Unlocking a Sustainability Win in Printed Circuit Board Fabrication – Webinar Transcript

Opening – 00:00:00

Katie Peris (Moderator): Hello and welcome to this MacDermid Alpha Electronics Solutions webinar. My name is Katie, and I will be your GlobalSpec moderator. Now let me introduce today's presenter. With us today we have Mark Edwards. Mark is the Strategic Account Manager at MacDermid Alpha Electronics Solutions. Mark welcome to today's event and with that I'd like to pass things along to you to get this webinar started. So, Mark go right ahead.

Mark Edwards (Presenter): Thanks for that introduction. Hello and thanks for joining us today. I'm happy to share with you today a chemical process technology in one of the steps of printed circuit board fabrication that can deliver quite a few sustainability benefits from reductions in water and power and chemical consumption to reduction in CO_2 emissions measured in kilograms per year. So, let's get started and have a look at the agenda.

Session Agenda – 00:01:02

Today we will be covering some of the macro trends, we will start at a high level, and the role of sustainability in electronics. And then I'll discuss some of what the larger global OEM electronics community has set for their goals and talk about which ones of those impact PCB fabrication. We'll be talking about primary metallization today, the incumbent process and comparisons of the alternative technology versus electroless copper and then of course what's different and better about the alternative. And the reason we're all here today is to find out what the benefits are, the impacts in terms of CO_2, water, power and chemical reduction. So, with that let's go to the next one.

Macro Trends and the Role of Sustainability in Electronics – 00:01:48

Alright, so whether you're a PCB designer, engineer, DFM specialist, supply chain, procurement, any role that you might have in electronics supply chain if you're dealing with circuit boards, some of these macro trends that I'll describe probably impact you from year to year. No matter the size of your company or where you are in the world. So, these would include things here like density, performance and reliability that everybody's dealing with, and they have goals around improving products and releasing new products that they have to address. Of course, supply chain risks, fluctuation of demand, all the other bullet points listed there at the bottom.

I don't list these in any particular order of importance, but I do put the sustainability environmental impact at the top here. This is kind of a new thing. I recall back to my days in the late 1980s in electronics. Sustainability and environmental impact of processes, materials and chemistries used in production of materials that I was involved with was not a water cooler topic, it wasn't in management meetings, it wasn't a part of anybody's goals at the time, that I saw. I would say in general this may not be anybody's top priority unless sustainability or environmental is in your actual job title, but it's definitely increased in importance. Companies of all sizes are being measured on that either by their customers or their own internal goals, so I essentially boil it down to making a quantifiable difference with more sustainable products processes and supply chains. And today I won't be talking about products or brands, I'll be talking about process technology and the benefits that it delivers. And this would be true of any of the markets that you might be in whether it's mobile device, automotive, industrial controls, telecom, wireless base stations, anything you can think of these (goals) generally impact your world at some point.

Sustainability is Real and No Longer Just a Buzzword – 00:03:59

So, let's move on and get a little bit of the voice of what the market is telling us. Sustainability is real it's no longer a buzzword. You may have existing goals that impact your day-to-day or quarterly or annual goals. You might be reflecting these goals onto your suppliers and in this case, specifically PCB fabricators. The largest OEMs, all the ones that we deal with, all have sustainability goals. Many of them have already made great strides with regards to their own operations and what they use in their buildings and how they use water and release waste into recycling supply chains, etc. And then they think about the suppliers, the fabricators in this case, they have the needs of the customer, they may have their own needs and goals to accomplish for their own corporation, individually, and then the third factor, which the OEMs may not feel day-to-day, is these (PCB) suppliers wherever their plants are located, they have to deal with local regulations on waste discharge, power consumption. They might even have to deal with rationing of power or water. So, the fabricators are really often sitting where all the demands roll downhill to. The better we are aligned between the OEM community and the fabrication community to know that there are options out there, the better we will be.

So, the good news is there's an opportunity in the supply chain, it's widely available, it's been around for decades, it's continuously improved and still is being improved currently. And it's relatively easy to implement because of its relationship with the overall board fabrication process. So, it's an alternative type of primary metallization and it's called Direct Metallization. And the good news is that it addresses many of these sustainability goals in parallel. So, what I'll do now is give you an idea of what the market has been telling us and what some of their goals are.

Global Electronics OEM Sustainability Goal Examples – 00:05:55

And I'm using some of the largest OEM electronics corporations in the world just so you can see a few examples here. We know and see carbon neutral, carbon neutrality, reducing CO_2

emissions. Of course, CO_2 is just one of the elements of greenhouse gases but it's the one that's being focused on the most. A lot of the initial goals that are set focus around 2030. Some call out 2025 but 2030 and 2050 aligns with some overall global protocols that people are trying to achieve. So, other than reducing greenhouse gases, people talk about having their entire value chain or supply chain help lift and help achieve these goals. And then you can see at the bottom here in the center with Apple they also mention the promotion or adoption of safer chemical alternatives. So, what I'll be discussing and sharing with you today would fit that bill as well. And then one thing that's interesting here on the bottom left Microsoft mentions becoming carbon negative by 2030 and then removing all the historical emissions they've had prior to that point by 2050. That's pretty aggressive. I hope, I wish them well with that one. It may be a challenge - pretty interesting to see if they can pull that off without just paying for credits.

Primary Metallization – 00:07:18

Okay so just a couple slides here on primary metallization, where it's used and why it matters. You don't have to be a chemist or an engineer to understand what I'm going to cover here. Any role should be able to pull out some benefits here as far as the content of what it is, where it's used and then ultimately what the benefits are if you choose to keep it as an option.

Primary Metallization Usage and PCB Types – 00:07:44

Okay, two simple pie charts here on the left just to give you an idea of how it's currently used in the marketplace. Electroless copper which I'll show you a little bit of a timeline in both technologies it's definitely the incumbent process, the most widely used type of primary metallization. There are a few types within electroless copper, there's also a few types within direct metallization. A current estimate is about 15 to 20 percent of the market uses a form of DM (direct metallization). And then to give you a little breakout of the red slice here on the bottom right you can see the types of PCBs, what printed circuit boards, where it's applied. So, this would be like a deployment of direct metallization. You can see flex circuits, rigid, rigid-flex – the lighter blue is rigid and then HDI or high-density interconnect designs. That gives you a feel for the applications here. There's a little slice of substrate-like PCBs, small but growing market - but there's a snapshot for you there.

Why Does Primary Metallization Matter? – 00:08:46

Okay, so maybe the most important thing if you haven't heard the term or whether you've been around circuit board fabrication your whole life is ‘why does it matter?’ It'll be obvious for those of you building circuit boards for decades. For anybody else, thought I’d just ground us here with a couple of basic elements. So, what is it for, right? It's used to connect layers together. I'll walk through the chart here on the bottom in just a minute. It's a necessary step before copper electroplating. Some people call this an activation step, and it's required before the final copper plating (which is used to give the trace its near final or final shape).

Either direct metallization or electroless copper is used to create these conductive pathways on the outer and inner layers.

So, let's take a look down below. On the bottom left you'll see a lamination (stack) with copper layers on it. This illustration shows a four-layer board - the green as the resin system and the glass cloth and the copper is in the gold color. So, the basic steps are shown here, there's many more steps as far as processing, but just to give you an idea of where it's used, you'd have a laminated board in process; you would drill and clean it and then you'd want to connect these layers to certain parts of the structure on the inside. Primary metallization helps you do that, and it's required for almost all the common PCB designs around. And then after that you would do electroplating with electrolytic copper. And then other steps - you'd strip the imaging and then you do the final etching, solder mask, silk screening and whatnot. So, in production of a circuit board, you might have 20 or 30 steps depending on the layer count, or you might have as many as 80 or 100. I talked to a fabricator recently and they had a total of 100 steps in their process to make a high density, 20 plus layer circuit board, with everything that they would do in the shop. But no matter how many times you run the board through after all these lamination cycles, primary metallization is used every time after drill and clean. So, there's a summary of primary metallization.

Direct Metallization Overview – 00:11:03

Okay, now that we've seen what role primary metallization plays, let's take a look at a little bit more meaty content here about what's the difference between direct metallization and electroless copper (what's different about this alternative).

Comparing Electroless Copper to Direct Metallization – 00:11:18

Alright, a couple photos and then a couple videos to look at here. So, I'll start with the photos on the right - here's a comparison what it looks like. This is a cross-section through hole on a multi-layer board and you can see this is before electroplating. This is the copper palladium on the surface of the barrel of this through hole with the electroless copper. Then on the right side, you see on the direct metallization with the carbon particles on the walls of the resin and glass fiber before electroplating. This gives you a visual of the difference. Again, already mentioned that the PCB starts with a non-conductive base material, that's the laminate, the green part and then either one of these processes is used to metalize the non-conductive surfaces before it goes to electroplating. And here's the specification called out that most people refer to here.

Leaner, Greener PCB Mfg. starts with Direct Metallization – 00:12:12

Alright, maybe another way to look at the differences between the processes, now that you've seen the visual, is the number of steps required. Again, I'm not going to go through all these processes, not going to talk about molecules here, we're just talking about efficiency and how these processes contribute to the bullet points on the right. So, starting with the electroless copper process on the left, it's about 14 or 16 steps depending on whether

there's an optional anti-tarnish step with another rinse. So, I draw your attention to the items in blue here, there's six rinses or seven rinses if you do the optional step. With the latest generation of direct metallization just two rinses are required. So, it delivers quite a few benefits as you can see on the right here - less water, power, there's less waste generated, there's fewer chemicals used. And electroless copper uses a bulk chemical reduction process, direct metallization is more of a coating process. Another good thing about the DM or direct metallization is that there's no precious metals used, there's no palladium in this process here on the right and also no formaldehyde which I'll give you a little bit more detail on later.

So, all these things contribute to lower consumption and each one of those elements has a component to contribute to lower carbon footprint or less CO_2 generated per day, week, month or year, versus the other process. So, it's a great story, and an efficient process. By the way, the bath tanks last quite a bit longer than electroless copper so not only is the process short, faster to propagate and efficient with the chemistry that's used in it, it lasts longer too. So, all these things work together to make quite an impact on sustainability.

Direct Metallization Line Configuration – 00:14:00

So, another way to look at the chart that I just showed is using a sample line configuration just so you can see the flow. Here's a typical small direct metallization line, there'd be other processes to the left and other processes to the right in the fabrication plant. In this case, just with the primary metallization step, using a carbon particle DM (direct metallization) - you have a cleaner and then the first rinse, there'd be the coating step for the actual carbon particle application. Then there's a fixer-etch process and then a rinse and then if the anti-tarnish is part of the specification, you'd get another coating and a rinse and then out after the dryer. That's what it would look like there. This is just one example; lines are often configured slightly differently depending on the board types and applications as well as the equipment builder themselves.

Plated Through Hole Using Direct Metallization – 00:14:55

All right so here's the fun little video we'll start with it. While it's running, so this video, and I'll run it a few times, shows a cross section through hole that is metallized with copper electroplating after the direct metallization step. So, this is after primary metallization, this is what it looks like - this is the actual copper being plated onto the hole walls. This shows the propagation. Just one example, it would look a little bit different if it was a micro-via or (another type of) via, but you get the idea. And again, I'll talk about the time later, as far as how (fast) it propagates versus the incumbent process. So, that's what it looks like. There are a couple other benefits. I won't go into those today since we're talking about sustainability, but I list them here for your review, where DM (direct metallization) actually outperforms electroless copper.

Electroless Copper Process Showing Hydrogen Gas Evolving – 00:15:53

Onto one other thing. This is just one possible issue that can occur with electroless copper - it's not that it occurs every time. Many people run their electroless copper processes well. We know this process and how to optimize it. I just want to show you one thing that CAN happen. As you think about designs that become more dense - thinner circuit boards, high density interconnects with through holes and vias and all kinds of other structures, this (hydrogen bubble entrapment) is something that can happen - causes possible skips in plating and other defects. So, hydrogen gas evolves from the electroless copper process, and it's constant. You can see here what it looks like going through the through holes in a multi-layer board. If you think about a via or a micro via on the outside like the cartoon image I showed you earlier it can entrap gas bubbles and cause issues. If the process is run well what you're seeing here doesn't cause any issues but with DM there is no hydrogen gas evolution in the bath, so it's an issue that we don't have to deal with at all.

Direct Metallization Technology – 00:17:03

Okay, you might be asking, like I would if I were in your shoes - tell me a little bit about the technology and how long it's been around. Again, without any reference to products or brands here I just wanted to give you some idea of the lineage of the technology if you were going to consider it or discuss it with your team.

Direct Metallization Technology Timeline – 00:17:22

So, here's a little bit of a timeline - the electroless copper process here been around since the 1960s. The carbon-based process technology was developed and released in the early 1980s. You can see here (the timeline) and then came a polymer version, then there's graphite in the 1990s. (Direct metallization) was improved and evolved for micro via PCB and flex circuits. Then onto direct metallization for HDI designs (high-density interconnect). And then continued on with the modified SAP processes for extreme high-density designs and then some additional improvements in the 2020s. And it continues to this day - additional improvements for low etch in mSAP processes here for folks who are managing a very tight copper budget as far as what copper they can etch away and what copper they have to have for high performance products. So, you can see both processes have been around for decades. Direct metallization is not new, but it continues to evolve and is doing so right now.

The Sustainability Impact of Direct Metallization Intro – 00:18:44

All right, and the main reason why we're here, now that we've got the background out of the way what primary metallization is, how it works, a little bit about the technology history, some visuals about the comparison of the process. Now we're going to look at the benefits and some areas including the four here on the next slide.

The Sustainability Impacts of Using Direct Metallization – 00:19:08

From left to right, we'll talk about these - the power savings, and we'll compare directly with direct metallization versus electroless copper in kilowatt hours used; talk about how much waste treatment, wastewater is generated in terms of liters, the water consumption itself (again in liters used) and then how these things roll up into CO_2 emissions in regard to kilograms of CO_2 per month or per year. The good news is that DM (direct metallization) delivers on all these areas and a few others. No formaldehyde (is used), which I'll hit in just a minute and no palladium, so it eliminates another risk factor as far as volatile precious metals cost.

Sustainability: The Power Consumption Impact (kWh) – 00:19:58

Okay onto the first one. So, with regards to kilowatt hour consumption what we did is we took high volume lines in Asia running at 200,000 board square feet per month. Some plants of course may have multiple lines - they might have 10, 15 or even 20 lines and in a large PCB fabrication shop in Asia, but we're talking about a given line running at this rate here on the bottom. You can see electroless copper on the left as far as running hours and a month it would be over 140,000 kilowatt hours, and then direct metallization would be just over 60,000. So quite a big impact here. You can see the savings in kilowatt hours, 57% reduction.

Sustainability: Waste Treatment Reduction – 00:20:44

Now on to waste treatment reduction. We shape this one in terms of cost, just relative U.S dollars to give you some perspective - if you've got multiple lines, then this could add up to be something significant. But as far as the amount of waste treatment that has to be dealt with electroless copper is up here $1600 or so, direct metallization $400 and change for a given line if you've got 10 or 20 lines of course, this adds up. That's a direct cost saving that's more of a something that falls to the fabricators, but you know when there are restrictions on what can be output (discharged) depending on the location of the fabrication site – if the costs rise for whatever reason, this (direct metallization) is just better insurance to manage those issues. And it's roughly 70% reduction, so quite significant, right?

Sustainability: The Impact on Water Usage – 00:21:42

Okay, now on to the impact of water usage. Electroless copper - here you can see in terms of liters per day, about 70,000 liters per day on a line running the same throughput and surface square feet and DM (direct metallization) is down here under 20,000 so it's quite a big impact. And while I've got a little bit of a case study I'll share with you on the power consumption, I did want to mention one thing - there was a substantial drought in Taiwan in 2021 the same year as the power case study I'll show you. And think about the cost of tap water at an industrial plant versus something that has to be trucked in. So, if there's a drought or other restrictions, no matter the cause, the fabricators sometimes have to truck in water using tanker trucks as opposed to delivery through you know industrial pipes in the Industrial Park. That cost can be upwards of 30 or 40 times per ton of water, so when

companies face issues with water restrictions - whether it's weather or other infrastructure challenges, this direct metallization is really good insurance against those issues.

Total CO_2 Emissions Output Comparison (*Scope 3 GHG*) – 00:22:58

Okay, now just to give you a flavor for how things roll up to CO_2 output and typically in terms of where this would be deployed in the supply chain. If you're an OEM we think about this being in terms of Scope 3 greenhouse gas ("GHG") emissions. If you're the fabricator these would be something you could track directly. So, on the left here's a summary. This is a two meter per minute lines as far as the throughput, 240,000 square meters per year comparing the two processes that I went over before. On the dark blue lines, you see the electroless copper and then the red, you see the DM (direct metallization) and the difference between those. So as far as the CO_2 impacts, it's a little bit different than the direct savings in you know liters and kilowatt hours. Power certainly contributes the most as far as the impact than the savings of using one process over the other. You can see some significant impacts for transportation, and this would be like delivery from a chemical warehouse to the fabricator for example. The amount of packaging that is consumed since the consumption rates are lower and the primary coating tank lasts a lot longer, there's just fewer deliveries that are required. And then the chemicals themselves, you can see here. And, if we think about the electricity of course that's things like electric motors if you've got six or seven rinse stations and you've got motors for those and then other tanks you have heaters and agitators those things add up given the line length and the (overall) complexity of the line.

So, electricity is the number one contributor to the overall CO_2 difference between the two, and then the chemicals are number three. And while you can't see it in the little blip here, water in itself doesn't necessarily contribute a lot to the CO_2 impact. The water consumption (difference) itself is still substantial like I showed earlier. And then, just as an aspirational goal, we took the best available data on the total amount of board square meters or board square feet available and just said based on this modelling that we've done - using best practice models as well as actual high-volume shops in Asia - what the impact would be. It would be somewhere on the order of 700,000 tons if people converted their primary metallization from electroless copper to carbon-based DM (direct metallization). Pretty substantial.

Understanding the Dangers of Formaldehyde – 00:25:24

Alright, one little side note here on formaldehyde. Just to make you aware of it. Again, it's essential to the electroless copper process. I think we all know it's a carcinogen, it can be inhaled or enter the bloodstream can cause these issues (listed) here. I recall when I was in a shop recently in Texas, I had walked into a room where there was a process going on for PCB fabrication and it was a smaller room with a low ceiling – but, when I walked in there without PPE (mask, etc.) it was a quite a reminder about the various things (chemicals) that were being added to tanks while I was in the room. That was really a shock to the eyes and lungs. I think I mentioned this in my LinkedIn article not long ago. And the benefit here, I'll show you on the next slide obviously is carbon DM (direct metallization) doesn't use

formaldehyde at all, but we also think about operator safety as well not just the benefits that roll up to the fabricator or the specifier.

Regulations Surrounding the Use of Formaldehyde – 00:26:27

So, you might ask as I did (about regulations). We did some investigation with our teams in Asia, digging up current and planned regulations on the use of formaldehyde – again, not used in carbon-based DM (direct metallization) but used in electroless copper. We couldn't find anything (on bans). I'm not sounding the alarm bell here. There are no current bans on it in the electronics industry that we could find anywhere in the major areas where electronics are produced (circuit boards or assemblies). Just give you some examples here in the red chart, United States, Japan, China, Thailand, and Vietnam. Here's the governing body. You might recognize some of these based on where you are and then the specific regulation that's called out. So, all we could find essentially was, there are regulations on the amount of formaldehyde that's either imported or manufactured. What we're saying here - the conclusion we're drawing, or at least the premise we're considering, or want you to consider is that if you're using safer, greener chemistries that are less likely to be restricted or banned it's reducing or eliminating a potential risk factor. Or on the flip side - if you run into an issue where formaldehyde use becomes a critical concern for your fabricator, at least know that there's an option to accomplish the same thing in primary metallization by using carbon-based direct metallization.

90% Reduction in Chemical Consumption & Waste Treatment – 00:27:50

Okay, so some additional information as far as what I've mentioned before on chemical consumption and waste treatment. Just wanted to give you a little bit more detail and comparing the processes (side by side) since these (factors) definitely contribute to sustainability impacts of the process. So, the good news about direct metallization, reduces the feed and bleed into the waste treatment stream. There's a lot less dosing that's required to balance the tanks. It also eliminates completely the generation of byproducts whether the line is running or it's idle - there's no Cannizzaro reaction, for those of you who are chemists or chemical engineers. As I mentioned before, being inside a fabrication shop you know it's safer for the operators and maintenance personnel, there's no possible exposure to formaldehyde, for example. There are chelators and other chemical compounds in the bulk chemical process for electroless copper, that just aren't needed or used at all in direct metallization.

So, let's have a look at the chart on the bottom on the left we've got the electroless copper and the run rate of the process element, on the right-side direct metallization. I'll talk about the optional zero liquid discharge (ZLD) here in a minute. So, for chemical replenishment you can see the run rates 70 milliliters per surface square foot and about 7 for direct metallization. So, it's about a 10 to 1 reduction. And the same thing on the electroless copper, 200 milliliters per square foot surface square foot. And for the water waste treatment and it's about 20 milliliters per service square foot for carbon-based direct metallization. There's another option that people are considering a little bit more frequently either because

of restrictions in their area or the costs of water, or they just want to conserve water and they just don't want to have to deal with the water treatment cost being high. It's called zero liquid discharge. It's closed loop rinse water recycling and I've got a small picture here to show you what it might look like (if added to a direct metallization line). This is an example of untreated or used rinse water and then after treatment this water would go back to the rinse water steps that I showed on the comparison chart earlier. It's not an option for everybody - just depends on the volume of the shop, but it's available and it's being considered more and more frequently either proactively to manage costs and control contaminants or because of restrictions where the fabricator is located.

Direct Metallization Uses Less Power – 00:30:20

Alright so here's a little bit of detail - it's a high-level case study based on the power shortages during the fall of 2021 and mainland China. You might be able to make out some of the areas in the map here but in Southern and Eastern China, where you know a lot of electronics production goes on there was power rationing that was happening. Either missing targets for availability of total kilowatt hours on the grid or outright rationing either reductions or customers being shut off. So, during situations like this, direct metallization provides benefits to all parts of the supply chain. If you're the fabricator you might decide 'hey, if I run more direct metallization, it's going to give me a little bit more insurance against using my maximum power allotment' and if you're the OEM, the impacts of any power restrictions in your supply chain at your fabricator level, it's less likely to impact on-time delivery. So, it's a little bit of insurance as I mentioned before. So, those customers and fabricators that use direct metallization in challenging times or just to conserve power, they are at a distinct advantage. They were then and they are now going forward. And then also I didn't mention it in detail earlier, the cycle time to run the primary metallization step with carbon-based direct metallization is shorter. You can see here five to six minutes for a typical cycle versus another five or six minutes added on top of it for electroless copper. So, you can accomplish the same thing in less time and impact on the environment. And then similar numbers here what I mentioned it's less power usage for 200,000 board square feet per month, 147,000 for electroless copper and 62,000 for carbon-based DM (direct metallization) that's kilowatt hours per month.

Direct Metallization Reliability Data-at-a-Glance – 00:32:22

Alright last couple things and we'll wrap up here. The focus of this presentation was not on reliability but I did want to mention a few things just so you know there's data available, robust data. We test to industry standard tests like the IPC TM-650 2.6.26 and 27 (IST) or OM testing. We (also) have some of our own tests that are developed - via pull testing is just one example. There are many others, some are industry standard based and some are versions of industry standards based on some of the largest OEMs globally. So, just wanted to let you know for sure in case you're wondering if you're in supply chain, procurement or quality, you know direct metallization will meet or exceed the PCB reliability standards that are out there and in many cases I mentioned on the one slide there's a couple things where it outperforms electroless copper. And, it's used in all the major markets that I mentioned

earlier. Specific details are available where necessary. Some of its shareable by NDA - it just depends on the situation but happy to provide additional clarity there, if needed.

Direct Metallization: A Sustainability Win for Electronics – 00:33:35

Okay, and to wrap up, direct metallization is a sustainability win for electronics in the PCB manufacturing step. To recap the statement we started out with – (direct metallization) does meet the general needs and requirements of having more sustainable products, processes and supply chains. Again, focusing on the process at the fabricator level and then overall in supply chain since the impacts can be felt both at the OEM or customer level as well as the fabricator level. And as we know - I don't think I mentioned this earlier - sustainability goals are impacting all parts of the electronics bill of materials from the circuit board to components to battery packs, cabling, displays, touch pads, housings - this is just one step where I'd say it's kind of low hanging fruit that's available now - it's been around for a while that's proven technology and if you or your fabricator in the electronics supply chain need to have options to explore or implement, this is one thing I propose that you consider.

So, just as a recap here on the left measurable reductions as I showed there, water, power and chemical consumption. Again, there's no palladium or formaldehyde used, the process uses safer less hazardous chemistries which gives you some insurance about future material restrictions or bans. And again, it's globally available, there's over 600 installed lines, it delivers high-performance on all types of PCBs - rigid, flex, rigid-flex including HDI designs. I'm just showing a cross-section of a rigid board here and flex circuit on the right. Thanks so much for your time, we'll move on to the Q&A here in just a moment.

Q&A – 00:35:36

Katie Peris: Thank you so much for that great presentation. All right Mark I'm going to ask you the first question, and we do have a bunch in our queue here. So, let's start with this one, direct metallization is a continuous line or is it a hoist kind of line?

Mark Edwards: Yeah, Katie, that's a good question. Typically what we see going forward with new installations, and recent (five or ten) years, I'd say horizontal is the most common by far, but vertical hoist operations is where it started, so either one is available. I'd say generally in Europe in the Americas the hoist versions are a little more common - in Asia it's almost all horizontal.

Katie Peris: Right, great thank you Mark so much. Alright next question we're going to do here today is, like I mentioned there are a bunch of the queue so if you don't hear your question being answered do not worry we will get you an answer following the webinar. Next one here, how long has direct metallization been based in PCB production?

Mark Edwards: Well, the technology was released in the mid-1980s I'd say the implementation and the ramp up in volume started in earnest in the 1990s and continues

today. So, about 30 years – it was still ramping up in the 1980s, so I'd say early to mid-1990s when it really hit its stride.

Katie Peris: All right great thank you so much for that answer. All right looking at the queue here Mark let's do this next one here. This person is asking in what regions of the globe is this technology?

Mark Edwards: Available in all major regions where circuit boards are made. Asia by far as the largest, many customers that we have in Asia they have multiple lines, in the Americas certainly a smaller footprint and in Europe is lower just given the migration of board fabrication business over the last 25 or 30 years from Europe and the Americas Eastward - that's where the predominant installs are. But, everywhere that large OEMs source boards – if you have 10 PCB vendors, it's not likely that all 10 have it - but somebody (global fabricator) that you would know has DM (direct metallization). Happy to discuss that on an individual basis, of course.

Katie Peris: All right great, thank you, Mark for that answer. Next one here this person is asking is it used on one board type over another example rigid, flex or rigid flex?

Mark Edwards: Yeah, Katie, it's used on all of those, I'd say as far as that you know the pie chart that I showed you earlier - the deployment of DM (direct metallization) - I'd say flex circuits probably has a little bit higher (usage of direct metallization) in fact, in some cases, it's the default process for flex. On rigid and rigid flex certainly lower percentage but we see it being used on all board types rigid or otherwise from lower layer counts to higher layer accounts. And of course, application of any chemical process depends on board design to a certain extent. That's a common question we get as well, but no issues with the basic laminate types of rigid, flex or rigid flex.

Katie Peris: Alright great thank you so much for that answer. So, as I mentioned before there are a ton of widgets along the bottom of the attendee console so feel free to kind of hover your mouse over those widgets it'll let you know what each one means, and we have a ton of items listed in the resource widget as well. So, if you click on any of the items in the resource widget, you're able to download some of those today or depending on which one you click on it may pull you out to a different link so that you can set up a meeting or just contact us today. All right, Mark, moving back over to our Q&A. All right next one here, is your CO_2 data from the best practice recommended or from actual customer data?

Mark Edwards: That's a great question. We get that a lot, of course. It's originally modeled with the best practice recommendation from the process of record, but we validate everything that we use to make comparisons and how we roll up content for CO_2 comparisons versus electroless copper with the largest production lines that we're aware of (customers in Asia). And of course, we supply both types of chemistry – for electroless copper and DM (direct metallization) - so we know the process inside and out. One thing I would say in terms of one of the elements of comparison, in some cases in Asian shops they actually run a higher rinse rate than is required by the process, so we could actually say

without any doubt that we're conservative on water savings. The other ones are pretty straightforward because we know how many motors are used, how many heaters, how many agitators, etc. and occasionally even those might be over-engineered and some people's equipment but we're being conservative in every estimate. And it's a hybrid - it's not only best practice data that we model, but we also use actual high volume shops that run the most demanding throughput.

Katie Peris: Great thank you, Mark, for that answer. So, moving into the queue here let's take this next one. All right this person is asking with all these advantages for DM (direct metallization) what's the reason the manufacturer has changed to DM (direct metallization).

Mark Edwards: I would say sometimes the fabricator can be the first mover on making it available, right, so some OEMs leave it up to their fabricator to run either a direct metallization process or electroless copper as long as the board meets the customers quality requirements and passes all the tests for their particular end-use environment. Fabricators can drive it, occasionally. Now fabricators clearly would see bottom line benefits that they could measure at the plant level running one line (type) versus the other. The OEMs typically call out other things like laminates and copper thickness and trace shapes and of course performance metrics, throughput, resistance, inductance all those various things so it's not one or the other. Either one (OEM or fabricator) can be the first mover and some cases the fabricators won't necessarily change until they get buy-in from the OEM and that's true of many other material selections as well.

Katie Peris: All right great Mark thank you so much for that answer. Let's go to this one here, we'll jump up. All right this person is asking what is the average cost difference for DM (direct metallization)?

Mark Edwards: So, we don't talk in terms of dollars or cents per square foot or inch. That's the fabricators conversation, but I wanted to address this because it comes up in almost every meeting. Generally, DM (direct metallization) is considered cost neutral or better, so we don't interfere with the fabricators pricing with the OEM ever - that's the conversation they own. We don't get involved in quoting the fabrication cost to the OEM at any point. But in general, it's a safe bet that it's cost neutral to an OEM.

Katie Peris: Great perfect thank you so much for answering that. All right as I mentioned we have a ton of questions in the queue we will do our best to get through as many as we can but if you don't hear your question being answered no worries, we will reach out to you following today's webinar. Okay next one here. Alright Mark so I'm going to go to this one here, do many fabricators use the closed loop rinse water recycling option?

Mark Edwards: Not as many as we would like, that's an option that's offered by our sister division, Envio. I would say that all fabricators do some level of recycling of process material, liquid materials - not all of them certainly do the closed loop that I described on the slides there. We actually have a little bit of illustration which I didn't include here just due to the time, but it is available especially when there's a process that needs to be controlled. The

good thing is you can really identify the contaminants and you can reduce the risk that input water contaminants contribute to process issues. I'd say it's more likely to make financial sense in Asia where the throughput is high, maybe not so much in the Americas but yes, our sister division (Envio) will review those applications on a case by case basis.

Katie Peris: Right, thank you so much for that answer. All right, digging through the queue here Mark let me grab our next one. Alright this person is asking direct metallization seems good in all aspects like power, water saving and cost effective, how come this is not so popular?

Mark Edwards: Oh, sure that one's actually easier than it sounds because the incumbent process is you know the default - the status quo is a very hard thing to change. A lot of people think 'right, it's been working the other way…why would I change?' and it's now the conversation has switched a little bit where fabricators are being pushed heavily by their OEM customers to bring innovation and offer alternative materials. It could be base materials, it could be packaging, anything they can think of where there's an equivalent - as long as the reliability and performance spec of the circuit board is met. Sometimes they'll say 'every year, you need to, as a fabricator, you have to come to the OEM and tell us what you can offer not just for performance and extending the PCB technology, line and space and etc. but what can you bring that would be equivalent or better with a sustainable or green options'. That's driving a lot of conversations and in many cases, Katie, and again thanks for the question, the fabricators have to provide the CO_2 footprint for Scope 3 greenhouse gas emissions with the quotation before they ever accept an order. So it's (becoming) a part of their daily operation just to get new inbound quotes addressed.

Katie Peris: Alright, great, thank you so much, Mark, for that answer. Right next one here this person is asking do you have an overview of PCB producer names who are offering DM (direct metallization).

Mark Edwards: No, we don't publish that openly, but typically the conversations happen around an OEM (who) will say '…oh that's interesting, that might meet some needs for what we're trying to accomplish in the next year or further out. Who do you know can you tell us who has this available in our supply chain.' So that's typically a direct conversation that we have with an OEM. I'm happy to answer that. With any global OEM/manufacturer, that's one of the very first two or three questions they ask is '…okay that's great, I'm interested, but can I get it?' and the reason they asked that is because it takes quite a bit to qualify a new supplier let alone actually running validation tests for any new lines that they might allow their boards to be made on.

Katie Peris: All right thank you so much for that answer, Mark. As I mentioned a couple times throughout the Q&A, we have some great resources for you if you want to grab those while we're answering some questions and if your question is not answered don't worry, we have a huge number of questions in our queue right now so most of these will get answered following the webinar. We will reach out to you with an answer after today's session. Alright

moving to our next one. Mark this person is asking, I heard you mention formaldehyde isn't that banned in certain places?

Mark Edwards: I'm glad this came up again. It's definitely not banned - we haven't found anything where that electronics are made, that it's been banned. It's certainly regulated, and I just want to clarify typically it's regulated on the amount of importation for certain countries at least the ones the five regions that I mentioned, and certainly there are permits for manufacturing - how much you manufacture. And of course, if formaldehyde was banned in PCB regions where factories produce bare boards that would kill the electroless copper process I don't anticipate seeing that in my lifetime. Certainly we know the focus on certain materials that are toxic, continues. I don't know that it's more on PCB than other parts of the electronic supply chain but yes, certainly it's critical to electroless copper, I can't see that (ban) happening.

Katie Peris: Okay, thank you Mark so much for that answer. We have a couple minutes left so we'll take one or two more questions. Let me grab our next one here Mark. All right this person is asking can you brief us or give us a comparison about the reliability test between electroless copper and DM (direct metallization)?

Mark Edwards: Definitely not enough time on this. I could definitely have a conversation with somebody to provide more info there. We've got at least a dozen tests that anybody would recognize and some good summaries of how it performs. The ones I mentioned of course you know IST, OM testing, hot oil testing, thermal cycling of various types and many more. But yes, certainly that's a half an hour on its own, but it'll be glad to address that further later.

Katie Peris: All right Mark that sounds good we will reach out to that person following today's webinar and get you a more detailed answer. Alright Mark we have time to take about one more question today, we're close to the top of the hour I'm just going to choose one from our queue here and reminder to everyone that if your question did not get answered we will reach out to you following today's webinar. Alright Mark so last one for today who is MacDermid Alpha and how are you involved in the PCB supply chain?

Mark Edwards: Oh, good question. MacDermid Alpha Electronics Solutions currently, at least in the Circuitry division that I represent…we are a wet process chemistry supplier. We have many other divisions, of course, that do soldering materials and fluxes for the assembly side. In our side, we're involved in the circuit formation, inner layer bonding, sustainable finishes - traditional metallic finishes, organic solubility preservatives – and many other things. Of course, electrolytic copper for trace formation. But, almost anything used in the buildup of circuit boards - if there's a chemical for it - we've got it. We don't do solder mask, base materials or foils or laminate pre-pregs. So, essentially, wet chemistry which would go in the tanks on the (PCB fabrication) lines. Great question, thank you.

Katie Peris: All right Mark thank you so much for that last answer. So, as I mentioned we have a ton of questions in our queue, and we will get back to you guys' following today's

webinar. We are almost at the top of the hour so we will wrap things up right now. So, I want to say a huge thank you to Mark for giving us a great presentation and for answering so many of our attendees' questions. Mark thank you so much for being here.

Mark Edwards: Appreciate it. Thanks everybody, thank you, Katie.

Katie Peris: So again, everybody thank you for taking time to attend this webinar event, take care and we will speak with all of you soon.