The Atomic Energy of Surface Finishes

Taking a smaller perspective with surface finishes helps to understand the benefits of each type of metal coating.

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EVERYONE HAS DIFFERING PERSPECTIVES on the world. There are Democrats and Republicans, Yankees fans and Red Sox fans, cat people and dog lovers and men from Mars and women from Venus–and then there are chemists and the rest of the world. Chemists have a much smaller perspective on the universe, at the atomic level. When I get a question about surface finishes, I start thinking atoms. The character of the materials coated on PCB copper results from the way they are deposited, atom by atom. If we think of the mechanisms of surface finish deposition, we can easily predict their performance, hardness, conductivity and wear resistance.

The simplest metal deposition mechanism is electroplating. When a PCB is placed into a bath of nickel sulfate, nothing happens, but if that PCB is connected to the negative end of an electrical power supply and the positive end to the plating bath, voilá, a nickel plated PCB. The amount of voltage needed has to exceed the reduction potential of the nickel; we need to squeeze an electron into the shell of electrons orbiting the positively charge nickel cation. The amount of current applied can be directly correlated to the nickel thickness. At two electrons per nickel atom, it's a simple calculation.

When electroplating, we end up with several microns of neatly stacked nickel, arranged rather similarly to oranges packed in a crate. Considering the fact that the distance from one nickel atom to another is about 1 angstrom to 2 angstroms (a tenth of a billionth of a meter), there are 10 layers to 20,000 layers of nickel atoms stacked up on the copper. The thinness, stacking order, purity and type of metal at the atomic level give each surface finish its properties. The result of 20,000 neatly stacked nickel atoms is a somewhat brittle, yet strong, grayish film of moderate electrical conductivity and enough durability to resist mild handling stresses, like those of one PCB sliding across the surface of another. But what if we had the desire to get the metal on the copper without all that rigging and rectifiers? Enter immersion metal plating, more technically known as galvanic displacement.

Galvanic displacement represents one step toward increased complexity in metal deposition. If we dump a handful of, say, silver nitrate into a tank of water, the solid silver nitrate salt dissolves. The NO_3 detaches from the silver atom, taking with it one electron, and that silver ion stays soluble in water in happy equilibrium with nitrate anion. If a surface of exposed copper is placed into the silver nitrate solution, the silver ion steals an electron from the copper on the PCB. The electron-satisfied silver turns solid, and the victim copper, deprived of its electron, becomes a cation, drifting around in the water. (It actually takes two silver atoms to steal enough electrons from copper to make it soluble.) This happens because silver has a higher affinity for electrons. Silver's electron affinity of 126 kJ/mol is higher than copper's at 119 kJ/mol, so silver does the stealing and copper does the giving.

Immersion plating relies on the exchange of metals and the exposure of underlying copper, therefore, immersion deposits are quite thin, usually less than one micron thick– just a scant thousand atoms or so. Thinness contributes to the more sensitive handling required of immersion metal deposits. Only metals with strong electron affinity will deposit. The electron affinity correlates with more tightly held electrons, which leads to atomic stability and manifests as relatively corrosion resistant metals, which do not easily oxidize (gold, silver and tin.)

The selection of immersion metal plating is usually driven by the desire to deposit metal without the need for electrical contact and bussing. Sometimes, we want to deposit a metal that cannot be immersion deposited, and we don't wish to return to bussed circuitry designs. Here, we're stuck with the most complicated surface finish, electroless metal deposition. Nickel, with an electron affinity of 112 kJ/mol, will not galvanically immerse on copper, so electrons need to get to nickel some other way–electroless deposition. If we take an unstable chemical, like sodium hypophosphite, and place it in a solution with nickel cations, the hypophosphite will give up electrons and supply them to the nickel; the nickel achieves a stable full shell of electrons and deposits on the copper as a solid metal. In the process, the hypophosphite molecule goes through some tricky disproportionation maneuvers, and some of the phosphorous gets trapped in the metal deposit, too. This makes the nickel in ENIG physically stronger than electroplated nickel, increases its electrical resistivity and makes it more resistant to corrosion. We know that slight increases in phosphorous concentration reduce the corrosion of black-pad nickel.

Understanding these mechanisms helps us determine the best type of surface finish for any specific application. Remember, the next time you need to sort out some big problems, make sure you start by thinking small, all the way down to the atomic level. **PCD&F**

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系统操作速度继续作为消费者对较快互联网连线、视频点播和移动通信等技术的需求的函数增加。因此，新的高性能PCB基底已出现，以解决较高操作频率的信号完整性问题。这些通常称为低介电常数(low Dk) 及/或低损耗 (Df) 材料。产品简介中所公布的“典型”价值提供有限的信息，通常是单一结构和树脂内容，并取自广泛的测试方法及测试样本配置。印刷电路板设计人员或前端应用程序工程师必须知道，根据产品简介中找到的有限信息所做的设计决定会导致错误，可延迟产品推出或增加装配的PCB 成本。本文旨在重点说明典型产品简介以外的关键选择因素，并解释为高速应用选择材料时如何必须考虑这些因素。

MAKING SENSE
of Laminate Dielectric Properties

Understanding material properties reduces the design cycle, facilitates stack up and provides a cost to performance advantage. **by RICHARD PANGIER and MICHAEL J. GAY**

System operating speeds continue to increase to answer consumer demand for such technologies as faster Internet connectivity, video on demand and mobile communications. As a result, high performance printed circuit board (PCB) substrates have emerged to address signal integrity issues at higher operating frequencies, commonly called low D_k and/or low loss D_f materials.

The published "typical" values found on a product data sheet provide limited information, usually a single construction and resin content, and are derived from a wide range of test methods and test sample configurations. A PCB designer or front end application engineer must be aware that making a design decision based on the limited information found on a product data sheet can lead to errors which can delay a product launch or increase the assembled PCB cost. To help designers, the following presents critical selection factors that go beyond a typical product data sheet and explains how these factors must be considered when selecting materials for high-speed applications.

Whether making a decision to buy electronic equipment, a mobile phone or substrate material, one of the first places a person looks is to the technical data sheet. The data sheet provides a snap shot of the product attributes that can be used to compare similar products. A laminate material data sheet should be used as a guideline and a comparison tool, not a design tool. It is, however, often used for that purpose.

The terms permittivity (D_k) and loss tangent (D_f) are used on the data sheet to describe laminate electrical performance properties. Both of these properties vary with changes of resin content, temperature and moisture content of the substrate material.[1,2] In addition to these factors, the test methods that are used to evaluate the laminate properties can produce values that vary significantly. A standard high T_g laminate data sheet states the "typical" electrical properties (D_k and D_f), at 1 MHz to 1 GHz for one resin content. For high-speed digital substrates, a data sheet will provide "typical" (not exact frequencies) data points for 2 GHz, 5 GHz and 10 GHz for one resin content. In some cases, the data sheet will specify the test method that was used to test the material. A PCB designer will need more information about the test methods used to prepare the laminate electrical data in order to make informed decisions about which laminate is the right choice for the application.

TABLE 1. Mid Dk resin system properties.

THICKNESS (MILS)	CONSTRUCTION	RESIN CONTENT %	DK	DF
2.5	1x1080	57	3.63	0.0122
4.5	1x2116	49	3.82	0.0114
7.0	1x7628	40	4.06	0.0115
106 PP	-	75	3.25	0.0141
1080 PP	-	65	3.45	0.0131

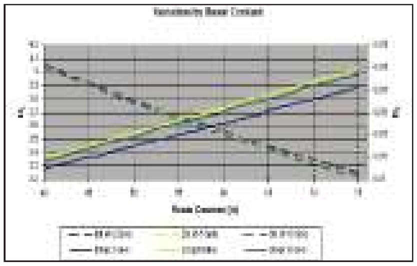

FIGURE 1. Variation of Dk and Df based on resin content.

Making an informed decision means the designer should consider the variations in the material properties as well as the test methods used to develop the material data, yet the typical data sheet does not provide this type of detailed information. As design requirements for high-speed digital applications continue to push the envelope of performance, it becomes critical to consider these influences.