

# Electrically mediated microetching for well-controlled formation of fine conductors on PCBs.

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## Abstract

New methods of conductor etching are required as the line widths and spacing of conductors on printed circuit boards (PCBs) continue to fall and spray etching reaches the limits of its ability to form high quality lines. Faraday has developed an electrochemical etch that uses non-steady state electric fields to provide control over the etching process. The method was tested by etching copper plated PCBs to form lines of conductors with widths of 140-63  $\mu\text{m}$  and spacings as low as 38  $\mu\text{m}$ . Results showed that the electrically mediated process gave superior results to a DC process with the same electrolyte solution and gave lower undercut and straighter sidewalls than could be expected from a controlled spray etching process.

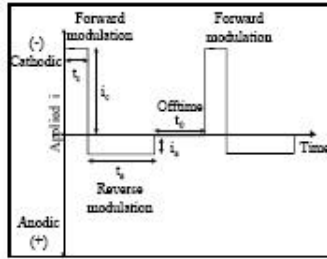
## Introduction

The need to reduce the space occupied by printed circuit boards (PCBs) in electronic products has resulted in increased packing density on the boards along with finer lines, lower line spacing and smaller pads. Currently, spray etching is the industry standard for patterning copper on PCBs [1]. Below line widths of about 75  $\mu\text{m}$ , spray etching does not work well due to mass transport limitations. Other etching processes, such as direct current (DC) and mechanical etching, are under development. To date, these have exhibited low etching rates and damage to the PCB from contact with the brushes.

We have developed a number of electrically mediated, or Faradayic<sup>TM</sup>, electrochemical processes for PCB and wafer processing, including an etch process for fine conductors on PCBs. Electrically mediated processes differ from DC electrochemical techniques in that they use non-steady state electric fields to control the etching or deposition of materials. The ability to set the current density and on-time for forward and/or reverse currents and alternate between these at a range of frequencies brings a level of control over electrochemical processing that is not available from DC methods. This paper demonstrates how electrically mediated microetching, referred to as Faradayic<sup>TM</sup> microetching, can be successfully used for manufacturing fine featured PCBs with minimal undercutting of conductors.

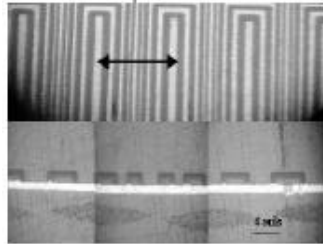
## Methodology

An electrically mediated waveform is an interrupted, asymmetric waveform with a forward current or voltage period followed by an reverse current or voltage period and an off time (Figure 1). The waveform parameters are the forward and reverse current densities ( $i_f$ ,  $i_r$ ), forward and reverse on times ( $t_a$  and  $t_r$ ), and the off time,  $t_o$ . Because there are unlimited combinations of peak current densities, duty cycles and frequencies to obtain an average current density, there is much greater potential for the control of etch or deposition processes than in DC methods. Detailed treatments of the effects of the waveform parameters on the chemistry of the electrolyte and boundary layers at the electrodes are given elsewhere [2-4].



**Figure 1.** An electrically mediated waveform. Unlimited combinations of peak current densities, duty cycles and frequencies can be used to obtain an average current density.

Faradayic™ microetching was demonstrated on multipitch test samples provided by Flextronics/Multek. Each sample contained 17 test matrices with 8 conductors of different widths (L) and spacings (S). The L/S values were 140/89  $\mu\text{m}$ , 114/63  $\mu\text{m}$ , 89/38  $\mu\text{m}$ , 63/63  $\mu\text{m}$ , 63/38  $\mu\text{m}$ , 89/63  $\mu\text{m}$ , and 114/89  $\mu\text{m}$ . Figure 2 shows design of circuits for each module and cross section of conductor sizes. The dry film resist and copper thicknesses were 35  $\mu\text{m}$  and 25  $\mu\text{m}$ , respectively.



**Figure 2.** A test sample showing the test matrices containing 8 conductors (above) and a cross section of the 8 conductors (below).

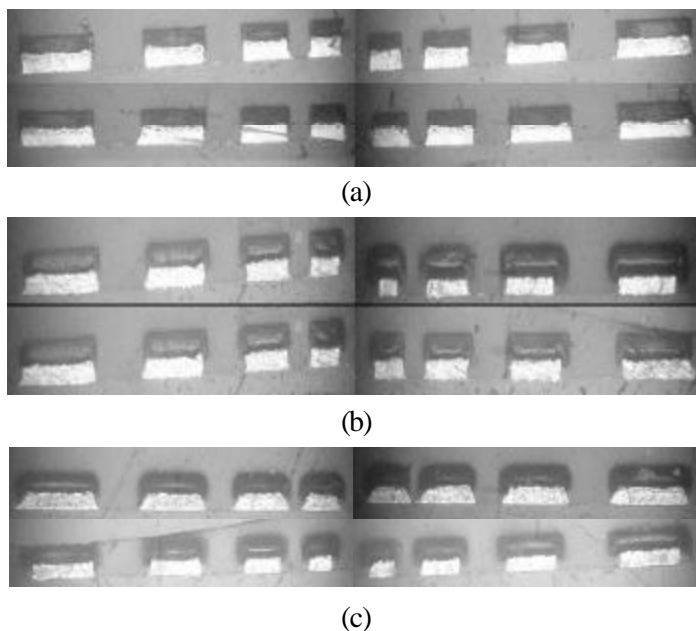
The test structures were subjected to three different etches; a Faradayic™ etch using  $\text{NaNO}_3/\text{NaCl}$  as the electrolyte, a DC etch at 5 V using the same  $\text{NaNO}_3/\text{NaCl}$  electrolyte, and a Faradayic™ etch using just  $\text{NaNO}_3$ . The test structures formed the anode of the electrochemical cell, with a titanium sheet the same size as the test sample forming the cathode. The cathode to anode separation was  $\sim 10$  mm, and each test was performed for 50 seconds, which is about the time used in a manufacturing process.

As a conductor's size affects its electrical properties, the etching process must be designed to minimize undercutting, produce straight and smooth walls and have a uniform side etching rate independent of conductor spacing. Five of the 17 matrices were examined on each sample after each etch. The conductors were examined in cross section using a Zeiss compound optical microscope. The copper vertical and horizontal etch distances, top width, minimum width and bottom width of conductor lines were measured to calculate undercut. The etch factor (ratio of etched depth to distance of side attack) and  $\text{Tan}\theta$  ( $\theta$  is the angle that the sidewall makes to the base of the conductor) were also calculated. The waveform frequency was 100-1000 Hz with an anodic duty cycle of 20-80% and an average potential of 5-25 V.

## Results

Figure 3 shows typical cross-sections of two test samples from each of the three etches, with each test sample showing eight conductors. Ideally, the undercut value should be  $< 6.5$   $\mu\text{m}$ , etch factor  $> 4$  and  $\text{Tan}\theta > 4$ , which are the values that could be expected from a well controlled spray etching process. The best results were obtained using electrically mediated

etching with the NaCl/NaNO<sub>3</sub> electrolyte. The results are further illustrated in Figure 4 where the desired values of undercut, etch factor and Tanθ are compared to the values calculated for each conductor from each etch.



**Figure 3: Cross-section from test samples after etching:**  
a) Faradayic<sup>TM</sup> microetch in NaNO<sub>3</sub>/NaCl, b) DC microetch in NaNO<sub>3</sub>/NaCl and c) Faradayic<sup>TM</sup> microetch in NaNO<sub>3</sub>.

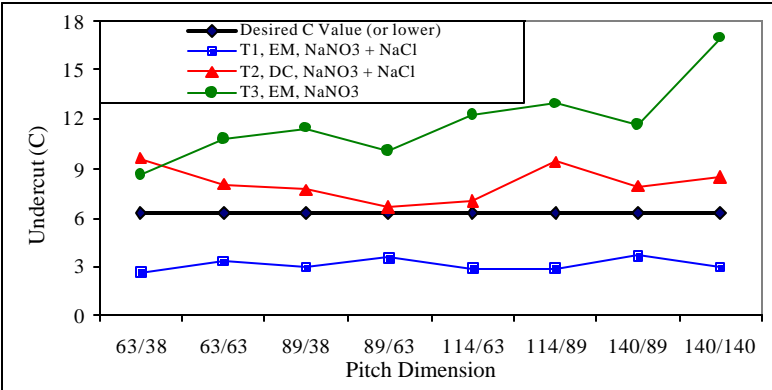
From Figure 4a it can be seen that the Faradayic<sup>TM</sup> etch in the NaNO<sub>3</sub>/NaCl electrolyte gave the smallest and most uniform undercut of the three etches and was the only etch to fall below the desired maximum undercut. The average undercut across all conductor sizes and pitches was 3.08 μm with a standard deviation (σ) of 0.35 μm. The Faradayic<sup>TM</sup> etch in NaNO<sub>3</sub> and the DC etch in the NaNO<sub>3</sub>/NaCl electrolyte failed to meet the specified maximum undercut giving averages of 11.9 (σ = 2.45 μm) and 8.1 μm (σ = 1.05 μm) respectively.

The etch factor for the Faradayic<sup>TM</sup> etch in the NaNO<sub>3</sub>/NaCl electrolyte (Figure 4b) was well above the desired minimum of 4 for all conductor sizes and pitches, indicating that this etch resulted in a much lower sidewall attack than the other etches. The average etch factor was 8.17 (σ = 0.84). The DC etch and Faradayic<sup>TM</sup> etch in NaNO<sub>3</sub> were both below the desired minimum etch factor with averages of 3.18 (σ = 0.41) and 2.46 (σ = 0.39) respectively.

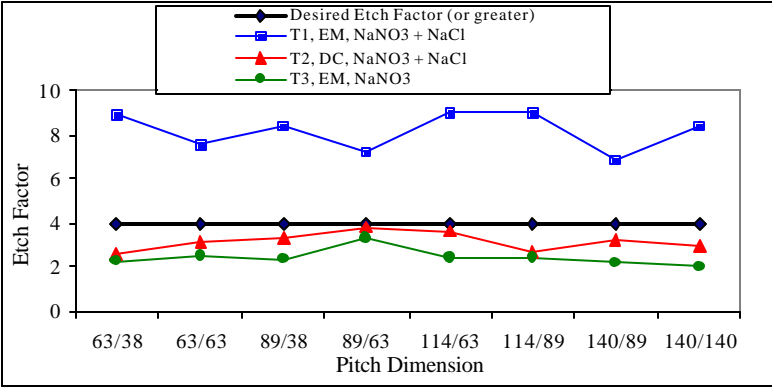
The Faradayic<sup>TM</sup> etch in the NaNO<sub>3</sub>/NaCl electrolyte yielded straight sidewalls to give high Tanθ values of above ten for seven of the eight conductors and above 20 for two of the conductors (Figure 4c). The Faradayic<sup>TM</sup> etch in NaNO<sub>3</sub> gave lower Tanθ values than the Faradayic<sup>TM</sup> etch in NaNO<sub>3</sub>/NaCl electrolyte in six of the eight conductors, but met or exceeded the minimum value in all cases. In four cases, the DC etch outperformed the Faradayic<sup>TM</sup> etch, but for the 114/89 μm conductor, the DC etch failed to meet the target Etch Factor of 4.

## Conclusions

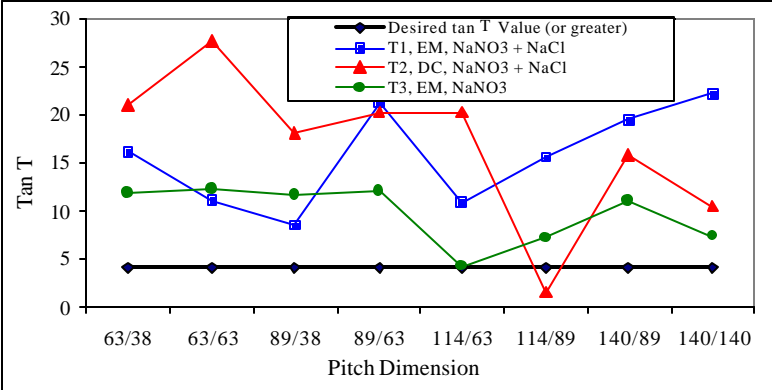
We have demonstrated the use of electrically mediated, or Faradayic™, microetching on test samples with a variety of copper line widths and spacings. The results show that the Faradayic™ microetching using NaNO<sub>3</sub>/NaCl as the electrolyte was able control the etching process for thin copper foils. The undercut, etch factor and Tanθ values were generally better than those that could be expected from a well controlled spray etching process. From these results, it can be expected that the Faradayic™ microetching process can be used to fabricate fine conductor lines with varying pitches on PCBs in a production environment.



(a)



(b)



(c)

Figure 4. a) The undercut. b) Etch factor and c) Tanθ calculated for the three etches at each conductor width and spacing. The desired values (maximum in a and minimum in b and c) for each parameter are also shown.

## References

1. C. F. Coombs, *Printed Circuits Handbook, 4<sup>th</sup> Ed*, McGraw-Hill, NY, p21.1-21.23 (1996).
2. N. Ibl, *Surface Technology*, **10**, pp 81-104, (1980).
3. D. Landolt, *Mass Transport in Pulse Plating* in Theory and Practice of Pulse Plating J-C. Puipe and F. Leaman (eds) American Electroplaters and Surface Finishers Society, Orlando, FL pp. 73-92 (1986).
4. K. Yin, *Surf. and Coatings Tech.*, **88**, pp 162-4, (1997).