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Coating Innovations
for Electronics

TI TECHNICAL INFORMATION

TI 15/13: Precleaning in the pcb fabrication process

Contents

The precleaning of a pcb and in particular its copper constituents has an important influence on the properties and resistances of later applied coatings. Initially it is of secondary interest whether the subsequent coating is an etch and plating resist, a dry resist or a solder mask. What is vital is that the coating exhibits sufficient adhesion to the substrate in order to meet the requirements on resistance, insulation, long service life, etc. inkeeping with the process and purpose intended.

With etch and plating resists, dry films or liquid resists the demands on the lifespan are relatively low and as a rule the required resistances are easy to achieve.

The demands made on a solder mask are considerably harder in many facets. Requirements on temperature resistance, thermal cycling resistance, climatic resistance and so on place higher stress on the solder mask and its bond to the substrate, especially in combination with chemical and lead-free surface finish processes (electroless tin, nickel-gold, lead-free HASL [hot-air solder levelling]) and lead-free solder processes.

Key factors in this respect include high packing density (tight groups of increasingly smaller components), fine structures and advanced requirements on surface quality. Selection of the correct precleaning method can also help in obtaining significant improvements and thus elevate the overall standard of the finished pcb. And, ultimately, by reducing the reject rate, cost saving potential is utilised.

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The type of precleaning has a major effect on the final properties and quality of the pcb. For this reason, special attention should be paid in particular to the pretreatment of the pcb prior to application of the solder mask. The later requirements on the final product are of prime relevance in this regard. With demands especially in the field of automotive electronics on the increase aspects such as permanent temperature resistance, resistance to changing climates, thermal shock resistance, etc. are critical.

The purpose of pretreating a pcb is to establish optimum conditions for application of the solder mask, enabling the latter to achieve its maximum adhesion and final properties. Besides cleaning the surface from residues from previous processes or removing potential oxide films, the objective of the pretreatment process is to create a defined surface roughness which has a positive effect on the ink adhesion. Usually an average peak-to-valley height of at least 2 µm (0.8 – 1.2 µm for flexible laminate) should be aimed for to obtain optimum results, important factors being the average roughness (R_a) and mean roughness depth (R_z), see also Section "Terms".

The pretreatment process also rounds off sharp conductor edges/corners. Because the radius of the corners is inversely proportional to the corner thinning, i.e. the degree to which the ink pulls back from the corners, rounded edges/corners promote a more favourable film thickness distribution and a better edge coverage. Normally, it is only possible to round the edges by means of mechanical pretreatment methods.

Undesirable results as shown in the following images can be avoided by optimum precleaning.

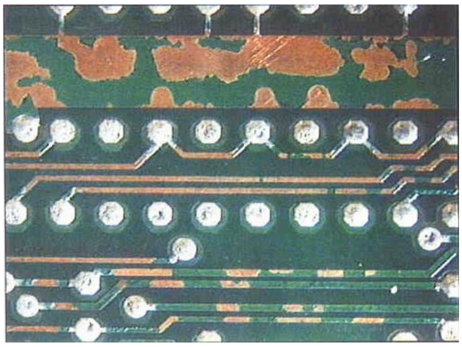


Fig. 1: Ink delamination during HASL
(© Lackwerke Peters)

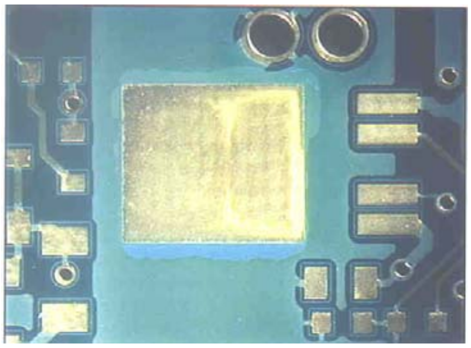


Fig. 2: Undercutting after ENiG
(© Lackwerke Peters)

The pretreatment methods described below give an overview of the processes available and used on the market. Which type of pretreatment is suitable for which application depends on many factors, some of which have a purely economic background. Consequently, a choice should only be made after considering all elements.

Precleaning methods for printed circuit boards

Basically, one differentiates between two types of pretreatment: (a) mechanical pretreatments where various methods – as a rule spraying abrasive materials or using special brushes – are utilised to clean/pretreat the surface and (b) chemical pretreatments where the surface is cleaned/ pretreated with the help of appropriate chemicals, e.g. acids. In some cases, chemical and mechanical pretreatment methods are combined.

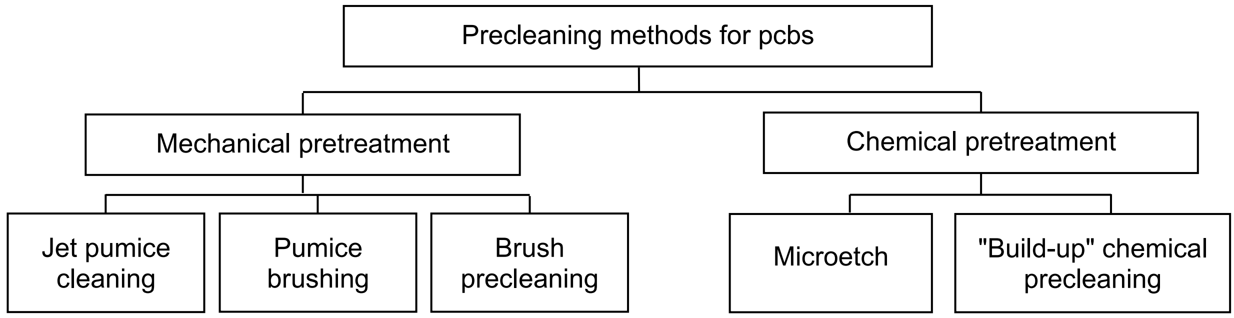


Fig. 3: Overview of precleaning methods for printed circuit boards

As with all processes, the various pretreatment methods have their specialities, benefits and drawbacks which are described briefly in the next section.

Mechanical pretreatment methods

Mechanical pretreatment methods belong to the traditional pretreatment types which basically can be divided into cleaning with a brush and cleaning by spraying with abrasive materials. With brush cleaning there are considerable differences between the brushes, media and parameters used which affect the results.

The standard mechanical pretreatment usually entails removing organic residues and oxide layers from the surface by a mechanical means while at the same time roughening the surface, thus generating the necessary average peak-to-valley height. The process abrades a certain amount of copper, up to 2 µm of copper depending on the parameter settings.

As a rule, printed circuit boards which have been mechanically precleaned can be subjected to any finish process without difficulty. Some restrictions are mentioned separately in the following.

Jet (pumice) cleaning

With jet cleaning a mixture of water and ground pumice are sprayed at high pressure onto the pcb surface through an array of nozzles. This pretreatment method establishes a uniform, plane surface. However, because the ground pumice particles are usually fairly round and not very hard, only a minimum amount of copper is abraded so that this type of pretreatment does not normally create a particularly good base for the subsequent solder mask application.

In particular if the surface is slightly oxidised or contaminated with other substances, experience has shown that this pretreatment method quickly reaches its limits. Also in combination with the standard chemical surface finish processes used today, the "hammered" copper surface after jet pumice cleaning does not present an ideal base for the solder mask.

It is possible to achieve better results by combining jet pumice cleaning with a chemical pretreatment method or by using corundum (aluminium oxide) instead of ground pumice as the following images demonstrate.

Fig. 4: Cu surface after jet pumice cleaning
2500x magnification
(© IS International Supplies s.r.l., Italy)

Fig. 5: Cu surface after aluminium oxide cleaning
2500x magnification
(© IS International Supplies s.r.l., Italy)

With the much harder corundum and sharp-edged geometry of the individual particles a considerably higher surface roughness can be achieved and the adhesion of the subsequently applied solder mask improved.

Because jet cleaning involves conveying a solids/liquid mixture at high pressure through hoses and nozzles, the precleaning equipment frequently shows signs of wear after a relatively short space of time meaning that the nozzles must be replaced, etc. This is accelerated once again when the much harder corundum is used.

After cleaning, the boards must be adequately rinsed in demineralised water, if possible in a high-pressure rinser at a water pressure of up to 100 bar to remove the ground pumice/corundum residues from the holes, including the small ones. The smaller the hole diameter or the higher the aspect ratio, the higher the risk of the holes getting blocked with residues.

(Ground pumice) brushing

Like with jet pumice cleaning the pretreatment with ground pumice brushing involves the use of a water/ground pumice mixture. However, contrary to jet cleaning the mixture is projected at the board continuously at a relatively low pressure. Rotating nylon brushes mechanically support the cleaning of the copper surface. Consequently, the cleaning result is far better than with jet cleaning alone and the surface is "sand-blasted". Due to the uniform yet rough surface, in general a very good adhesion of the latterly applied solder mask is achieved. A further advantage of this procedure is that boards of varying thicknesses can be pretreated in the same machine usually without the need for any adjustments. The relatively soft nylon brushes make this easily possible.

The same as with jet pumice cleaning after ground pumice brushing the boards must be sufficiently rinsed in demineralised water in a high-pressure rinser to remove any pumice residues.

It is equally possible to improve the adhesion by using corundum instead of ground pumice, but the overall higher wear of the machine is still to be expected.

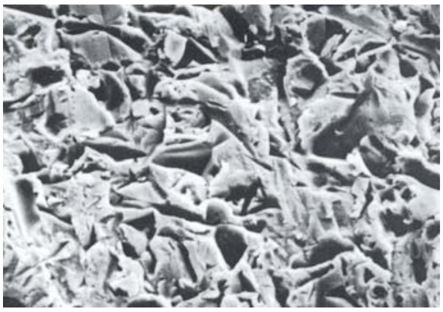


Fig. 6: Cu surface after ground pumice brushing 2500x magnification
(© IS International Supplies s.r.l., Italy)

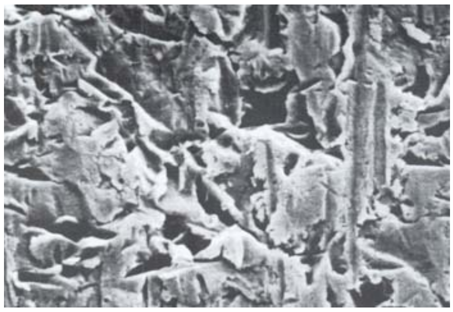


Fig. 7: Cu surface after aluminium oxide brushing 2500x magnification
(© IS International Supplies s.r.l., Italy)

What jet cleaning and ground pumice brushing have in common is the relatively complicated rework that is necesssary on the used suspension. The copper elements and other contaminants left over from the pretreatment process are filtered from the suspension in a separate process (centrifuge). The suspension is then channelled back into the cycle. This process is simplified if corundum is used because of its high specific density.

As a rule, the concentration of the ground pumice suspension should range between 10 and 16% of ground pumice. Typically, the concentration is around 12%. Similar figures apply for corundum.

Corundum has the additional benefit that it can be purchased in different grades and shapes enabling the precleaning process to be adapted to one's individual requirements.

In principle, ground pumice is also available in different grades, but the higher deterioration (soft particles get broken or rounded) means that the grade and/or shape of the particles soon change making it necessary to replace the medium. The harder corundum also triumphs in this respect.

Brush precleaning

Brush precleaning involves the use of various types of brushes impregnated with sanding media. Due to the characteristically high revolution speed and adjustable brush pressure, depending on the chosen brush a good to very good surface roughness and adhesion of the subsequent solder mask are achieved. The oscillation of the brushes (i.e. the transversal movement in relation to the feed direction) and the travel direction of the brushing bar are important factors. Amongst other things, the oscillation ensures the brushes wear evenly and that a uniform brush stroke – in other words a uniform roughness – is obtained.

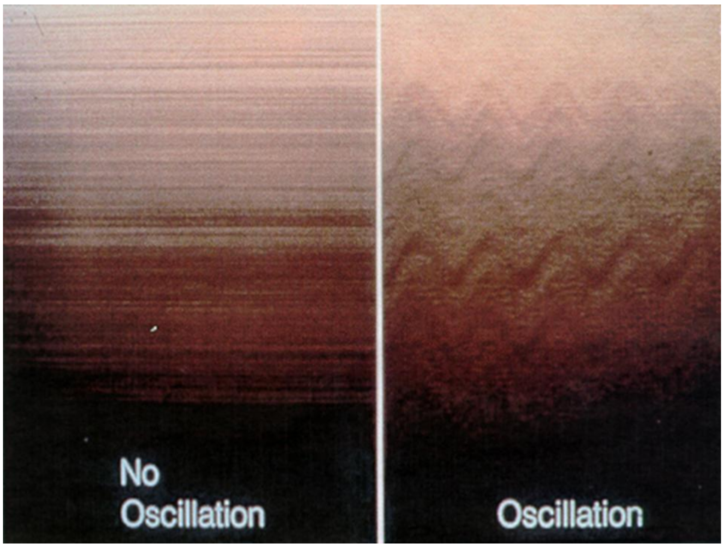


Fig. 8: Comparison of the Cu surface after cleaning with and without an oscillating brush
(© Falkenrich, Iserlohn, Germany)

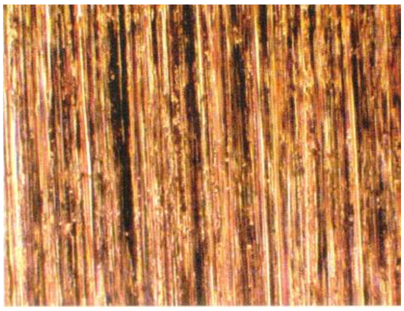


Fig. 9: Cu surface after brush precleaning
(© Falkenrich, Iserlohn, Germany)

With so many different types of brushes and potential parameters, such as brush pressure, oscillation, backing roll pressure, feed rate, etc., the quality of the brushing result depends very strongly on the operator's experience.

Overall it can be said that the surface roughness, uniformity and the adhesion of the latterly applied solder mask achieved with conventional brush precleaning is good to very good. The main drawback of this type of pretreatment is that the distance of the brushes must be adjusted for every board thickness.

Chemical pretreatment methods

The number of different chemical pretreatment methods available on the market is immense and it is relatively difficult to directly differentiate between the various products. Therefore the chemical pretreatment methods are split into "abrasive methods" (microetching) which usually have no or little influence on the surface topography and the "build-up methods" which effect a strong change in the surface topography.

Microetching

The term "microetching" is the general classification for all precleaning methods where the copper is abraded by the attack of acids (e.g. H_2SO_4/H_2O_2) and other chemicals (e.g. NaPS, sodium peroxodisulfate, $Na_2S_2O_8$). The copper is abraded very evenly in the range of 1 ± 0.2 µm. The even abrasion of the copper means that the microetching process normally has very little influence on the surface topography. Accordingly, the average peak-to-valley height after microetching depends strongly on the roughness of the printed circuit board prior to microetching. The microetch process does not round the conductor edges so that often very sharp edges remain. Because microetching only attacks the copper and removes potential oxide layers, organic contaminations, such as fingerprints, from handling the boards may not be removed. In this case the printed circuit board must be degreased in a previous process to free it of residues of grease, oil and other organic pollutants.

Generally speaking, the efficiency of microteching is limited when it comes to the necessary preparation of the copper surface for the subsequent solder mask application. The results achieved with this type of precleaning restricts its use, if at all, to boards that are latterly furnished with an OSP (Organic Solderability Preservative) finish.

Often microetching is used in combination with mechanical pretreatment methods in order to remove oxide layers between the conductors.

"Build-up" chemical precleaning methods

"Build-up" chemical precleaning processes comprise those methods where an oxide layer is systematically created or where no uniform abrasion of the copper takes place. The methods include black and brown oxide processes and methods that utilise special etching principles.

All these methods have in common that they can effect major changes in the surface topography and surface roughness. Normally, these methods are used for the pretreatment of multilayer inner layers where an extremely high adhesive power is required to laminate the individual layers. As these systems became further enhanced they also started to be used for the pretreatment of printed circuit boards prior to application of the solder mask.

While brown oxide and black oxide processes (available under various trade names) play a lesser role in the pretreatment of pcbs before solder mask application (the resultant surface structure is problematic during the development process or the later surface finish process), the processes that utilise special etching principles have gradually established and proven themselves in an increasing number of fabrication setups. As a rule, such methods work by the grain boundary etching principle (see Section "Terms"), enabling a very good surface roughness to be achieved which leads to an excellent adhesion of the subsequently applied solder mask.

The following images offer a comparison of the surface structure after microetching (by example of NaPS or an acid etching medium) and grain boundary etching (in this case MECetchBOND MEB):

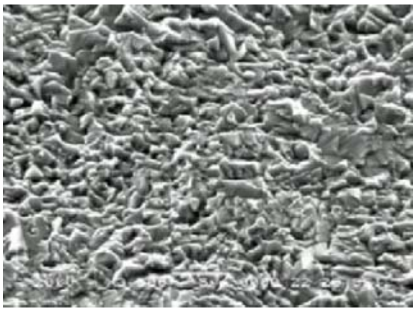


Fig. 10: Cu surface after NaPS

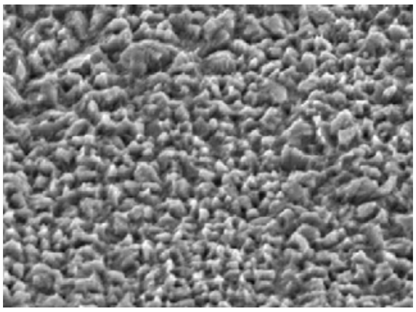


Fig. 11: Cu surface after H_2SO_4/H_2O_2

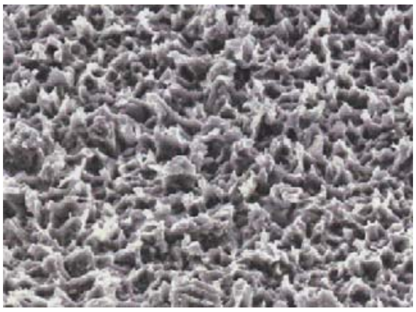


Fig. 12: Cu surface after MECetchBOND MEB

3500x magnification (© MEC Europe NV, Gent, Belgium)

The significantly improved solder mask adhesion increases the resistance of the overall structure, e.g. to chemical surface finish processes. This way, it is possible to attain good resistances to Ni/Au or CSn processes even with a low wet ink weight.

The savings naturally stand against the costs for these processes. Being multi-step processes where partly only special materials can be used, initial investments in the appropriate equipment are necessary, plus the expenditure for the process chemistry must equally be taken into consideration.

However, even if the costs are much higher than for microetching or brushing, in general these processes are worth their while due to the lower reject rate in the follow-up processes and reduced solder mask consumption. This should be remembered when weighing up the costs for such pretreatment processes.

Moreover, there are applications where it is either necessary or specified to use these special pretreatment methods because the requirements on the finished assembly with respect to the temperature resistance, thermal cycling resistance, climatic resistance, etc. demand it. In particular there is the permanent temperature resistance of up to 2000 hours at 150°C and the thermal cycling resistance of –40°C to +150°C with a holding time of 30 min and a transition time of < 10 s, all this up to 2000 cycles while boasting excellent adhesion at the same time.

Besides MECetchBOND by MEC Europe named as an example above, there are other comparable precleaning processes, such as FerroEtch by Atotech or MultiPrep by MacDermid.

Drying after precleaning

The process of drying the printed circuit boards after precleaning has a major influence on the adhesion of the solder mask, therefore a separate section has been dedicated to this topic.

The pcb surface must be dry prior to precleaning to avoid problems with wetting of the subsequently applied solder mask and to achieve optimum adhesion of the solder mask especially in chemical surface finish processes. Problems can also occur during HASL where even miniscule residues of moisture, particularly in the holes, can give rise to considerable difficulties with the adhesion. For this reason, special attention must be paid to drying the holes in the pcb.

In the past, systems that work with both a hot-air fan and a vacuum facility where the holes are sucked empty have proven a good option. With both systems so-called "slit systems" are considered ideal because an extremely small area can be dried very effectively. "IBM nozzles" where the air is forced through fine openings under high pressure have become more and more established. Due to the ensuing friction the air gets very hot, dispensing with the need for supplementary heating elements. The "IBM nozzles" are fed by means of side channel blowers. The advantage that no additional heating elements are needed is counteracted by the space required by the side channel blowers.

But even if a pcb appears to be dry and its surface in good order after precleaning, problems can still arise. This is often due to the use of standard mains water to rinse the boards. Depending on the region the mains water can contain large amounts of salts or lime. When the boards are dried the leftover water film dries and residues of salt or lime remain on the copper surface, impairing adhesion of the solder mask and potentially causing problems in the finish processes.

Therefore it is vital to regularly control the quality of the rinsing water. Fluctuations in the mains water quality can lead to inconsistent results which are frequently the reason behind problems and failures.

To obtain optimum rinsing results and as clean a surface as possible, it is advisable to use deionised or 100% desalinated water, at least in the final rinsing zone. Even if this is linked with higher costs, as a rule the increased process reliability and prevention of expensive failures make it worthwhile.

Verification of wettability

Although the results at the end of the pcb manufacturing process show whether the pretreatment method used was the right choice, there are simple and quick tests that can be performed directly after the pretreatment step to ascertain the cleanliness (grease-free condition) and wettability of the copper surface. The "water wettability" test constitutes applying water to a copper surface and determining the flow behaviour. If the water covers the complete surface and runs off as a whole, i.e. without forming droplets or trickles, this normally indicates a good wettability and a correspondingly clean surface. If the water collects into drops and more or less pearls off the copper surface, this is a sign of wetting problems and the precleaning process should be reviewed.

The same test can be performed with a felt-tip pen. In this case, the pen mark on the board should fuzz (run).

Conclusion

Which pretreatment method one prefers depends on many factors, such as the type of surface finish process and achievable quality, and naturally also financial aspects.

The RoHS directive (EU directive 2011/65/EU "Restriction Of the use of certain Hazardous Substances in electrical and electronic equipment") and the resultant changes both in printed circuit board fabrication as well as in the assembly field lead to overall higher expectations being placed on the pretreatment process. The significantly higher temperatures of the HASL and lead-free soldering processes during assembly or the alternative surface finish processes such as nickel/gold or electroless tin subject the solder mask to a higher load and require an overall higher resistance.

In this respect, particular mention should be made of the electroless tin process. For lead-free soldering during the assembly process a much thicker layer of tin up to 1.2 µm is required (previously 0.6 to 0.8 µm) than with leaded soldering. This high tin layer is achieved by considerably longer contact times and/or more aggressive chemistry. The extra load for the solder mask and its adhesion to the substrate is substantial.

As a consequence of the RoHS directive the subject of precleaning has increased in importance and must be addressed under the new evolving conditions.

After taking all factors into consideration, the modern chemical precleaning methods (based on grain boundary etching) have proven their worth against the traditional precleaning methods with a mechanical back-up (brushing, ground pumice/corundum brushing). The importance of the precleaning process becomes even more evident in light of the required permanent temperature resistance (e.g. 2000 h at 150°C) of the pcb/assembly or thermal shock load (-40°C/150°C, holding time 30 min each, 10 s transition time). Equally in this respect chemical precleaning methods demonstrate their efficiency alongside the traditional methods.

Our **Application Technology Department (ATD)** would be happy to help you with the selection, optimisation or expansion of a suitable precleaning process as well as support your evaluations and choice of the right equipment.

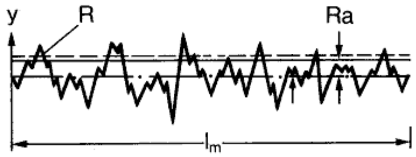
Terms

This chapter describes some of the terms and defintiions used above. You can find further information amongst others in the DIN EN ISO 4287 "Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters".

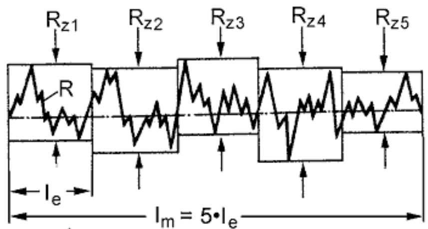
- **Roughness**
  Roughness is the term used for imperfections in the surface. Various formulae can be applied to characterise the roughness which each take different peculiarities of the surface into account. The most common terms or roughness parameters are R_a (average roughness) and R_z (mean roughness depth).

- **R_a, average roughness**
  R_a is the average value that is calculated from all deviations in the roughness profile from the centre line over the defined sampling length. Theoretically, Ra equates to the distance of several lines which are formed when the peaks above and the valleys below the centre line are converted into rectangles of the same size.

$$R_a = \frac{1}{l_m} \int_0^{l_m} |y|\, dx$$



- **R_z, mean roughness depth**
  R_z is the mean value of the roughness depths in the roughness profile measured over five consecutive sampling lengths. The greatest extremes within each sampling length are added together; the range is then divided by the number of sampling lengths.



$$R_z = \frac{1}{5}\left(R_{z1} + R_{z2} + R_{z3} + R_{z4} + R_{z5}\right)$$

- **Optical interference method**
  Besides the profile method and SEM analysis the optical interference method is also suitable to determine roughness data. Below are images of copper surfaces that were subjected to different pretreatments:

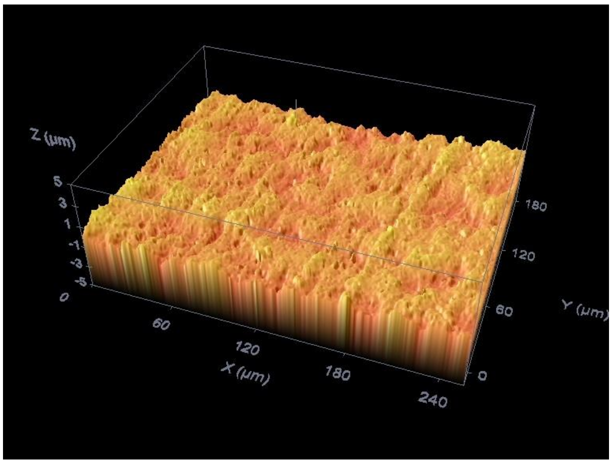


Fig. 10: jet pumice
(© Atotech Deutschland GmbH, Basel, Switzerland)

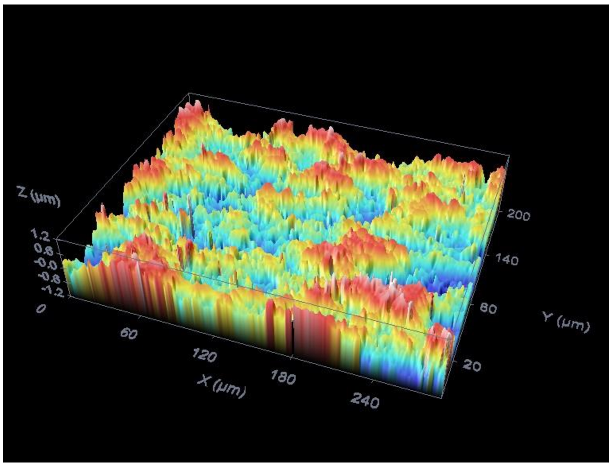


Fig. 11: pumice brush
(© Atotech Deutschland GmbH, Basel, Switzerland)

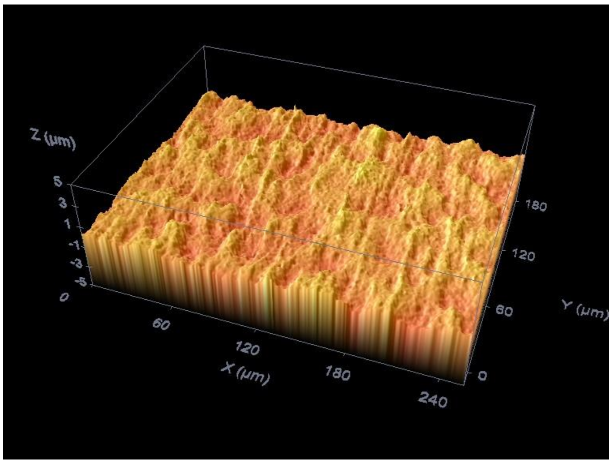


Fig. 12: standard available microetch
(© Atotech Deutschland GmbH, Basel, Switzerland)

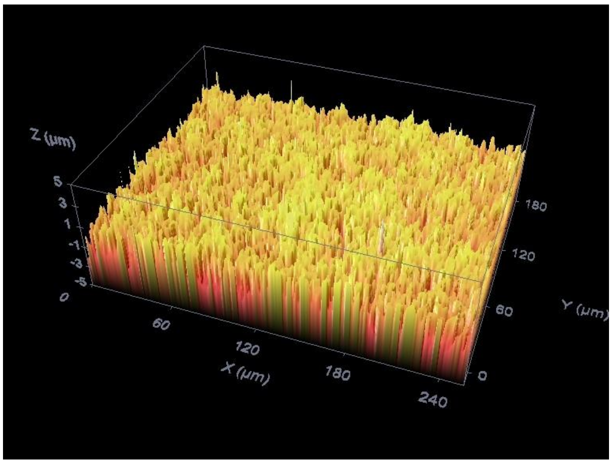


Fig. 13: Ferro Etch, Atotech
(© Atotech Deutschland GmbH, Basel, Switzerland)

- **Grain boundary etching**
  At room temperature metals usually exist as structures made up of various crystals (grains). With grain boundary etching the contact surfaces between the individual crystals (the grain boundaries) are the focus of attack. This results in a correspondingly high surface roughness in comparison to microetching where the metal is more or less abraded parallel to the surface.
- **Electric conductance (rinsing water)**
  The electric conductance value is the reciprocal value to the electric resistance and specifies how good electricity is conducted. In aqueous media, such as the rinsing water in brushing units, this value is increased by contaminations (salts, lime, etc.). Thus a high value indicates heavy contamination of the rinsing water.
- **Surface tension/Interface tension**
  The interface tension of a liquid at the interface to the air is known as the surface tension. By definition it is a magnitude of energy (per surface unit) and describes the effort required to increase the surface area. Amongst others, the surface tension is the reason why freefalling water pulls together to form a droplet or why insects can walk on water. When a solid is wetted by a liquid the differences in the surface tensions are of key importance; the quality of the result is reflected in the following few practical rules:
  - Substrates with a high surface tension are easy to wet
  - Liquids with a low surface tension wet easily
  - Optimum wetting is achieved when the surface tension of the liquid is significantly lower than the interface tension of the solid.

  As the surface tension of the substrate approaches that of the liquid, the wetting becomes poorer. If the surface tension of the substrate is lower, no more wetting takes place. As a rule, metals have a very high surface tension index so they can be easily wetted, whereas plastics have a much lower surface tension index and are therefore more difficult to wet.

Sources

Atotech Deutschland GmbH Electronics Materials
Zweigniederlassung Basel (F+E), Mattenstrasse, 4058 Basel, Switzerland
www.atotech.com

Falkenrich GmbH
Oststrasse 30, 58636 Iserlohn, Germany
www.falkenrich.de

IS International Supplies s.r.l., Italy
http://www.internationalsupplies.it

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