

COSMETICS AS A POTENTIAL SOURCE OF PARTICULATE CONTAMINATION
IN THE CLEAN ROOM

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Since the early 1980's, all major semiconductor manufacturers invoked the "no-cosmetics" policy. This had some severe psychological effects on the female workforce which comprised approximately 90% of the wafer fab employees. In the interest of business (as well as wafer yield), this policy was upheld. This paper discusses some of the psychological responses by the fab operators. Several experiments were performed which indicated that cosmetics presented a source of particulate contamination but at the same time cosmetics can prevent skin flaking. However, the use of cosmetics by both men and women could be detrimental to the cleanroom even when the personnel may not actually be wearing the cosmetics in the clean room. This paper is to raise the level of awareness to the problem of cosmetics in the clean room and to offer some clean room protocol procedures that can minimize and possibly eliminate much of the human contaminants. Cosmetics in the clean room is not restricted to the female workforce. Men are also guilty of using cosmetics while in the clean room. This paper examines this problem and suggests cleanroom guidelines.

INTRODUCTION

A rule of thumb for "killer" defects is that the size of the particulate must be greater than 10% of the line width. Although some geometries on older devices remain above $1\mu\text{m}$, most new devices (for example the x386 and x486 family of products produced by both Intel and Advanced Micro Devices), are near $0.7\mu\text{m}$. Obviously, trying to detect a particle less than $0.07\mu\text{m}$ is difficult using normal particle detection tools (such as the Inspex, SurfScan, Aeronca, Dreyden, etc.). Therefore, the wafer fabs must concentrate on changing the mind-set of all clean room employees. For new employees this is relatively simple - they get this training in new employee orientation. But what about the older clean room employees? In the late 1970's, it was sufficient for the clean room employees to wear a smock and face mask. For a true class 1000 or class 100 clean room, this was adequate protection for the semiconductor products. As the geometries decreased and the clean rooms were required to go to class 10 and then class 1, the protection from human contamination became the primary concern. Contamination from equipment, general airborne particles, process, and process materials was generally understood and could be corrected or at least identified. The human contribution to contamination was a little more difficult for contamination control engineers to identify and control. There is a

wealth of information in the literature on the types of contamination generated by the human body^{1 - 7}. One of the authors describes the clean room personnel as walking torches of contamination. This paper will consider the effects of cosmetics on the human skin rather than the human skin flakes. In many cases, it is the constant use of cosmetic-type products that causes the skin flakes to slough off more than normal. Skin flakes constantly slough off the body but there are ways to minimize this. Several tools are at our disposal to determine the type of contamination found on semiconductor products (and processes). These include scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), Auger electron spectroscopy (AES), and secondary ion mass spectroscopy (SIMS)⁸.

The results of one study showed that there are three main types of on-die contaminants that come from humans: internal body effluvia (spittle, chemically altered spittle, and sneezes), external body effluvia (perspiration, fingerprints, and dandruff), and cosmetics. Both internal and external body effluvia are well documented by Lowry, et al.^{1,2,9} and will not require further discussion. Cosmetics, however are not well documented. In order to be fair to the authors that do mention cosmetics in their published articles^{8 - 10}, very few studies have been done concerning cosmetics as a serious source of particulates since cosmetics have been banned from the clean room. In some estimates, over 95% of these human particulates could be eliminated by improving the design of the face mask or shield as well as placing shields around microscopes.^{11 - 14} Many semiconductor companies have done both.

BACKGROUND

The space program requires 100% electronic uptime on all major systems. In 1985 one of the shuttle missions was scrubbed because mission guidelines did not allow lift off with only 4 of 5 computers operational. The cost of the aborted mission was in excess of \$10 million and the cost of the removal and replacement of the defective component was approximately \$500,000. Failure analysis of the shuttle component found corrosion of the semiconductor metallization as a result of human contamination (spittle, in this particular instance)¹⁴. Similar accounts are described by FAA computers and banking computers failing for similar defects in their CPU IC's.

The space shuttle incidence has caused NASA and FAA to personally audit prime semiconductor contractors. They found that 1 - 3% of all semiconductor devices had some form of human contamination. Since human-related contamination is more of a reliability issue, military specs are now in place to require all microcircuits to be chemically analyzed for any on-die contaminants prior to sealing¹⁵.

Of course human contamination is not the only source of contamination. In addition to human contamination, there is contamination due to dirty equipment, improper processing, mishandling of product, impure or dirty process materials, and electrostatic discharge (ESD). ESD is not often considered as a source of contamination but all particulates have a charge. Some of the charges are positive and others are negative, depending on the type of particulate. Any process that rotates, spins, rubs, or otherwise contacts a semiconductor device creates a charge. If that charge is positive, then it will attract all negative airborne particulates. Similarly, if the charge is negative, then the semiconductor device will attract any positive airborne particulates. Equipment and processes also contribute to the overall problem of contamination. In one study described in the literature¹⁶ the manufacturer found that the ion implanter was charging the wafers causing the wafers to getter all particles which came loose during loading. Figure 1 illustrates the different sources of particulate contamination. This chart will vary from fab to fab but will be approximately as shown. The newer semiconductor facilities will probably find that human contamination may be lower on the graph but this is because their clean room attire covers

nearly the entire employee. Changes by improving clean room protocol will minimize the sources of contamination in the areas that are considered most important.

One of the human contaminants to be eliminated from the clean room was cosmetics. This was a simple fix by establishing the no cosmetics policy. As expected, this created quite a stir among the female employees. The semiconductor management at Motorola, Austin, TX selected engineering sponsors to oversee the study of cosmetics in the clean room. Was it really as serious a problem as suggested? Three contamination control engineers from three different fabs were given the task to study the effects of cosmetic contamination in the clean room and to also obtain some feedback from the wafer fab personnel. The engineering sponsors selected nearly thirty fab operators (including three fab technicians) to systematically develop experiments and to draw conclusions based on the results.

The first task was to devise a questionnaire for all clean room personnel in order to obtain their responses concerning their general feelings toward the no-cosmetics policy. Approximately 960 employees answered the questionnaire. This was 98% of the fab personnel! The questions ranged from "What is your skin type?" to "What brands (or types) of cosmetics do you wear?" Women represented 85% of this study. Two significant questions asked of the women were "Would you give up make-up for the benefit of the company?" and "If you had dry skin, would you change your cosmetics?" Both questions received a 66% negative vote. Now the process of changing the mind-set would be difficult because it was clear that women were resisting the removal of cosmetics. Therefore, the task ahead of the team was to convince the fab personnel that a no-cosmetics policy in the clean room was necessary in order to maintain the competitive nature of the company.

The second task was to develop experiments that could be repeated as often as necessary to illustrate that cosmetics were a serious source of contamination. The experiment was simply having operators with and without cosmetics performing simple wafer handling chores: wafer inspections at an inspection station next to the Aeronca particle monitor. This test was repeated several times per week, using different operators with different skin types. Figures 2 and 3 summarize the results of this testing. Both men and women were tested across all three fabs. In Figure 2, women of all skin types generated more particles when

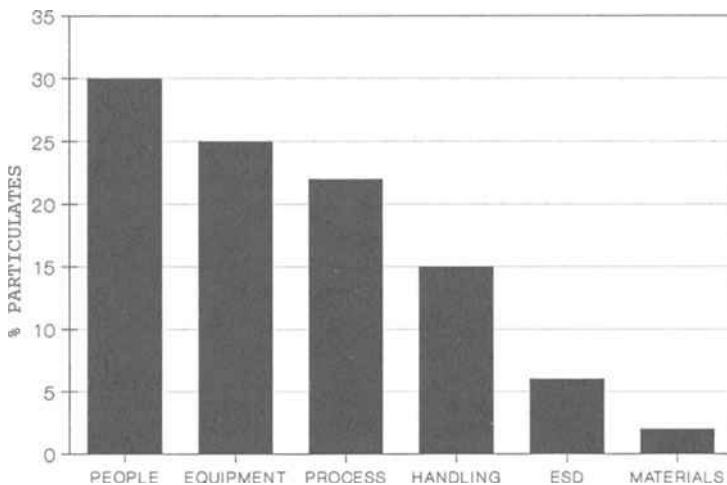


Figure 1. Various contaminant sources in the semiconductor industry clean rooms.

not wearing makeup. This would seem normal since nearly all cosmetics (or, more specifically, make-up) has a moisturizer base which keeps the skin less dry in the harsh conditions of the clean room. The one exception is that women classified as having oily skin flaked about the same, with or without cosmetics. This is because the skin will not slough off as much since the skin has its own built in moisturizing system, called keratin¹⁷. Similarly, women with dark skin tend to have less dryness because of the excess skin pigmentation which also acts as a moisturizer.

In Figure 3 it may seem unusual that men of all skin type were the worse particle generators (note the differences in the scale of the graphs between Figures 2 and 3) while women who wore make-up generated fewest particles. The explanation to this is quite simple. Men use "cosmetics" such as shaving creams and after shave lotions which contain alcohol and sodium hydroxide which dry the skin - hence more skin flaking.

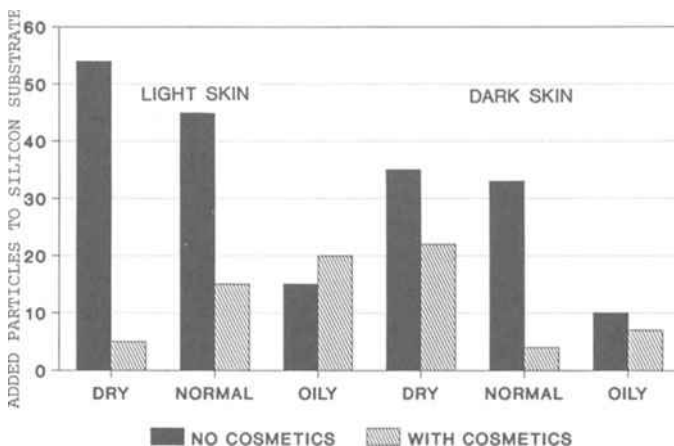


Figure 2. Particulates added to silicon wafers by women with different skin types and conditions, with and without cosmetics.

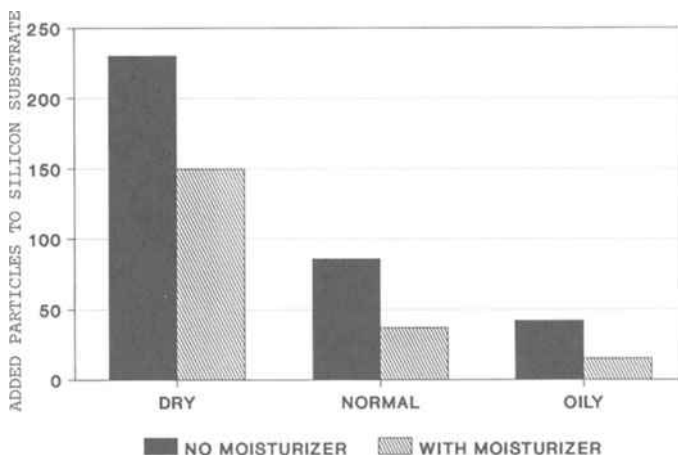


Figure 3. Particulates added to silicon wafers by men with different skin conditions, with and without prolonged use of a moisturizer.

However, women who wore make-up still were particle generators. There are several articles which detail the chemical nature of skin flakes^{1 - 5}. Cosmetics, on the other hand, contain different chemicals and react differently when they contaminate semiconductors^{17,18}.

CHEMICAL COMPOSITION OF COSMETICS

Although the semiconductor industry uses the term "no-cosmetics policy", this is a misnomer. It should be stated as a "no-makeup policy". This distinction should be readily clear. Men wear cosmetics all the time - so do women. After all, shouldn't we include after shaves, colognes, shaving creams, deodorants, perfumes, and moisturizers in the same category? Cosmetics serve two main purposes; a) to enhance one's appearance and b) to protect the skin. Even cosmetics that are used to protect the skin find their way to the microcircuit (or other products relating to clean rooms). In an unrelated experiment in which Advanced Micro Devices was in the process of developing a new site-wide wafer fab protocol spec, the training department began dry-runs of the series of classes involving the new, more rigid clean room procedures. One of the classes involved selected wafer fab operators and the purpose was to demonstrate the proper method to put on the clean room attire. However, the gloves were treated with a phosphorescent powder (the same type used by the police to "lift" fingerprints). Some of the older operators could feel the powder but they passed it off as being part of a new style of glove. After all the participants were in their proper clean room attire (including the gloves), the trainer discussed various protocol rules with the operators. About a half hour later the trainer informed everyone that the gloves had been lightly dusted. One by one, each person stood in front of a full length mirror while the trainer scanned their body with a black light. With few exceptions, there were yellow fingerprints all over their smocks as well on unprotected areas such as their faces and arms. This test was to illustrate that human contamination can find its way to the work area even with all possible protective measures in force. Of course, when the operator is wearing a cosmetic substance that is not detectable, it can very easily get to the work station.

As shown in figures 2 and 3, human particulates occur regardless of whether or not the clean room operator wears cosmetics. Cosmetics (including a few make-up items such as lipstick, fingernail polish, eye shadow, mascara, etc.) manage to find their way into the clean room. Many of the human particulates are not only skin flakes or cosmetic flakes, but generally a combination of the two. Table 1 illustrates the chemical analysis of skin flakes as well as the dominant elements (with their first ionization potentials) found in cosmetics. Many of the ingredients found in cosmetics (or make-up) are helpful to the skin and cause no problem in the clean room. Typically, low sodium moisturizers, lanolin soaps and oils will not be harmful in the clean room. Due to proprietary reasons, the exact chemical nature of some of the ingredients of cosmetics and make-ups was not divulged. However, the trade names gives excellent clues as to the general recipes.

Since oil and water do not mix, it is necessary to stabilize the oil and water mixtures by using emulsifiers. Emulsifiers act as cleansers to remove dirt and oils from the skin surface. Common emulsifier ingredients include glycerol stearate, sodium lauryl sulfate, sodium oleate, stearic acid, emulsifying wax, ammonium lanolate, and others.

Water soluble ingredients that create a protective layer on the skin are called humectants. This layer helps control the evaporation of moisture from the skin. Humectants include propyl glycol, glycerin, sorbitol, and a few sodium derivatives.

Powder products (called powder flow agents by the cosmetics industry) such as blushes and eye colors help the color glide on smoothly. They also help the products hold their cake form. When powder products are applied to the skin, the ingredients help absorb oil in the skin. Powder flow agents include zinc stearate, calcium silicate, magnesium stearate, calcium stearate, lithium stearate, and silica.

Oxygen can cause some cosmetic ingredients to deteriorate. Antioxidants are used to prevent oxidation. They also prevent offensive odors from developing. Antioxidants include BHA, BHT, citric acid, and propylgallate.

Colorants are added to lip colors, nail colors, eye colors, blushes, foundations, and other color cosmetics. Colorants include oxides (iron, titanium, chromium), titanium dioxide, mica, D&C red (calcium and/or barium), FD&C red #3 (aluminum), talc, ferric ammonium ferrocyanide, as well as other variations of these ingredients to obtain the correct color.

Emollients are oil-soluble ingredients which form a protective barrier on the skin. This barrier slows down the rate of moisture loss from the skin and helps soften it. Emollients include oils (mineral, castor, lanolin, corn, hydrogenated vegetable, sunflower, and cotton seed), alcohols (isopropyl, lanolin, oleyl, and stearyl), and various stearates, palmitates, lactates, and oleates.

Preservatives ensure that the cosmetics are free from microorganisms. These cosmetics contain ureas, a nitrogen compound used to destroy the microorganisms.

Waxes and viscosity modifiers give the various cosmetics the proper consistency for application. These ingredients consist of the group of waxes (such as beeswax, paraffin, cellulose gum, lanolin, microcrystalline, synthetic and xanthan gum), aluminum hydroxide, magnesium aluminum stearate, aluminum starch, and kaolin.

There are also ingredients described by the cosmetic industry as "special purpose ingredients." Only a few are shown below:

- Acrylic/acrylate copolymer - smudge resistant
- Aloe vera gel - soothe and smooth the skin
- Ammonium acrylate - temporarily lengthens and thickens eyelashes
- Dimethicone - makes creams and lotions easier to apply
- Oat flower - natural skin smoothing agent
- Petroleum distillate - water resistant solvent
- Phosphoric acid - pH modifier
- Citric Acid - pH modifier
- Sodium hydroxide - pH modifier
- SD alcohol 40 - removes excess oil from oily skin
- Vitamins A, D, E - help promote healthy skin
- Witch Hazel - natural astringent
- Allantoin - natural skin soother
- Menthol - natural skin soother
- Sodium citrate - pH modifier
- Lactic acid - pH modifier

An EDS (Energy Dispersive Spectroscopy) analysis was performed on selected cosmetics. The cosmetics that were selected for analysis are the more common make-ups that can find their ways into the clean room. EDS is only a qualitative tool and does not give percentages of an element. Only relative levels are detected. In the following graphs, the larger peaks are of more concern. The smaller peaks may not necessarily indicate that the detected element was from the cosmetics. All samples were prepared by applying a small amount of the cosmetic to a

Table I. Chemical Analysis of Skin Flakes Vs. Cosmetic Flakes

Electrolytes in Skin Tissue		Dominant Elements in Cosmetics	
Cations	first ionization potential	Element	first ionization potential
(Concentration in the body)			
Na+ (3179 ppm)	-2.710 eV	Ti	6.82 eV
K+ (152 ppm)	-2.931 eV	Tc	7.28 eV
Ca++ (14 ppm)	-2.868 eV	P	10.49 eV
		Si	8.15 eV
Anion		Al	5.99 eV
		Fe	7.87 eV
Cl- (2556 ppm)	+1.358 eV	Mg	7.65 eV
HCO ₃ ⁻ (1664 ppm)	+1.080 eV	Cr	6.77 eV

slide and analyzed using the EDS option of the SEM (Scanning Electron Microscope). The typical energy level was between 10 keV and 16 keV.

Figure 4 is the typical spectrum of a moisturizer. Note the high silicon and titanium peaks. This particular moisturizer also has an abundance of other harmful metallic elements, such as magnesium, aluminum, and iron. Some moisturizers are clean room safe but those that are not safe can go undetected in the cleanroom until the product fails.

Figure 5 illustrates a spectrum for a common face powder. As with the moisturizer, there is a significant amount of silicon and titanium as well as magnesium, aluminum, calcium, and iron. Face powders are not readily detected by supervisors and can be worn inside the clean room without being detected.

Another common cosmetic that makes its way into the clean room is nail polish. This is particularly a problem for those who wear long fingernails which can puncture clean room gloves. Nail polish is not typically banned from the clean room. Figure 6 shows the significant proportions of sulfur and silicon, as well as the popular magnesium, calcium, and titanium. The above three figures indicate that some very harmful cosmetics do get into the clean room and there is no suitable means of "policing" these cosmetics. Moisturizers, face powders, and some fingernail polishes are transparent to supervisors and managers. The key to solving this problem is for proper education of the clean room operators.

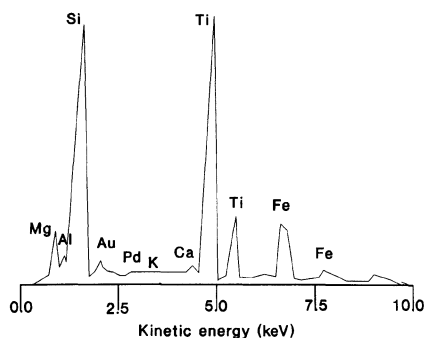


Figure 4. EDS spectrum of a common moisturizer.

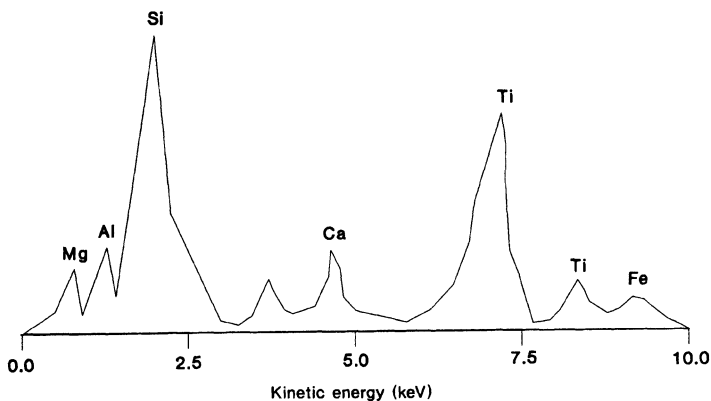


Figure 5. EDS spectrum of a common face powder (residue).

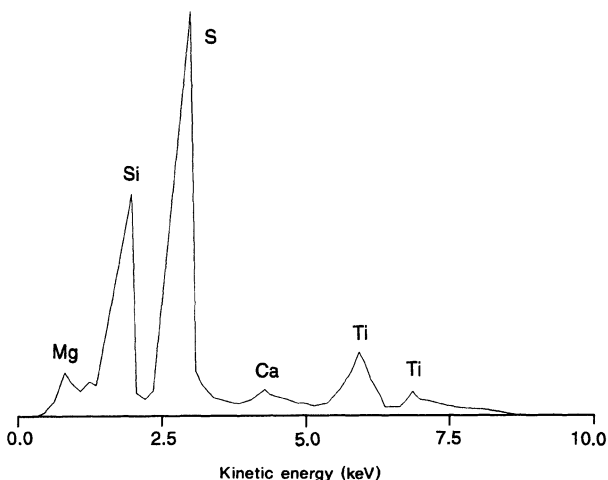


Figure 6. EDS spectrum of a common nail polish (residue).

The final cosmetics that were analyzed are a little more obvious than the prior three (as far as being detected in the clean room): namely black mascara, lipstick, and eye shadow. Figure 7 is the spectrum of a common black mascara. Note the significance of iron (or iron compounds) as well as a multitude of other highly ionizable elements, such as phosphorous, aluminum, silicon, etc.

Figure 8 is the spectrum for a common red lipstick. The highly ionizable elements are still present but in different proportions. Lipstick is high in titanium but also has an abundance of the same elements found in mascara.

Figure 9 illustrates the spectrum of a common eye shadow. Again, many of the elements are highly ionizable, such as titanium, phosphorous, iron, magnesium, aluminum, chromium, etc. Some of these latter cosmetics (mascara, eye shadow, and lipstick) are less likely to make it to the clean room but it does happen - often undetected. Operator awareness may be the only means of combatting this problem and, hopefully, the semiconductor industry (and other clean room related industries) can face the problem head-on and urge the operators to use their own judgement concerning the use of make-up and cosmetics as well as proper skin care.

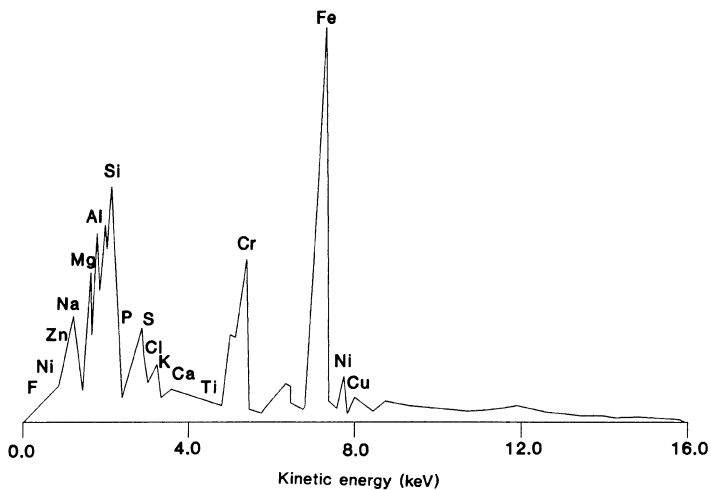


Figure 7. EDS spectrum of a common black mascara.

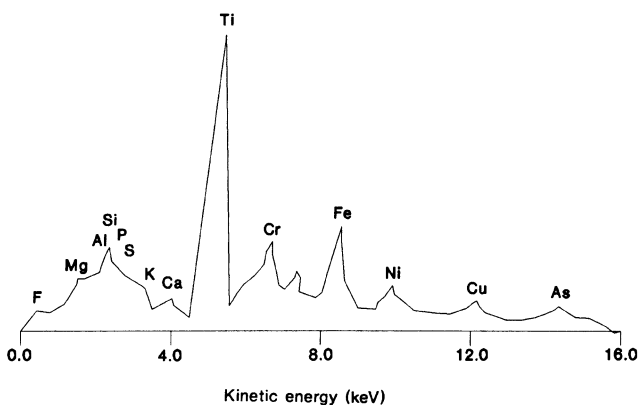


Figure 8. EDS spectrum of a common red lipstick.

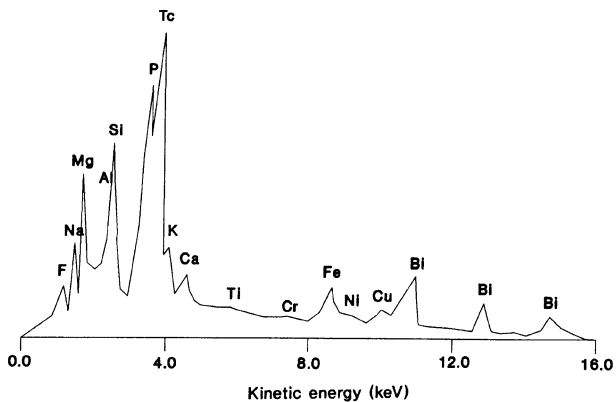


Figure 9. EDS spectrum of a common eye shadow (violet) (The cosmetic company whose products were analyzed asked not to be named for proprietary reasons. All analyses were performed by the SEM labs at Motorola, Inc., Austin, TX and Advanced Micro Devices, Austin, TX)

EFFECTS ON SEMICONDUCTOR PARAMETRIC VALUES

Many of the contaminants in cosmetics are harmless to the wafer fab. But as this paper has illustrated, most cosmetics of all types contain chemicals and compounds that can be devastating to semiconductor processing. The EDS illustrations of Figures 4 through 9 show an abundance of easily ionized elements with low 1st ionization potential. The lower this potential, the easier it is for that element to combine with other elements. Also, Table I shows the common elements in body fluids (or skin tissue) which also have low first ionization potential. As in the case of the space shuttle where the defect was latent, that is, it occurred after the device had been tested and was in the field, many of the defects caused by cosmetics can also be latent. It is these defects for which we have more concern. The immediate defects are usually caught at the manufacturer's facility or even at the subsystem level. Most of the highly ionized metallic elements can cause immediate damage such as metal shorts, breakdowns in the oxides, threshold shifts, and various resistance changes.

To illustrate the effects of cosmetics on the parametric values of the semiconductors, several wafers were contaminated with after shave, talc, eye liner, lipstick, blush, mascara residue, moisturizer, and skin flakes/hair. The tests were performed on Keithley testers at the first electrical test (after the first metal deposition step and before the insulating layer between the double metal process).

The first wafer was contaminated with a common talc. Five sites were measured on each wafer and the delta average values for the five sites are shown below. The following parameters were most affected:

n-channel threshold voltage	$\Delta + 0.10$ VDC
p-channel breakdown voltage	$\Delta - 4.72$ VDC
source-drain resistance(N+)	$\Delta + 8.59 \Omega/\square$
p-channel threshold voltage	no change
metal 1 to poly+ resistance	$> 800 \Omega$

The next wafer was contaminated with lipstick. This device did not exhibit as severe problems as the device described above but, nevertheless, the device would not function had it been put in use by the customer.

n-channel threshold voltage	$\Delta + 0.06$ VDC
p-channel breakdown voltage	no change
source drain resistance(N+)	no change
p-channel threshold voltage(3 of the 5 sites were 0.0 VDC)	
metal 1 to poly+ resistance	no change

The wafer contaminated with dried mascara residue did not exhibit many of the problems seen by the previous wafers. Only the metal 1 to poly+ resistance was affected($\Delta +140 \Omega$)

The wafer contaminated with the blush had no immediate affects on the wafer parameters. These last two examples may cause latent problems, or they could fail the functional test further in the semiconductor process.

A significant change in the n-channel threshold voltage was observed on the wafer contaminated by eye liner. The value shifted by $- 0.16$ VDC. The p-channel threshold was not affected.

The effective p-channel length was the most affected parameter on the wafer contaminated with an after shave lotion. The value changed by $-0.60\mu\text{m}$, or about 50% of the original length.

These are just a few of the types of parameter changes that can occur when cosmetics (and cosmetics on skin) come in contact with a

semiconductor device in the clean room. Most of the processes leave the semiconductor device unprotected until the end of the process. After that point, there is less concern about product contamination, but the elements and compounds found in both human skin and cosmetics can affect even a "protected" device.

CHANGES IN CLEAN ROOM PROTOCOL

It will be up to the individual clean room employee to abide by his or her company guidelines for general skin care - even to the point of suggesting brand names of cosmetic products that are clean room safe. One company has installed sodium free moisturizer in each of the rest rooms and has asked the employees to use the product. Women are more accustomed to using moisturizers so using company supplied moisturizer was not a real problem. Men, however, hesitated, and in many cases refused to use moisturizers although the data were clear that continued use of a moisturizer by men had a dramatic reduction of skin flakes (Refer back to Figure 3). Much of the skin care procedures are the responsibility of the individual employee and cannot be adequately monitored by the clean room supervisors.

Some clean room protocol procedures that are in effect in some semiconductor facilities include "double gloving." That is, the operator wears two pairs of gloves until the gowning procedure is completed, then the operator discards the outer glove. Once inside the clean room, a second glove is again worn over the "clean" first glove. In this way, the operator can discard the outer glove anytime it becomes soiled or damaged (by equipment, touching one's exposed body, etc.) and replaces the outer glove only. This procedure is considered expensive by some fabs but the effects are minimal wafer contamination due to handling problems.

Employees must come to work well groomed. Daily showering or bathing is strongly suggested. After a haircut, the hair must be washed. Fingernails must be kept trimmed and not long or jagged (in order to keep from puncturing the gloves). These requirements can be monitored with relative ease.

In many cases, employees will have to learn to change their habits, primarily in their choice of cosmetics. Talc must not be used and heavy use of aerosol deodorants, perfumes, aftershaves, and colognes must be controlled. Non-aerosol perfumes, colognes, and aftershaves should be used in moderation and not applied during working hours.

Lanolin based lotions are recommended for dry skin. All employees should apply a moisturizer immediately before entering the clean room (most moisturizers are only effective for 2 to 4 hours and probably less in the laminar flow clean room). All employees should wash their hands with a lanolin based soap to minimize drying and flaking skin. Some of the Class 1 clean rooms have wash basins in the gowning areas for this purpose.

And, finally, each clean room should decide on the proper attire for their own environment. If Class 1 protocol is too strict for the amount of allowable particulates, then some of the above protocol suggestions can be modified or even deleted.

SUMMARY AND CONCLUSION

This paper showed the effects of cosmetics as a particulate contaminant to the semiconductor industry. In most cases, cosmetics lower the contamination due to skin flakes but creates another problem by causing cosmetic particulates which contaminate the semiconductor devices. Unlike most human contaminants, the cosmetic contamination can

cause immediate parametric failures, such as lowered breakdown, higher continuities, shifted threshold voltages and severe changes in resistances. Often the cosmetic contamination presents a reliability problem where the effect of the contamination is not seen until the semiconductor device is installed in a system.

The evaluation of clean room protocol is on-going in most semiconductor companies. It is still a matter of educating the clean room employee on the hazards of any foreign substance in the clean room, especially those substances that can ionize and drastically change the characteristics of the semiconductor device.

Proper skin care is the major factor and cosmetics play an important part of that. The wrong cosmetics can dry skin and cause skin flaking. Yet, cosmetics (such as make-up worn by women) are still banned from the clean room. Every effort must be made by the employees to follow the procedures and suggestions given to them by their clean room engineers.

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