HOW PRODUCTION TECHNOLOGIES INFLUENCE SURFACE QUALITY OF ULTRACLEAN GAS-SUPPLY EQUIPMENT: REQUIREMENTS FOR SURFACE QUALITY

(First of four parts)

Georges Bourscheid and Horst Bertholdt

New technologies in the semiconductor, chemical, food, and pharmaceutical industries are making increasingly tough demands on the process-media wetted surfaces of auxiliary systems, particularly ultraclean gas-supply systems. As a result, ever more meticulous and exacting means of testing are being used to detect and reveal defects on surfaces or in adjacent layers of the systems.

Manufacturers of ultraclean gas components are obliged to examine their production methods and, where necessary, adapt them to the more stringent requirements. Industrial advisory companies can provide advice and evaluation services.

This article is the first in a series aimed at providing answers to questions about how to achieve the required surface quality and what surface-testing methods to use. In Part I, we will focus on the rising demand for purity in the process medium and the resulting specifications for the production of ultraclean components.

REQUIREMENTS FOR ULTRACLEAN GAS SUPPLIES AND COMPONENTS

As circuits on chip surfaces become increasingly miniaturized, the sizes of particles that can cause critical defects have also decreased (Table I). In manufacturing an ultraclean gas-supply system, it is critically important to ensure the system's leak-tight integrity, purging quality, and purity and freedom from particles at the point of use. As semiconductor elements become even smaller, purity requirements will become even more stringent.[1–8]

All semiconductor components (valves, filters, regulators, tubes, and the like) must be produced in such a way that they will not release any additional particles into the process medium.[9–12] Furthermore, the mi-

Chip Memory Capacity (Kb)	Critical Particle Size (μm)
16	0.4
64	0.3
256	0.15
1×10^3	0.09
4×10^3	0.05
16×10^3	0.03
64×10^3	0.01

Table I: Critical particle sizes for highly integrated circuits.[2,3,5]

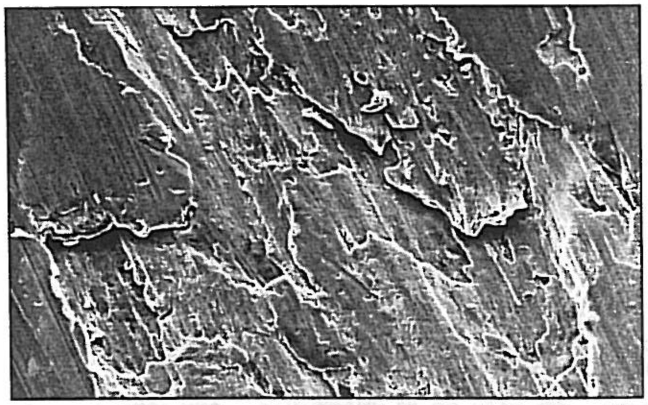

Figure 1: Electronic microscan photograph showing the unfinished surface of an orifice on an AISI 303 valve (enlarged 500×). The flaky fissuring is typical of this material. The surface roughness is about Ra 0.8 μm.

crostructure of each inner surface should be finished so that the surface shows no propensity for trapping particles, moisture, or other damaging compounds (e.g., phosphorus from the polishing electrolytes). Figure 1 shows a typical example of an unfinished surface.

While the valve surfaces represent only a minor part of the entire inner surface of an ultraclean gas-supply system, it has been shown that the valves act as collectors and dispensers of particles.[10] Increased particle generation occurs as a result of turbulent flow, particularly when the valve is in throttling position. Therefore, all parameters that could influence both particle retention and release must be considered in the design of an ultraclean valve. The most important such parameters are material, valve design/construction, and surface processing/treatment procedures (Table II).

GUIDELINES AND SPECIFICATIONS

At present, there are no standard guidelines regarding the manufacture, surface requirements, or test procedures for ultraclean components. The specifications of individual companies are based mainly on the current requirements of cleanroom technology.[4,13–21] The most important industrywide basic cleanroom and technology standards are U.S. Federal Standard 209D, the VDI 2083 cleanroom standard, and British Standard 5295. Table III presents the categories of purity of FS 209D and those suggested in the draft of VDI 2083, including some new categories.

Parameters Influencing the Quality of Ultraclean Gas Components	Requirements
Material	• Corrosion resistance. • Good electropolishing characteristics. • Good machinability. • Material purity (inclusion rate, analysis, melting process). • Good welding characteristics.
Surface (processing/ treatment)	• Surface quality (structure, smoothness). • Freedom from particles. • Cleanliness (freedom from monolayers of organic and inorganic compounds, salts, etc.). • Zero or minimal trapping propensities (outgassing/good rinsing characteristics).
Design	• No dead zones or as few as possible. • Small gas-wetted surfaces. • Surface finish suitable for electropolishing. • Zero or minimal particle generation during operation. • Low external and internal leakage rates.

Table II: Requirements for material, surface quality, and design of ultraclean gas components.

Component-manufacturing requirements vary widely, depending on the individual semiconductor producers (although austenitic CrNi-Steel AISI 316L [corresp. DIN Material Nr. 1.4404/1.4435] has become the predominant structural material, replacing copper). Some customers specify nonelectropolished valves with cleanroom assembly, while others demand electropolished valves without cleanroom assembly. The trend in ultraclean gas components is definitely moving toward electropolished quality, including cleanroom assembly. Table IV shows the range of material

Categories of Purity		Particles/m³			
VDI 2083 Part 1	FS 209D	>0.02 μm[a]	>0.1 μm[a]	>0.5 μm	>55 μm
0[a]	0.1[a]	3.5×10^3	1.2×10^2	3.5×10^0	—
1[a]	1[a]	3.5×10^4	1.2×10^3	3.5×10^1	—
2[a]	10[a]	3.5×10^5	1.2×10^4	3.5×10^2	—
3	100	—	1.2×10^5	3.5×10^3	—
4	1000	—	—	3.5×10^4	2.5×10^2
5	10,000	—	—	3.5×10^5	2.5×10^3
6	100,000	—	—	3.5×10^6	2.5×10^4

[a]—*New particle-size and purity categories.*

Table III: Extended categories of purity, according to drafts of VDI 2083 and FS 209D.

Material	AISI 316L (W.No1.4404/1.4435)
Melting analysis	DIN 17 440, with and without limited analysis
Surface treatment	Polished (mechanically, chemically, electromagnetically)
Surface roughness inside, RA-max	<0.2 to <0.8 μm
Contamination by water-soluble substances	<0.1 to <0.5 mg/m^2
Organic residue	None
Contamination by water-soluble substances (particles)	<350 to <700 particles >0.2 to >0.5 μm/m^3
Nonmetallic material inclusions	<10 inclusions/mm^2
Surface structure	No selective structural aggression (intercrystalline corrosion)
Coloring (discoloring)	None
Clean assembly (according to FS 209D)	Class 1–10,000
Leakage rate	10^{8}–10^{-10} mbar L/sec.

Table IV: List of current requirements for material and surface quality of ultraclean gas valves.

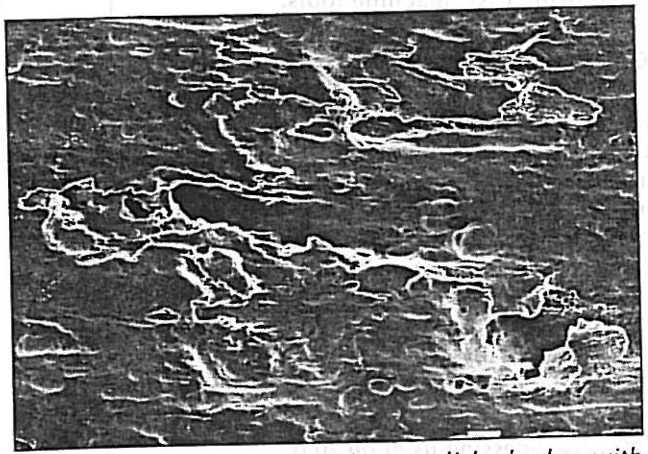

Figure 2: Inner surface of an electropolished valve, with an absolutely insufficient polishing result.

and surface-quality requirements for electropolished valves. All the figures and limit values shown are aimed at ensuring that the process gas reaches the wafer in an absolutely clean state. However, the definition of the requirements is not sufficient on its own to achieve this aim. The greatest deficiency in the quality assurance of ultraclean gas-supply systems is that neither valve manufacturers nor semiconductor producers have a testing technique available that can meet the corresponding requirements. As a result, the measured values obtained are frequently not comparable with one another, especially in tests for soluble residue, particles, organic contamination, leak-tightness, and purity of material. (Specifications and testing methods will be critically evaluated and discussed in Part III.)

Even when extreme care is taken, the quality demanded in the specifications cannot be reliably tested. The inner surfaces of valves provide a good example of this problem, since their poor accessibility makes reliable, nondestructive testing impossible. As a result, the polishing quality of this type of surface is often poor (Figure 2). Typical examples of concealed problems will be discussed in Part II of this series.

It is clearly very important that all quality control measures be thoroughly evaluated prior to production. Such measures pertain to the entrance control, each step of production, cleaning, testing, and the final control. Important points will be set and documented, then strictly adhered to during fabrication. It is worth making such an effort, since this type of self-monitoring by suppliers, in conjunction with standard fabrication and testing measures, will make it possible for deviations from quality to be detected at the outset.

CONCLUSION

As this article has emphasized, surface technology has barely been able to keep pace with the progressive miniaturization in semiconductors. This is especially true of the specifications, evaluation, and testing of the surfaces of parts and components for ultraclean gas-supply systems. As devices continue to shrink, there will continue to be many detailed problems to solve. Only through a thorough analysis of the entire production process will it be possible for production/surface technology to meet the continually rising demands for quality and purity in ultraclean gas technology. A standard quality assurance program would improve quality (and likely also reduce costs) for both component and semiconductor manufacturers.

(The reference listing will appear in a future installment of this series.)

Georges Bourscheid is the industrial director of Ceoduex S.A., Lintgen, Luxembourg. He has worked for the company for six years and is in charge of plant management as well as marketing and sales of specialty gas equipment. He has extensive experience in product and process technologies related to cylinder valves, line valves, regulators, and gas-distribution systems requiring ultra-high-purity conditions.

Horst Bertholdt has been the managing director of CSD-Engineering, Steinhardt, Nürnberg, West Germany, since 1984. He has more than 25 years of R&D and engineering experience in the field of microcontamination, including specification, qualification, control, and protection of pure and ultrapure surfaces as well as the design and implementation of cleaning and decontamination processes. ■