}{\sigma}\right)\right\} \\ &= \frac{1}{\sqrt{2}}\left\{\frac{d-(\mu-m)}{\sigma}\phi\left(\frac{d-(\mu-m)}{\sigma}\right)\right. \\ &\quad \left. +\frac{d+(\mu-m)}{\sigma}\phi\left(\frac{d+(\mu-m)}{\sigma}\right)\right\} \\ &= \frac{1}{\sqrt{2}}\{3C_p(2-C_a)\phi(3C_p(2-C_a))+3C_pC_a\phi(3C_pC_a)\}, \end{aligned} \tag{9}$$

$$\begin{aligned} b &= \phi\left(\frac{\mathrm{USL}-\mu}{\sigma}\right)-\phi\left(\frac{\mu-\mathrm{LSL}}{\sigma}\right) \\ &= \phi\left(\frac{d-(\mu-m)}{\sigma}\right)-\phi\left(\frac{d+(\mu-m)}{\sigma}\right) \\ &= \phi(3C_p(2-C_a))-\phi(3C_pC_a). \end{aligned} \tag{10}$$

In addition, the remaining terms O_p/n represent the error of the expansion having a leading term of order $1/n$ in probability and can be estimated through simulation.

By taking the first order of the Taylor expansion, $\hat{S}_{pk}$ can be approximated by a mathematical approach as [7,14]:

$$\hat{S}_{pk} \cong S_{pk} + \frac{1}{6\sqrt{n}}\frac{W}{\phi(3S_{pk})}. \tag{11}$$

The estimator $\hat{S}_{pk}$ is approximately distributed as $N(S_{pk},(a^2+b^2)/36n\phi(3S_{pk})^2)$ and the estimator is asymptotically unbiased. However, the terms O_p/n cannot be calculated in the mathematical approach. As a result, the simulation approach can lead to more accurate results and is adopted in this research.

4. Simulation for the critical values

The formula of the normal approximation obtained for the distribution of $\hat{S}_{pk}$ is rather complicate, and its reliability/accuracy has not been investigated. For the yield measurement index S_{pk} to be useful to the practitioners, we investigate the critical values c_o computationally using the SAS simulation programming software. Since the critical values c_o is a function of the parameters C_p and C_a, the sensitivity analysis of the two parameters are included in the investigation to ensure that the critical values obtained are reliable.

The simulation was carried out with $N = 10{,}000$ replications for each sample size of n. Type I errors of the test are set to the commonly used $\alpha = 0.05$, 0.025, and 0.01. The simulation results indicate that the critical values are rather sensitive to the two parameters C_p and C_a for sample sizes $n \leqslant 60$. For example, given fixed $S_{pk} = 2.00$ with $n = 60$ and $\alpha = 0.01$, the range of c_o (the difference between the maximal c_o and the minimal c_o) can be as large as 0.05. For practical purpose, we may take the maximal value of c_o among those parameters of C_p and C_a we investigate, to obtain conservative bounds on the critical values for test reliability purpose. This approach ensures that the decisions made based on the critical values, having the risk of wrongly concluding an incapable process as a capable one, is no greater than the preset type I error α, particularly, for short run applications.

Table 2
Sample sizes required for the range of c_o to be within the specified errors, 0.01(0.01)0.10

Error	S_{pk}				
	1.00	1.25	1.50	1.75	2.00
0.10	–	–	–	–	–
0.09	–	20	20	–	–
0.08	–	25	–	–	–
0.07	–	–	25	25	30
0.06	15	–	–	–	–
0.05	–	–	30	35	60
0.04	–	45	50	–	95
0.03	30	55	65	85	100
0.02	35	75	125	120	135
0.01	70	80	130	135	145

Table 2 summarizes the sample size n required for the range of c_o to be within the specified errors, 0.01(0.01)0.10, for $S_{pk} = 1.00$, 1.25, 1.50, 1.75, 2.00, and risk $\alpha = 0.05$, 0.025 and 0.01. For instance, when $S_{pk} = 1.00$ and $n = 15$, the ranges of c_o are 0.03, 0.04 and 0.06 for $\alpha = 0.05$, 0.025 and 0.01. Therefore, for the range of c_o to be within the error of 0.06, the sample size must be 15, which is entered with error = 0.06, $S_{pk} = 1.00$ in Table 2. It is noted that when the sample size n exceeds 145, the range of c_o becomes negligibly small (not greater than 0.01). Table 3 displays the critical values c_o obtained from the simulation (taking the maximal ones among those with different C_p and C_a) for $S_{pk} = 1.00$, 1.25, 1.50, 1.75, 2.00, $n = 5(5)200$, and risk $\alpha = 0.05$, 0.025 and 0.01.

5. An application example

In this study, we investigate the photolithography process of a semiconductor fab in Science-Based Industrial Park in Taiwan. This paper tries to calculate the most suitable number of chips that should be selected in the case that the stability of a stepper which performs the critical process, alignment and exposure, is

Table 3
Simulated c_o for various S_{pk}, $n = 5(5)200$, and $\alpha = 0.05, 0.025, 0.01$

n	1.00			1.25			1.50			1.75			2.00		
	0.05	0.025	0.01	0.05	0.025	0.01	0.05	0.025	0.01	0.05	0.025	0.01	0.05	0.025	0.01
5	2.06	2.32	2.55	2.96	3.51	4.56	3.51	4.26	5.72	4.01	4.95	6.39	4.81	5.91	7.44
10	1.62	1.78	2.05	2.02	2.26	2.55	2.48	2.74	3.12	2.81	3.11	3.54	3.26	3.66	4.19
15	1.46	1.57	1.75	1.98	2.05	2.23	2.19	2.37	2.59	2.51	2.71	2.98	2.91	3.14	3.47
20	1.37	1.45	1.57	1.88	1.96	2.06	2.05	2.19	2.37	2.37	2.54	2.78	2.74	2.92	3.15
25	1.31	1.38	1.48	1.71	1.79	1.86	1.98	2.09	2.24	2.27	2.40	2.58	2.63	2.77	2.97
30	1.28	1.34	1.43	1.66	1.71	1.81	1.93	2.02	2.15	2.21	2.32	2.51	2.57	2.71	2.86
35	1.25	1.31	1.38	1.61	1.69	1.80	1.89	1.98	2.08	2.17	2.26	2.41	2.51	2.62	2.76
40	1.23	1.28	1.35	1.57	1.67	1.79	1.85	1.93	2.04	2.13	2.22	2.33	2.47	2.57	2.71
45	1.22	1.26	1.32	1.56	1.62	1.78	1.82	1.90	1.98	2.10	2.19	2.30	2.43	2.53	2.66
50	1.20	1.24	1.30	1.53	1.60	1.76	1.80	1.87	1.96	2.08	2.15	2.25	2.40	2.50	2.61
55	1.19	1.23	1.28	1.49	1.56	1.75	1.79	1.86	1.93	2.06	2.13	2.21	2.38	2.47	2.57
60	1.18	1.22	1.27	1.48	1.54	1.71	1.77	1.83	1.91	2.05	2.11	2.20	2.36	2.44	2.55
65	1.17	1.20	1.26	1.47	1.53	1.66	1.76	1.82	1.89	2.03	2.09	2.17	2.34	2.42	2.51
70	1.16	1.20	1.24	1.46	1.51	1.64	1.77	1.80	1.87	2.02	2.08	2.15	2.33	2.40	2.50
75	1.15	1.19	1.23	1.45	1.49	1.63	1.74	1.79	1.85	2.01	2.07	2.14	2.31	2.39	2.48
80	1.15	1.18	1.22	1.44	1.48	1.62	1.73	1.78	1.93	2.00	2.05	2.12	2.31	2.37	2.46
85	1.14	1.17	1.21	1.43	1.47	1.61	1.72	1.77	1.83	1.99	2.04	2.11	2.30	2.36	2.43
90	1.14	1.17	1.21	1.42	1.46	1.60	1.71	1.76	1.81	1.98	2.03	2.09	2.28	2.34	2.42
95	1.14	1.17	1.20	1.41	1.45	1.59	1.71	1.75	1.80	1.97	2.02	2.08	2.27	2.34	2.42
100	1.13	1.16	1.20	1.40	1.44	1.55	1.70	1.74	1.80	1.96	2.01	2.07	2.27	2.33	2.41
105	1.13	1.16	1.19	1.39	1.43	1.50	1.70	1.74	1.79	1.96	2.00	2.06	2.26	2.32	2.38
110	1.13	1.15	1.19	1.38	1.42	1.48	1.69	1.73	1.78	1.96	2.00	2.05	2.25	2.31	2.37
115	1.12	1.15	1.18	1.37	1.41	1.47	1.69	1.73	1.77	1.95	1.99	2.04	2.25	2.30	2.36
120	1.12	1.14	1.18	1.37	1.40	1.47	1.68	1.72	1.76	1.94	1.98	2.03	2.24	2.29	2.36
125	1.12	1.14	1.18	1.36	1.39	1.45	1.68	1.71	1.76	1.93	1.97	2.02	2.24	2.29	2.34
130	1.12	1.14	1.17	1.36	1.39	1.45	1.68	1.71	1.75	1.93	1.97	2.02	2.23	2.28	2.34
135	1.11	1.14	1.17	1.36	1.38	1.42	1.67	1.70	1.75	1.93	1.97	2.01	2.23	2.27	2.33
140	1.11	1.13	1.16	1.35	1.38	1.42	1.67	1.70	1.74	1.93	1.96	2.01	2.22	2.27	2.33
145	1.11	1.13	1.16	1.35	1.37	1.41	1.66	1.70	1.74	1.92	1.96	2.00	2.22	2.26	2.32
150	1.11	1.13	1.15	1.35	1.37	1.40	1.66	1.69	1.73	1.92	1.96	2.00	2.21	2.25	2.31
155	1.10	1.12	1.15	1.35	1.37	1.40	1.66	1.69	1.73	1.92	1.95	1.99	2.21	2.25	2.30
160	1.10	1.12	1.15	1.35	1.37	1.39	1.65	1.69	1.72	1.92	1.95	1.99	2.21	2.25	2.30
165	1.10	1.12	1.14	1.34	1.36	1.39	1.65	1.68	1.72	1.92	1.94	1.98	2.20	2.24	2.29
170	1.10	1.12	1.14	1.34	1.36	1.38	1.65	1.68	1.71	1.92	1.94	1.98	2.20	2.24	2.29
175	1.10	1.11	1.14	1.34	1.35	1.38	1.65	1.68	1.71	1.90	1.94	1.98	2.20	2.24	2.28
180	1.10	1.11	1.14	1.34	1.35	1.38	1.65	1.67	1.71	1.90	1.94	1.97	2.19	2.23	2.28
185	1.09	1.11	1.13	1.33	1.35	1.37	1.64	1.67	1.71	1.90	1.93	1.97	2.19	2.23	2.28
190	1.09	1.11	1.13	1.33	1.35	1.37	1.64	1.67	1.70	1.90	1.93	1.96	2.19	2.22	2.27
195	1.09	1.11	1.13	1.33	1.35	1.37	1.64	1.67	1.70	1.89	1.92	1.96	2.18	2.22	2.27
200	1.09	1.11	1.13	1.33	1.35	1.37	1.64	1.67	1.70	1.89	1.92	1.96	2.18	2.22	2.26

examined, or in the case that the quality of an engineering lot needs to be confirmed. In a wafer fab, there are 25 pieces of wafers in a lot, and each piece of wafer has 400 chips. As a result, one lot has 10,000 chips. We need to estimate the number of chips in a lot that should be selected for CD measurement.

The manufacturing specifications are, USL = 210 nm, and LSL = 190 nm. Based on historical data, the process characteristic we investigated is justified to be in statistically control and runs in stable condition, which follows rather close to the normal distribution. The result in Section 4 shows that a sample size greater than 145 is sufficient to ensure that the decisions made are insensitive to the process precision and the process accuracy. In the experiment, 150 chips are randomly selected for CD measurement, and the collected data of observations are shown in Table 4. Sample mean, standard deviation and $\hat{S}_{pk}$ are calculated next.

Sample mean, $\bar{X} = 202.133333333$,

Sample standard deviation, $S = 1.988782862$,

$$\frac{1}{2}\Phi\left(\frac{\text{USL} - \bar{X}}{S}\right) = 0.4999809078,$$

$$\frac{1}{2}\Phi\left(\frac{\bar{X} - \text{LSL}}{S}\right) = 0.4999999997,$$

$$\hat{S}_{pk} = 1.372731973.$$

Table 4
The collected sample data of 150 observations (unit: nm)

199	200	201	203	203	205	202	205	203	201
205	206	203	201	199	205	203	204	202	206
205	205	201	201	205	202	200	198	201	201
201	200	199	198	201	204	202	203	204	202
201	198	200	201	203	204	200	200	202	203
200	200	206	202	204	208	200	199	203	201
203	200	200	201	201	203	202	201	202	201
202	204	201	202	203	201	201	202	201	203
202	202	203	200	204	202	204	198	200	201
201	203	202	199	202	205	204	203	205	207
202	201	202	201	200	203	201	201	203	205
204	201	205	201	199	202	205	204	203	202
200	201	202	202	202	201	204	203	201	200
203	204	203	200	203	204	200	202	202	202
205	206	205	202	204	207	201	201	199	201

With risk $\alpha = 0.05$ and $n = 150$, we use Table 3 to check the simulated c_o for various S_{pk}, and the values of c_o are 1.11, 1.35, 1.66, 1.92 and 2.21 for $S_{pk} = 1.00$, 1.25, 1.50, 1.75 and 2.00, respectively. As a result, the required critical value is $c_o = 1.35$, a value which is closest and smaller than the estimated value $\hat{S}_{pk}$ of 1.37 calculated from the sample data. Thus, $S_{pk} = 1.25$ is obtained. In addition, from Table 1, when $S_{pk} = 1.25$, a corresponding yield of 0.99915825 is found. Note that at a fixed C_a, as C_p increases, the yield rate increases too. Therefore, we may conclude that the process meets the precision requirement $C_p > 1.25$, and the process yield is no less than 99.9916% (equivalently, with a nonconformities of 84 PPM). Therefore, we recommend the testing sample number be 150 chips in a lot.

6. Conclusions

CD control is the critical step for maintaining a high level of yield in wafer fabrication. In this paper, we consider the yield measurement index S_{pk} proposed for normal processes. The measurement index S_{pk} establishes the relationship between the manufacturing specifications and the actual process performance, which provides an exact measure on process yield. The distribution of S_{pk} is analytically intractable though, and process performance testing cannot be performed. Fortunately, $\hat{S}_{pk}$ can be used to fulfill the task. In this paper, a photolithography process in a semiconductor fab was investigated, and the testing process performance of CD measurement was considered based on the yield index S_{pk}. We obtained the critical values required for the hypothesis testing, using the standard simulation technique for various commonly used performance requirements. Extensive simulation results were provided and analyzed. The results indicated that a sample size greater than 145 is sufficient to ensure that the decisions made are insensitive to the process precision and the process accuracy. The investigation is useful to the practitioners for making reliable decisions in testing process performance.

Acknowledgements

The authors like to thank the editor and anonymous referees for their helpful comments and suggestions, which significantly improved the paper. This research is also supported in part by Grant NSC 93-2416-H-167-006.

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