Tool Optimization for Improving Productivity and Yields

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Abstract

Tool cleanliness is a prerequisite for increased production ramp, reduced tool downtime and high process yields. Any materials used in the build of material (BOM) must be verified to be clean both in the bulk of the material and on its surface after machining and cleaning. Bulk analyses are destructive due to the nature of the test and the information required. In contrast, surface analyses should be nondestructive so the part may be reused after surface cleanliness testing, or re-cleaned if the test indicates the part does not pass its cleanliness specification. Wafer tool specifications are in place for particles and metals by the OEMs. Particle specification depends on the method of wafer clamping, and wafer metal specification for tool acceptance is typically in the range of 1-5x10^{10} atoms/cm^2. No generally accepted organic specifications are in place. Currently, there are no accepted tool parts particle, metal and organic specifications. Very few machine shops, cleaning houses, OEMs or fabs have developed baseline tool parts cleanliness specifications. This paper describes key analytical techniques for bulk and surface characterization of tool parts.

Introduction

In the sub-100nm technology node, even irreducible differences in the components of identical tool chambers can influence yield and mean time between failures (MTBF). Advanced process control is required to minimize systematic and random variability in hundreds of active tool parts or build of material (BOM). Tool cleanliness is a prerequisite for clean processing; it is an invisible condition that can change the integrity of the wafer surface during processing. The overall equipment productivity in fabs is only ~60 percent. Tool downtime relating to contamination issues includes unscheduled equipment stops, wafer tests, equipment PM, equipment setup time and equipment start-up standby time. The current focus is to increasing profit margin that requires fabs to maximize yield and increase overall equipment productivity and wafer throughput. This places greater emphasis on having cleaner tools, and deliberate selection of BOM is essential because any surface and bulk contamination is a contamination source. In addition, a systematic approach using advanced characterization techniques must be applied

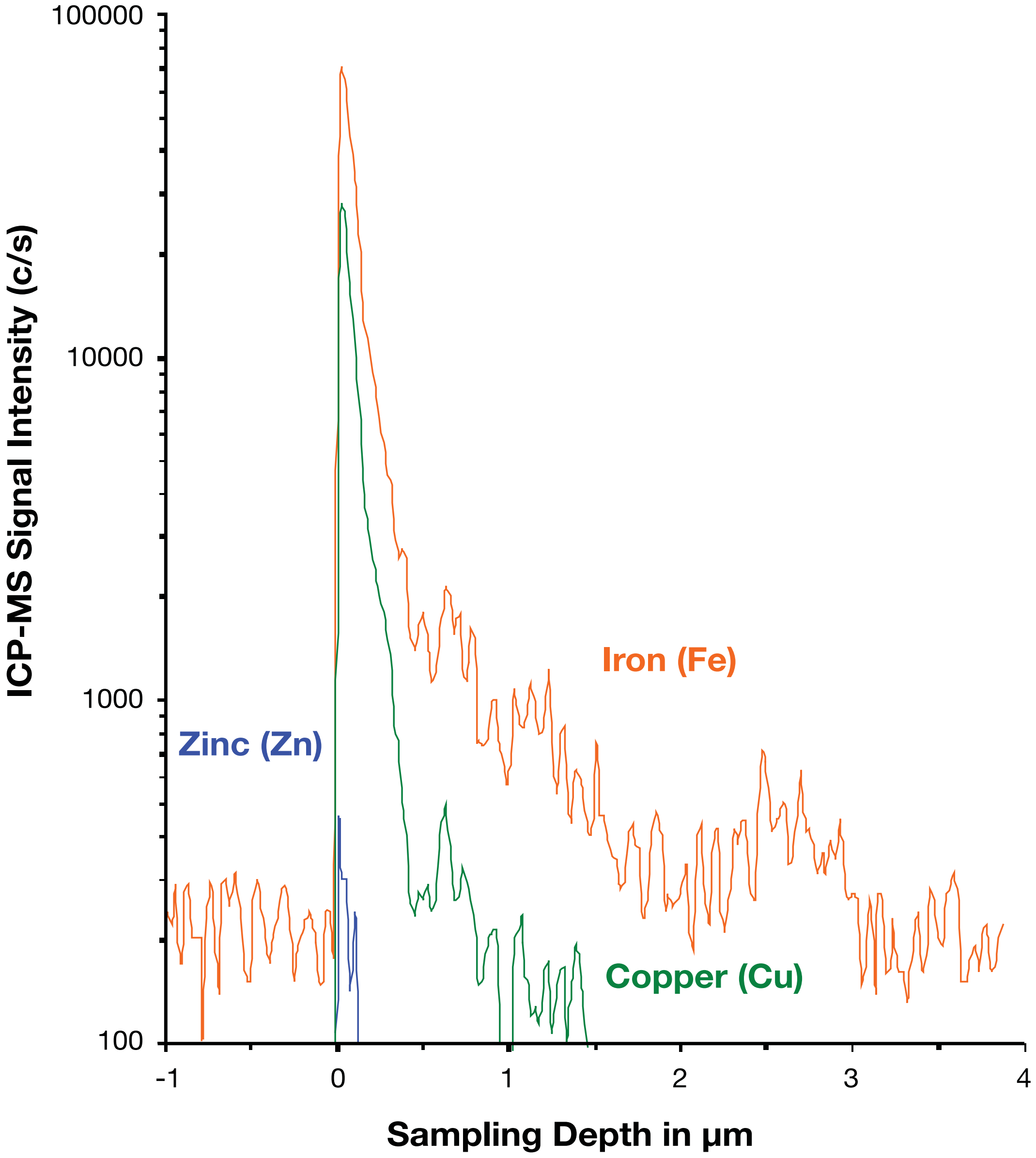

Figure 1. Laser Ablation ICP-MS Depth Profile of Ceramic

when an escalation occurs to quickly identify and resolve the tool contamination.

Material Selection and Bulk Cleanliness

A complete characterization of starting materials for machining tool parts is necessary. Bulk contamination can migrate to the surface during thermal treatment or after many cleaning cycles that involves the removal of the material. Materials such as ceramic, quartz and O-ring vary in bulk cleanliness by vendors and by lot-to-lot. Traditional O-rings with inorganic fillers such as SiO_2, $BaSO_4$, ZnO, Carbon or TiO_2 will shed metallic particles onto the wafers after ~6,000 wafer counts. Laser ablation ICP-MS (LA ICP-MS) can determine bulk metal composition, so a low metallic concentration filler O-ring can be selected for use. Alternatively, an O-ring using organic-filled material can be used to extend MTBF to 20,000 wafer counts. Ceramic and quartz parts must be bulk-characterized to ensure the bulk contaminants are present at low concentrations, as these contaminants will eventually become near or at the surface of the tool part after many cleaning cycles or after extended plasma etching and will migrate to the wafer surface during processing. Figures 1 and 2 show LA ICP-MS profiles of ceramic and quartz analyzed to several microns in depth. Quality differences of materials provided by vendors have been revealed by LA ICP-MS and demonstrated to be the root cause of wafer contamination during processing.

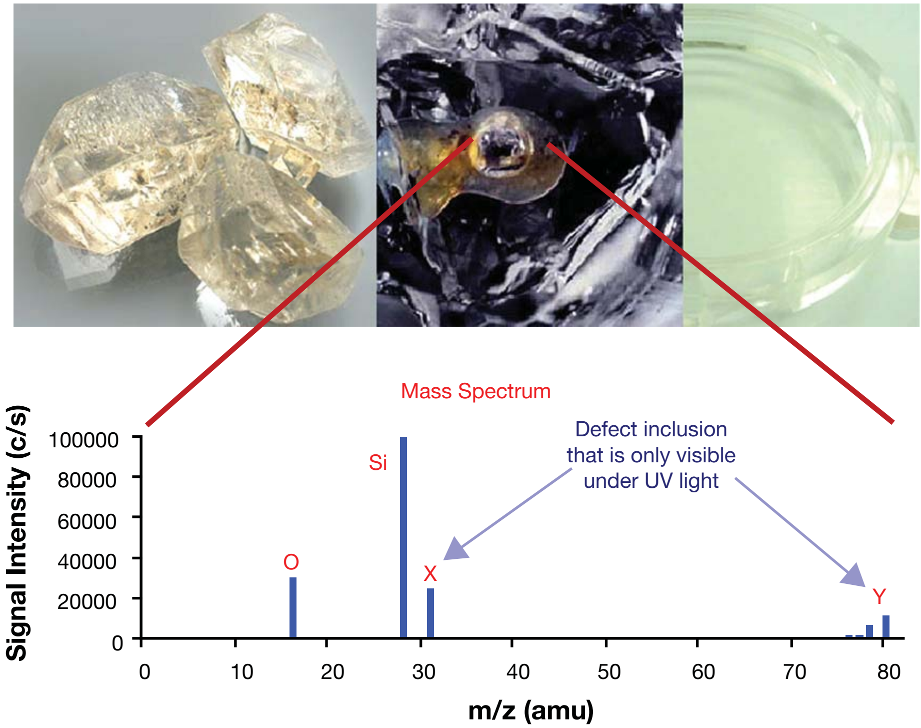

Figure 2. Laser Ablation ICP-MS Bulk Elemental Survey of Quartz

Machined parts are likely to have major surface and subsurface contamination from machine lubricant oil; metal cross-contamination from drill bits; water and solvent residues from rinsing; and contamination from the oven during thermal treatment to relieve stress. Contamination on machined parts may be ranked in importance thusly: Organic > Particle > Metal > Anion.

These machined parts will be precision cleaned, resulting in minor surface contamination remaining typically from handling, cleanroom environment and packaging. The contaminants of concern are Metal > Particle > Organic > Anion. It is important when making a decision regarding material selection and component design that both functionality and its cleanliness requirement are taken into account. A simple material contamination cycle is shown in Figure 3.

Tool Parts Characterization

Table I shows the chemical surface test methods that are nondestructive, wherein the part may be used in the tool after it has passed cleanliness qualification without additional cleaning. Common test methods used are summarized in the table.

Table 2 shows the physical surface test methods that are destructive and used primarily on coupons in R&D of cleaning recipes and material compatibility studies; first on particles, and then if absolutely necessary, on real parts. Common test methods used are summarized in the table.

Additional surface techniques frequently used include:

- UV (black) light: visual inspection for residue polymer on the surface
- Profilometry: surface roughness and surface layer thickness

Case Study

After a weekend predictive maintenance event, the base pressure increased, and Cl was detected at 5×10^{13} at/cm^2 instead of 5×10^{10} at/cm^2 by TXRF. All metal concentrations measured by TXRF were at or below 5×10^{10} at/cm^2 (the wafer cleanliness specification). Chlorine on the wafer was not from insufficient rinsing after acid cleaning that included the use of HCl, since no residue

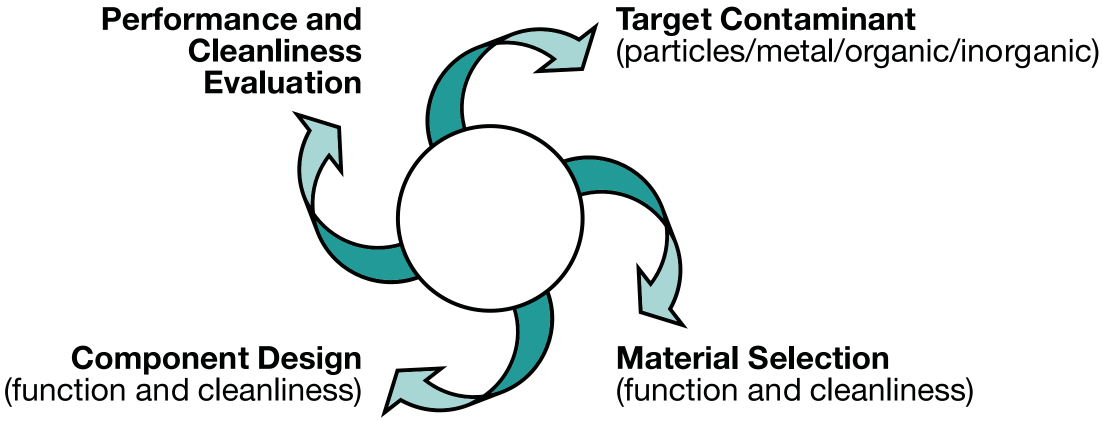

Figure 3. Material Contamination Reduction Cycle

ionic Cl was detected on the wafer surface from UPW extraction and ion chromatography of the extract aliquot. The chlorine was determined to be from an organo-chloride compound using full wafer TD GC-MS.

Interestingly, a static wafer that was left on the ESC for one hour in the tool showed no Cl by TXRF, while a dynamic test with a wafer cycled through the tool showed surface Cl at 5x10^{13} at/cm^2. This experimental observation will reveal its significance once we identify the contamination source.

The organo-chloride compound was identified as a common flame retardant. Flame retardants are often used on foam

SEMICONDUCTOR PROCESS	Metal	Acid extraction & ICP-MS	1
		UPW extraction & ICP-MS	2
Wafer Production Thermal Oxidation/Film Photolithography Etch Doping/Ion Implant Dielectric Deposition CMP		Drop scan etch & ICP-MS	3
	Organic	Solvent extraction & GC-MS	4
		Solvent extraction & NVR/FTIR	5
	Ionic	UPW extraction & Ion Chromatography	6
	Particle	UPW extraction & LPC (SEM-EDS)	7

1. Metal – whole surface extraction
2. Metal – extraction efficiency less than acid
3. Metal – localized surface acid extraction
4. Organic – solvents to extract organic residue and UPW/TOC
5. Organic – weight of NVR and organic identification
6. Ionic – whole surface extraction
7. Particle – whole surface particle counting and identification

Table 1. Chemical Surface Test Methods (Nondestructive)

SEMICONDUCTOR PROCESS	Metal	AES	1
		TXRF	2
Wafer Production Thermal Oxidation/Film Photolithography Etch Doping/Ion Implant Dielectric Deposition CMP		VPD ICP-MS	3
		SIMS	4
		TOF-SIMS	5
	Organic	Full Wafer Outgassing TD-GCMS	6
		TOF-SIMS	7
		XPS	8
	Ionic	XPS	9
	Particle	FE-AES	10

1. AES: 30-50 Å, at percent DL, elemental survey, conducting surface
2. TXRF: 30-50 Å, 10^9-10^{15} at/cm^2, elemental survey, flat surface
3. VPD ICP-MS: SiO$_2$, 10^7-10^{15} at/cm^2, elemental survey
4. SIMS: any depth, 10^8-10^{15} at/cm^2, elemental specific
5. TOF-SIMS: monolayer, 10^7-10^{15} at/cm^2, elemental survey, any surface
6. Full Wafer Outgassing: ng/cm^2, organic survey on selected wafer surface
7. TOF-SIMS: monolayer, ng/cm^2, organic survey, any surface
8. XPS: 30-50 Å, at percent DL, elemental/chemical state survey, nonconducting surface
9. XPS: 30-50 Å, at percent DL, elemental/chemical state survey, nonconducting surface
10. FE-AES: 10nm spatial resolution for elemental characterization

Table 2. Physical Surface Test Methods (Destructive)

cushions, sofas and beds to prevent them from catching on fire. After reviewing the BOM, the root source of the organo-chloride compound was eventually traced to a vibration isolation pad that was blue in color. The BOM specified a black vibration isolation pad that does not outgas. This was confirmed by outgasing the blue and black isolation pads by ATD GC-MS using the industry standard method, IEST WG-CC031. The outgased organic compounds from the blue isolation pad matched the wafer outgased organic signature.

The static and dynamic wafer test results now become clear. No water leaks if you hold a wet sponge. However, if you squeeze the sponge lightly or even shake the sponge with your hand, some water will leak out. This is the case with the vibration isolation pads. When the wafer handler is static, the pads are not active and do not outgas. In contrast, when the wafer handler is moving and transporting the wafer, the pads are adsorbing any vibrations produced, and in the process, they will compress and outgas. So, even though the design specification for vibration insulation was met using the blue pad, its bulk properties were not investigated, resulting in a contamination escalation.

Conclusion

All tool components and parts must be designed using materials that are compatible both to its function and cleanliness. This means individual tool parts in the completed build tool must have cleanliness specifications for its technology node. The smaller the technology node, the cleaner the tool must be. One way of establishing a parts cleanliness baseline is to select a tool that passes all particles, metal, ionic and organic wafer testing. If the tool passes these wafer acceptance tests, then the individual part cleanliness is likely to be acceptable too. This paper described the test methods for surface and bulk material characterization.

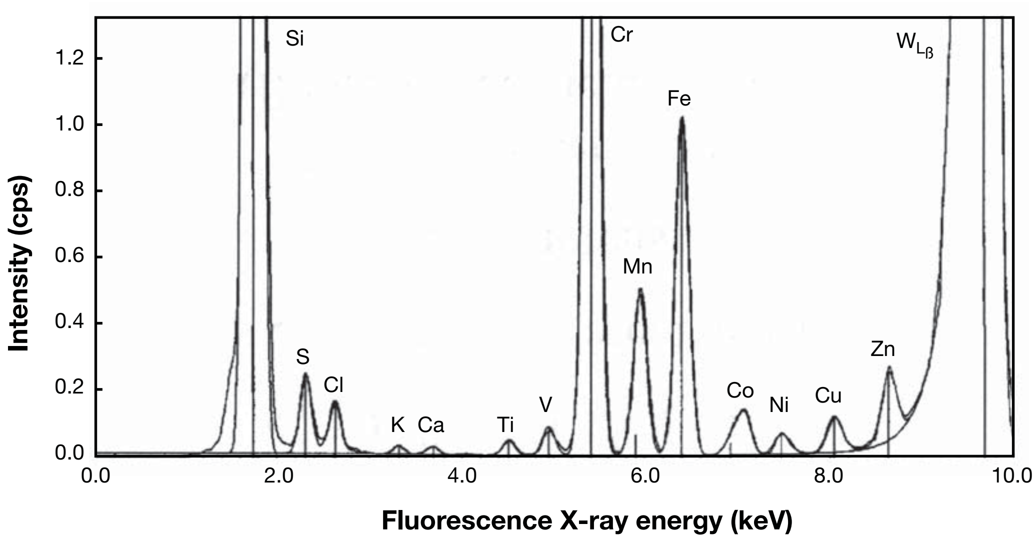

Figure 4. TXRF Spectra of Wafer Processed in the Tool

Most importantly, the surface test methods are nondestructive, and when carried out with meticulous care, the part may be packaged with a certificate of analysis (CoA) and returned to the end user for installing into the tool. The case study illustrates the consequence of not having a part cleanliness specification. If OEMs, fabs and their supply chains operate with parts cleanliness specifications, they will maximize their yield and increase overall equipment productivity and wafer throughput, which in turn will increase their profit margins.

About the Authors

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Dr. Victor K. F. Chia is a director at Air Liquide-Balazs NanoAnalysis, responsible for advancing surface contamination technologies, global sales and international business development. He received his Ph.D. in analytical chemistry from the University of California, Santa Barbara and was a postdoctoral fellow at Lawrence Berkeley Laboratory. Dr. Chia has published over 40 papers and co-authored several chapters on SIMS and contamination characterization.

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