Readout
HORIBA Technical Reports

特集　半導体プロセス計測　　August 1996 ■ No.13

Photomask Inventory Management and Recertification

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(Pages *17−24*)

株式会社 堀場製作所

特/集/論/文　「半導体プロセス計測」
Feature Articles

Photomask Inventory Management and Recertification

Robert W. Murphy*,　Barrie H. Skinner**

1. Introduction

One of the most difficult steps in the photomask process is that of cleaning and pelliclizing a mask or reticle. When a pellicle is attached to a photomask, a micro-environment is created in the space between the pellicle membrane and mask substrata. This space by specification is free of defects at the time of manufacture[1,2]. During use, the pellicle membrane serves as a barrier to ambient particulates and contaminants from reaching the focal plane (chrome/glass surface) of the photomask[3]. Although pellicles are very effective in protecting the photomask, latent defects from inside the pellicle cavity may form on the focal plane during use[4].

This paper describes the types and sources of defects that develop during the lifetime of a photomask in wafer fab. Inspection equipment and techniques for Photomask Recertification will also be discussed.

2. Photomask defects

A photomask defect is an unintended feature or material on a photomask or pellicle causing die failure on a silicon wafer[5]. Photomask defects can be classified as either hard or soft. Hard defects are permanent or semi-permanent (repairable) defects on the chrome or glass surface created during mask manufacture or use (i.e.

ホトマスクの在庫管理と再保証

1.　はじめに

ホトマスク工程で最も難しい作業の一つは，マスク/レチクルの洗浄とペリクル膜の製作である．ペリクル膜は大気中のパーティクルやコンタミネーションからは保護するが，使用中にペリクル内部に潜在欠陥が生じることがある．本稿では，使用中に発生する欠陥の種類と原因，さらに，ホトマスクの再保証用の検査設備と検査方法についても述べる．

2.　ホトマスクの欠陥

ホトマスクの欠陥はハードとソフトの二つに分類される．ハード欠陥は修復が困難で，クロームの斑点状の汚れ，ピンホール，ひっかき傷などがある．ソフト欠陥は，マスクの洗浄やペリクル膜作成時に除去可能な欠陥で，パーティクルと

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chrome spot, pinhole, scratch, etc.). Soft defects are temporary and sometimes mobile defects which are created during mask manufacture or use which can be removed during mask cleaning and pellicle attachment. Soft defects can be further classified as either particles or contamination. Particles are soft defects with a wide focus range (i.e. dust, lint). Contamination are soft defects with a narrow focus range (residual resist, water spots, chemical stains, haze).

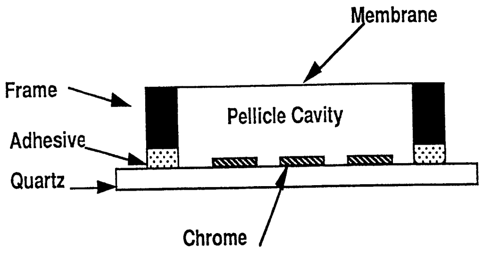

Fig.1 Pelliclized photomask

Membrane damage is the most common reason for pellicle failure6). Most often, membranes are damaged during handling in wafer fabrication. The formation of printable latent soft defects within the pellicle cavity occur with lower frequency but may be more serious. Unlike damaged membranes, latent soft defects do not present an obvious signal that there is a problem. Quite often, the first indication of a problem is a loss of wafer yield. The soft defects that form can only be detected using sophisticated inspection techniques. Because of the unpredictable nature of soft defect formation and the high cost of wafer yield, photomasks are often inspected routinely on a periodic basis (Photomask Recertification).

3. Sources of latent soft defects

3.1 Particles

The basic parts of a pelliclized photomask are shown in Figure 1. When a photomask is cleaned and pelliclized, the chrome surface of the mask is free of soft defects. During usage or shipment, latent defects may form on the chrome surface. Figure 2 shows a particle under the pellicle (PUP). Particles on the glass between areas of chrome can of course block light and print unwanted images on the wafer. Particles on the chrome surface will not cause immediate printing problems, but may be mobile with the potential of problems in the future.

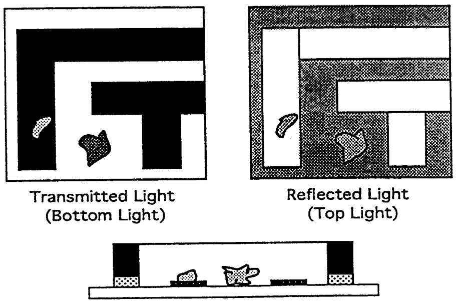
Transmitted Light (Bottom Light)
Reflected Light (Top Light)

Fig.2 Particle under the pellicle(PUP)

Particles on the chrome/glass surface may develop from a number of sources which include: 1) the pellicle membrane, 2) the pellicle frame, and 3) the pellicle adhesive. Figure 3 shows an example of membrane particles. Particles clinging to the underside of the membrane may be missed by inspections during manufacture and drop to the chrome/glass surface in use. Variations in temperature, pressure, and static electricity can cause the particle to move or drop to the surface. Exposure to ultraviolet light may also cause the particle to lose adhesive properties and drop to the surface.

コンタミネーションとに分れる．パーティクルは塵芥，糸くずなど焦点深度の深い欠陥で，コンタミネーションは残留レジスト，水による汚れ，化学的汚れ，ヘイズなど深度の浅い欠陥を指す．

ペリクル膜自体の損傷はウエハハンドリング時に生じやすい．ペリクル膜の内側に生じる潜在的なソフト欠陥は，発生頻度は高くはないが質が悪い．この欠陥は，ウエハの歩留まりが低下して始めて気付き，検出には高度な検査技術が必要となる．歩留まり低下がコストアップに直結するため，ホトマスクは定期的に検査される(ホトマスクの再保証)．

3. 潜在的ソフト欠陥の発生原因

3.1 パーティクル

ホトマスクの洗浄・ペリクル膜形成直後はクローム面に欠陥がなくても，使用/

Figure 4 shows a frame particle. Frame particles are difficult to detect unless specific frame inspections are done during pellicle attachment[1]. Again, as with membrane particles, changes in ambient conditions (temperature, pressure, static) may cause the particle to release from the frame and drop to the surface. Exposure to ultraviolet light may also be a factor.

Adhesive stringers and particles are shown in Figure 5. Exposure to ultraviolet light may cause the adhesive material to become brittle and break away from the adhesive. In addition, if the seal between the adhesive and the glass surface is poor, pressure gradients between the pellicle cavity and the ambient environment can force air through the adhesion gaps and cause particles to dislodge.

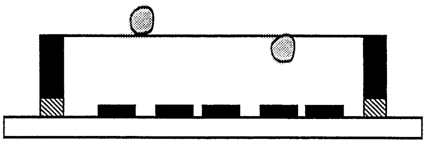

Fig.3 Membrane particle

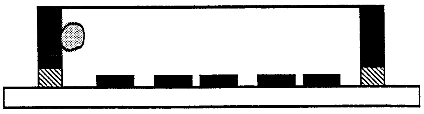

Fig.4 Frame particle

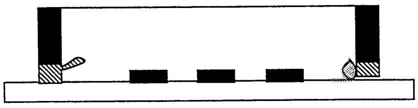

Fig.5 Stringer/Adhesive particle

3.2 Contamination

Latent contamination developing on photomasks is usually in the form of some kind of deposition or crystal formation on the glass or chrome surface. Light crystal formation or haze is manifested by a "fogging" of the plate. Microscopic examination of haze usually indicates a granular (crystal) appearance. Severe crystal formation on the edges of the chrome surface has been documented that is visible to the unaided eye[7]. Haze or crystals are caused by incomplete mask cleaning (residual chemicals or resist), pellicle adhesive outgassing, exposure to solvents, photochemical (UV light) interactions or a combination of all or some of these. In some cases, the source of haze is not easily determined.

4. Photomask defect inspection

Photomasks are inspected for defects in a variety of ways. Some are automatic systems using sophisticated optical image comparators or surface scanning laser technology to detect defects on the photomask substrata. Manual systems, such as microscopes or collimated high intensity light are also frequently used. As each system has limitations, effective photomask defect inspection usually includes a combination of manual and automatic techniques.

4.1 Automatic photomask defect Inspection

(1) Image comparison inspection systems

Figure 6 shows a schematic of an Image Comparison system. In image comparison, two identical features on a photomask (die to die inspection) are inspected using video technology. Video signals from each image are compared and

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運搬中に潜在欠陥が形成されることがある．クローム面上のパーティクルは直ちに印刷されないが，ガラス面(透明部)に移動すると問題になる(図1,2)．パーティクルの発生原因はペリクル膜，フレーム，接着剤などが，使用途中に温度，圧力，静電気などの環境条件の変化，さらには，紫外線照射によって付着力を失って落下することもある．フレームに付着したパーティクル(図4)も，ペルクル上と同様，使用中に落下することがある．接着剤は紫外線照射によりストリンガー(接着台部)が脆くなってパーティクルの原因ともなる(図5)．

3.2 コンタミネーション

潜在的なコンタミネーションは，異物が蒸着または結晶化して曇り(ヘイズ)として表れる．ヘイズの発生原因は，マスクの洗浄不足，接着剤からのガス放出，溶剤の飛散，紫外線による化学反応などに起因しており，原因の特定ができないこともある．

analyzed. Since the features from each image are identical, the video signals should be exactly the same. Differences in the signals indicate the presence of a mask defect. A video image can also be generated from design data used to produce the mask. In this way, the video signal from a physical image can be compared with a video signal from the data (die to database inspection). This comparison is useful on reticles that have only one die or when data integrity is being evaluated. Image comparison systems are typically used during mask manufacture to inspect for hard defects on a photomask. These systems can also detect soft defects in the clear areas of a photomask. Particles or contamination on the chrome surface or pellicles cannot be detected with image comparators. Only the chrome surface of the photomask is inspected.

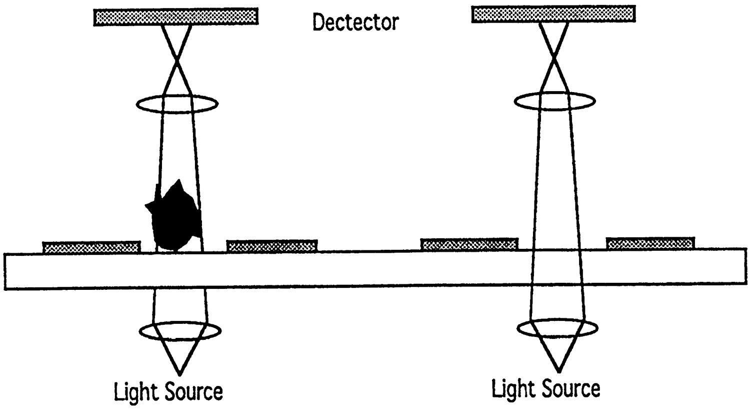

Fig.6 Image comparison inspection system

(2) Surface scanning laser inspection systems

Figure 7 shows a schematic of a Laser Inspection System (i.e. Horiba PD-3000A). Employing laser scattering methods, these systems can discriminate between light scattered from a particle adhering to the reticle or mask pattern surface and light from the pattern. These systems are also capable of inspecting not only the chrome surface, but the glass side of a photomask and two pellicle membrane surfaces if present. Low profile contamination or hard defects are not easily detected by these systems.

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4. ホトマスクの欠陥検査

ホトマスク欠陥検査には多種類あり，光学画像比較法や表面走査レーザ検査法による自動検査システムの他，顕微鏡による手動検査も行われている．それぞれに限界があり，効果的な検査のためには，両者を組み合わせるのが一般である．

4.1 自動ホトマスク欠陥検査

(1) 画像比較検査装置

画像比較装置(図6)は，ホトマスク上の２つの同じパターンを測定し，両者のビデオ画像信号を比較・解析して検査する．パターンが一つしかないときやデータの保全性を評価する場合は，ホトマスクの設計データと比較する場合もある．画像比較検査装置は，主にホトマスク製作時のハード欠陥の有無の検査に使われる．ホトマスクのガラス面のソフト欠陥は検出できるが，クローム面やペリクルのソフト欠陥は検出できない．

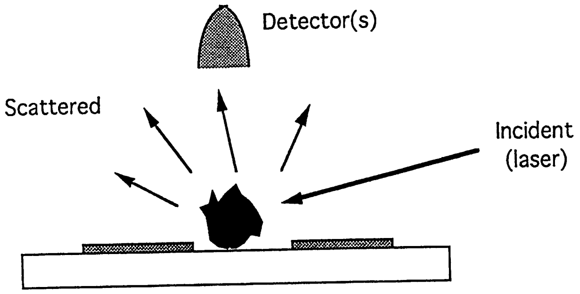

Fig.7　Laser-based particle detection system

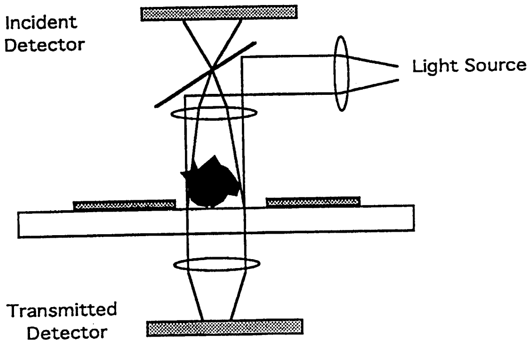

Fig.8　Reflected/Transmitted light inspection system

(3) Transmitted/Reflected light inspection systems:

Figure 8 shows a schematic of a Transmitted/Reflected Light Inspection System. Using a laser source, these systems produce brightfield images of both transmitted and reflected light of a photomask feature inspected. Since light can only be reflected, transmitted or scattered from or through a feature, these systems quantify the reflected and transmitted components and compute the scattered remainder (defect). These systems are capable of detecting particles and contamination on both the chrome and clear areas of a photomask. Hard defects are not easily detected. Unlike laser scanners, these systems can only inspect one surface (chrome) of the mask.

4.2 Manual photomask defect inspection

4.2.1 Microscope inspection

All automatic inspection systems have some limitations. To ensure defect free photomasks, microscope inspections are also necessary. These are three main types of microscope inspection, all of which can be used to inspect photomasks.

(1) Transmitted light

Figure 9 shows a schematic of transmitted light microscope inspection. With transmitted light, chrome images are dark and unpatterned areas are clear.

(2) Reflected light

Figure 10 shows a schematic of reflected light microscope inspection. With reflected light, chrome images reflect light and appear clear. Unpatterned areas do not reflect light and appear dark. This mode is useful for detecting extra chrome defects since contamination and particles also do not reflect light (i.e. chrome reflects light while contamination does not).

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(2) 表面走査型レーザ検査装置

レーザ光でレチクルやマスクの面上を走査し，散乱光を測定・解析して，パターン面とパーティクルとを識別する(図7)．ホトマスクのパターン面やとペリクル面を含む4面の検査機能を持っている．ただし，微小コンタミネーションやハード欠陥の検出は難しい．

(3) 透過/反射型光検査装置

レーザ光の透過光および反射光を測定・演算して，散乱光量<欠陥>を算出する．この装置は，クローム部とガラス部分の両方を検出できるが，表面走査型レーザ検査装置とは異なりホトマスクの片面しか検査できない．

4.2 手動式のホトマスク欠陥検査

4.2.1 顕微鏡検査

欠陥のないホトマスクを得るためには顕微鏡による検査も欠かせない．主な顕

(3) Dark field

Figure 11 shows a schematic of a dark field microscope inspection. With dark field, light is scattered off the chrome surface at an oblique angle. This causes the chrome images to be dark, while chrome edges and particles appear bright. Particles are often easily seen with dark field inspection.

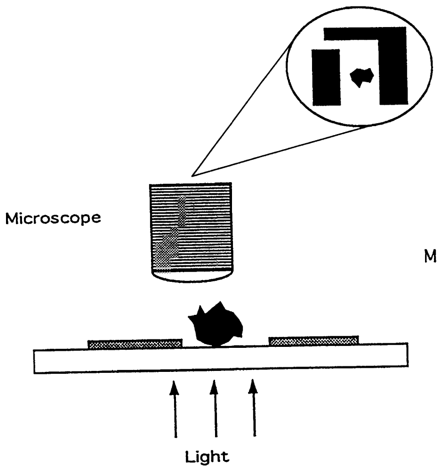

Fig.9 Microscope inspection (Transmitted light)

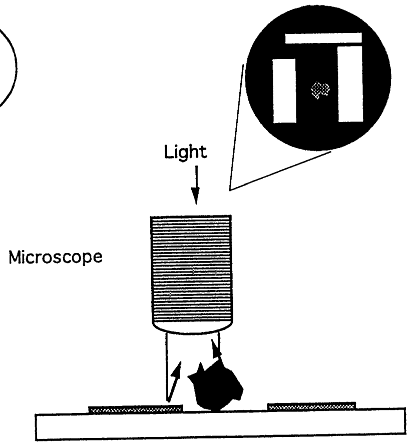

Fig.10 Microscope inspection (Reflected light)

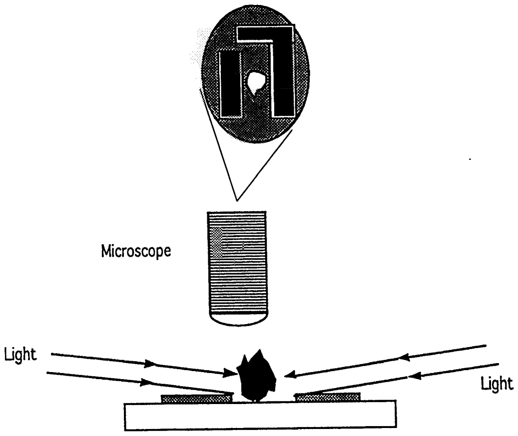

Fig.11 Microscope inspection (Dark-field light)

4.2.2 High intensity light inspection

A High Intensity Light Inspection uses a collimated halogen light source (150W or greater) directed at the photomask from a low angle. Light striking particles on the mask surface are scattered appearing as bright pin dots of light. This inspection is quick and with good technique can detect particles down to about 1 micron[1].

5. Photomask recertification

Photomask recertification is the periodic inspection of masks during use to ensure that latent soft defects have not developed on the chrome surface. Most high volume wafer fab operations include some kind of routine mask inspection at some specified interval to reduce the risk of missing catastrophic yield killing defects on the photomask.

微鏡検査方法には次の３種類がある．

(1) 透過方式

クローム面は暗く，パターンが描かれていない部分は明るく見える(図9).

(2) 反射方式

クローム面は明るく，パターンが描かれていない部分は暗く見える(図10). コンタミネーションやパーティクルは光を反射しないため，クローム欠陥を検出するのに有効に働く．

(3) 暗視野方式

暗視野顕微鏡では，光はクローム面で斜めに散乱して暗くなり，クロームの端部とパーティクルが明るくなるため，パーティクルを容易に見ることができる(図11).

At Apex Lithography Services, a process has been developed to provide a reticle recertification service. Figure 12 is a flow chart showing the steps in the recertification process. Incoming Inspection consists of both a High Intensity Light and Low Power Microscope(5×) examination. At incoming Inspection, the attempt is made to detect defects on the photomask at a macro level. These defects include haze, scratches, pellicle membrane damage, etc. The primary purpose of Incoming Inspection is to detect obvious defects before the mask is committed to time consuming, expensive automatic inspection systems.

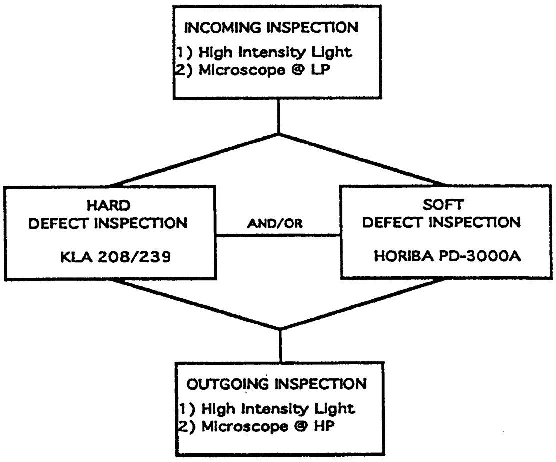

Fig.12 Photomask recertification –Process flow–

The Automatic Inspection step consists of either "die to die/ die to database inspection tool" or "laser scattering particle detection method". Since the primary concern is the formation of latent soft defects, the later is usually the equipment of choice. This type(i.e. HORIBA PD-3000A) is fast (approx 15 minutes) and capable of detecting particles at a sensitivity of 0.5 microns. The former is recommended only for cases where hard defects are suspect. The former type inspection can add several hours to the process flow and is often not feasible in a high volume, short cycle time environment.

The Outgoing step consists of a through High Power Microscope (20×) inspection as well as another High Intensity scan. The purpose of the outgoing inspection is to detect any hard or soft defects that may have been missed by the automatic systems. All automatic systems have defect capture rates ranging from 90-95% which is not sufficient to meet photomask recertification requirements.

4.2.2 高強度光検査方式

コリメータ付きの光源を低い角度でホトマスク照射すると，パーティクルからの散乱光は明るくピンドット状に光る．本方式は短時間で，約1 μm以下の粒子が検出可能である．

5. ホトマスクの再保証

ホトマスクの再保証とは，マスクを定期的に検査し，潜在的ソフト欠陥のないことを保証するものである．ウエハ生産現場では，定期的なマスク検査により歩留りの低下を予防している．

Apex Lithography Services社(ALP)はレチクルの再保証サービス提供を開発した(図12)．入荷検査は，高強度光検査と低倍率顕微鏡(×5)により，ヘイズ，ひっかき傷，保護膜の損傷などをマクロにチェックする．入荷検査で明らかな欠陥

The reticle recertification process continues to evolve as requirements and available equipment changes. Research continues at Apex Lithography Services in the following areas: 1)Frequency of periodic inspections, 2) Sensitivity of inspections, 3) Equipment evaluations, 4) The source of latent defects, and 5) Proper photomask handling and storage techniques.

6. Summary

The sustained integrity of a reticle while in use in wafer fabrication is one area of yield improvement that has been largely ignored. Latent soft defects do form on photomasks after manufacture and initial qualification. These defects may form during shipping or with use and handling. Active photomask recertification programs are necessary to ensure the continuous quality of photomasks.

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をチェックした後，自動検査に移る．

自動検査装置には，画像比較型とレーザ走査型がある．コンタミネーションによるソフト欠陥の検査には後者(PD-3000A)が使われている．PD-3000Aは高速(約15分)で，0.5μmの検出感度がある．前者はハード欠陥検査に限られ，大量・短時間検査には適さない．

出荷検査は，高倍率顕微鏡(×20)と高強度光法により徹底的に行う．本検査の目的は，自動検査で見落される可能性(欠陥検出率　90～95%)がある欠陥の検出にある．

レチクルの再保証は絶えず進歩しており，ALPでは，①定期検査の回数，②検査の感度，③装置の評価，④潜在欠陥の発生原因，⑤正しいホトマスクのハンドリングおよび保存技術などの研究を進めている．

6. まとめ

レチクルの保全を確実に行うことが歩留まり向上につながるが，これまでは無視されてきた．ホトマスクの品質を保証するためには，積極的なホトマスクの再保証が必要となる．

(抄訳　編集部)