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European Organization for Nuclear Research

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# Screening week report Chemical

***A new method to make microvias for high-density flexible PCBs***


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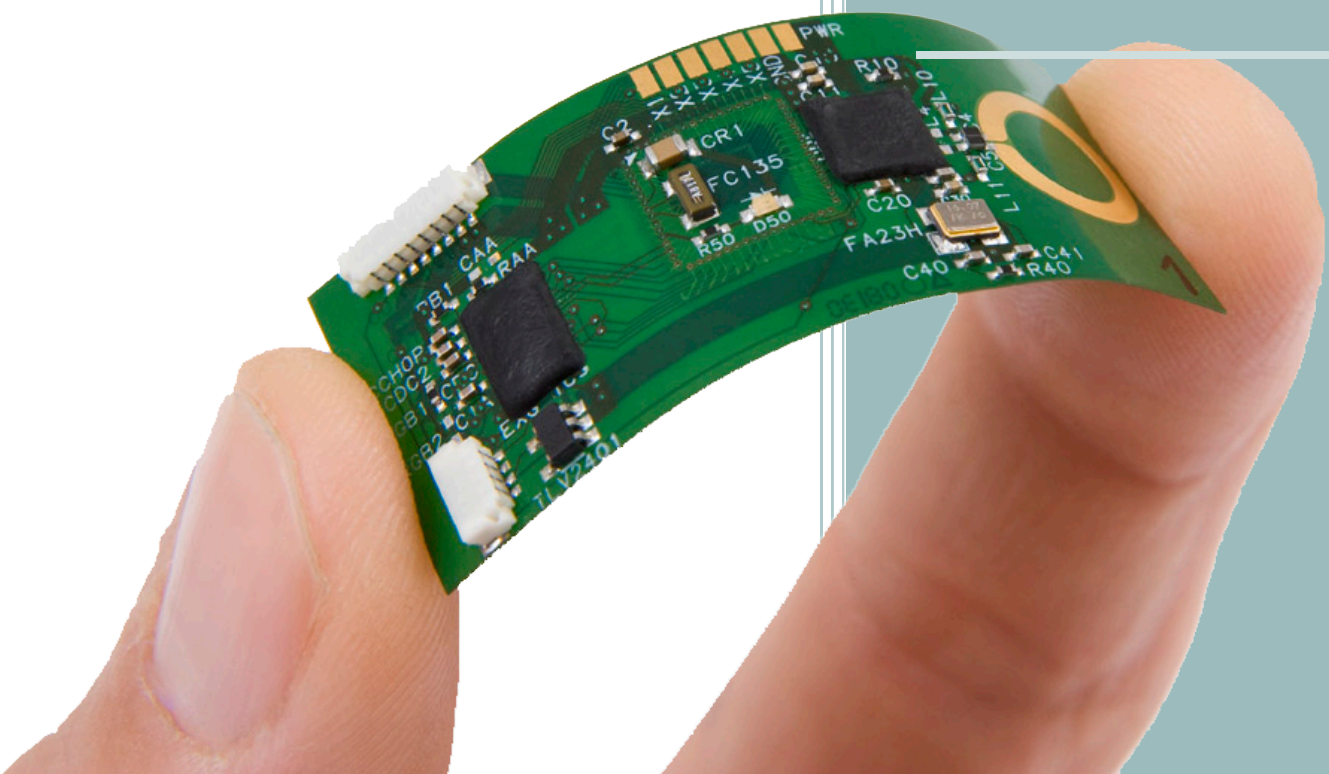

# Acknowledgements

This report is a result of the MoU between NTNU School of Entrepreneurship (NSE) and the Knowledge & Technology Transfer (KTT) department at CERN. The report is a study of the technological opportunities and commercial potential of a technology from CERN, and was created by the students of NSE during the NSE Screening Week 2009 at CERN. In addition to this report, the students held a presentation on the same topic.

The technology was presented to the students monday November 9th, with a deadline Thursday, November 12th. The presentation was held the following Friday.



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# Summary

Most of the electronics used today contains circuits printed on a circuit board (PCB). These PCBs can be both rigid (RPCB) and flexible (FPCB). In the PCB production industry there is an increasing demand for boards with higher circuit density. Microvias is the name of one of the key technologies required to obtain increased density.

The entire FBCP manufacturing process is currently continuous with the exception of the microvia production step. This production step require expensive equipment.
The **CMV (Chemical Microvias)** process is microvia production method that can be included in the continuous process and therefore eliminate the current disruption in the production line. This creates a more efficent production line with less human involvement, and reduces costs compared to current methods. There are is also considerable savings in reduced equipment cost and maintenance cost by using the CMV technology.

The customers that benefit the most from a more efficient production line will be volume manufacturers, and the ones that benefit from low equipment cost are prototype manufacturers. The most attractive business model identified for these segments is becoming a one stop shop for microvia production, selling equipment and chemicals, and licensing out the technology.

The CMV process is developed at CERN by staff researcher Rui de Oliveira, and is patented in several countries. Rui de Oliveira has no intentions of pursuing the commercialization of the technology. The commercialization process will not require extensive technical competance.

The total market size of microvia FPCBs is estimated to be around € 2.1 bn pr year. It is estimated that CMV can produce a revenue through licences and sales of € 8.6 million in the first 3 years.

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# Product

## Problem

In all kinds of electronic systems, ranging from cell phones and laptops to tailored control systems in the Large Hadron Collider at CERN, microcontrollers need to be interconnected. This is done by placing the microcontrollers on non-conductive boards and connecting them by thin lines of copper called interconnects. Such boards are called printed circuit boards (PCB), and can consist of several layers of interconnects. These PCBs can be rigid (RPCB), flexible (FPCB) or semiflexible.

In multilayer PCBs, conducting vias are required to electrically connect the various layers. To make the vias, a hole has to be made through the dielectric layer, and the inside walls of the hole needs to be coated in copper in order for the connection to be conductive. The method usually applied when making vias is mechanical drilling, which works fairly well for large vias.

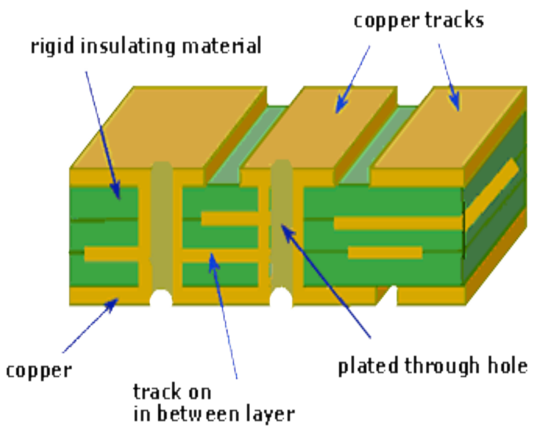


**Figure 1: Multilayer PCB**

For high-density interconnects (HDIs) the vias need to be very small, typically with a diameter measuring in the micrometer range. These vias are called microvias. The most common method used to make microvias today is called *laser ablation*, and uses a high-energy laser system to make holes in the PCB.

There are two significant problems related to laser microvia production. The first problem is price: The equipment required to make the microvias using laser is very expensive. This is mainly a problem for manufacturers of PCBs who wish to expand their service range into including microvias, and therefore face significant investment costs. In addition, the annual maintenance cost is high and the laser unit needs to be changed periodically.

The second problem, affecting large-scale flexible PCB production, is that the microvia production step impair the production efficiency to a great extent. This is because it is a discontinuous step in an otherwise continuous process, and requires a lot of manual handling. Large-scale PCB production is done using reel-to-reel techniques. The PCB is rolled up on a large reel, and this reel is then passed through each production step and rolled onto a new reel. The way the production is done today, the only production step that cannot be done reel-to-reel is the microvia creation step. Because the laser can only process one microvia at a time, the reels are cut into smaller sheets. Each sheet is then processed by a technician in the laser system. After the microvia processing is complete, the sheets are glued back together on a reel in preparation for the next production step. This makes microvia production very costly, both in terms of production time and technicians.

An additional problem for laser manufacturing of vias is related to cleanliness of the via holes. The laser process leaves residues on copper areas in the hole and on the hole walls, which has to be removed by plasma etching. These areas also require a certain consistency of shape, size and, as mentioned, cleanliness for the metallization process that complete via connections.

## Solution / Product description

CERN has developed and patented a new method for producing microvia, which allows for multiple microvias to be processed simultaneously. This method is based on chemical etching, and is called chemical microvias (CMV). For complex FPCB designs with large numbers of microvias, this method directly saves production time compared to using current methods. More importantly, CMV allows for continuous reel-to-reel microvia production. Introducing CMV thus improves the bottleneck production step in FPCB production, reducing production time and the need for interactions by technicians.

The equipment required for CMV is also cheaper than for laser ablation by several orders of magnitude, and is virtually maintenance free. The chemicals consumed in the process are relatively cheap, especially compared to laser maintenance costs. For PCB manufacturers who wish to expand their business to include microvia technology, the initial investment costs will be easier to overcome. For companies with existing microvia-capable production lines, the advantage of CMV lies in reducing maintenance costs and increasing production speeds, while reducing staff.

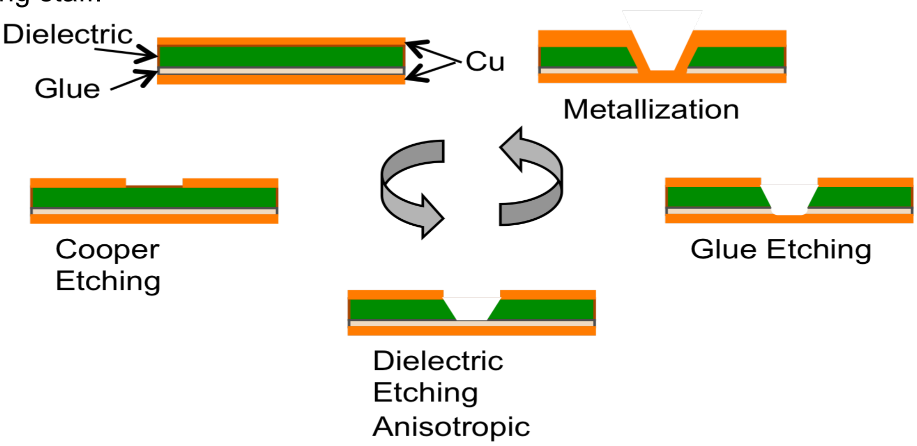


**Figure 2: The CMV process**

The CMV method does not leave the residues associated with laser ablation. However, the method is only compatible with the type of dielectric material used in flexible PCBs. The market for this method is therefore naturally limited to flexible or semi-flexible PCB production, which is about 30% of the total PCB market.

The method is well tested and is used today by the ICE group in the Engineering Department at CERN in their PCB production as their sole means of making microvias. The technology is ready for commercial use.

The technical aspects of the method are more thoroughly examined in the appendix.

## Innovation height

The CMV method uses known concepts from other areas, such as microcontroller production. As such, the technology is in no way revolutionary. However, the benefits from this method when applied to the microvia production process are substantial. The innovation lies in the usage area, and therefore the innovation height is significant.

## Protectability

The method of making CMV is patented in Europe, France, the US, Russia and Taiwan, and patents are filed/pending in China, South Korea and Canada as well. The patents were all filed in the period 2001-2004 . All the patents are owned by CERN.

Since what is patented is a method rather than a product, enforcing the patents is very hard. Patent infringement will be very hard to both expose and prove. A possible infringement case that was discovered during the course of this acid test is explained in appendix.

# Market

## Trends

> *"Everything is getting smaller and denser"*
> *— Leif Masrud, Product Support Engineer, Minco*

The PCB industry is experiencing a big increase in the demand for high-density interconnected structures. In addition the PCB industry is highly characterized by the boards getting smaller combined with increasing circuit density and greater complexity. The reason for this is devices getting more complex and smaller, such as cellphones, PDAs, computers and avionics.

> *"In this market the name of the game is high volume, therefore speed, speed, speed."*
> *— Ronald D. Schaeffer, CEO, PhotoMachining, Inc.*

For big manufacturers of PCBs, flexibility in the production line is not a major concern. Volume manufacturers tends to look for solutions that is easy to use, fast to set up, and probably most important, has a fast production rate and high throughput. Smaller and custom manufacturers on the other hand tend to look for more flexible solutions to be able to satisfy prototype and smaller quantum customers.

## Segmentation

The PCB market can roughly be divided into rigid and flexible PCBs. About 30% of the PCB market is in the flexible segment. Further, it can be divided by the two size categories of companies in the market: Large companies that mass produce PCB units, and smaller ones that produce tailored PCBs and prototypes. Each of these can again be divided into companies that produce complex PCBs requiring microvia capability, and companies producing simpler PCBs. All over, about 20% of the PCB market requires microvia capability.

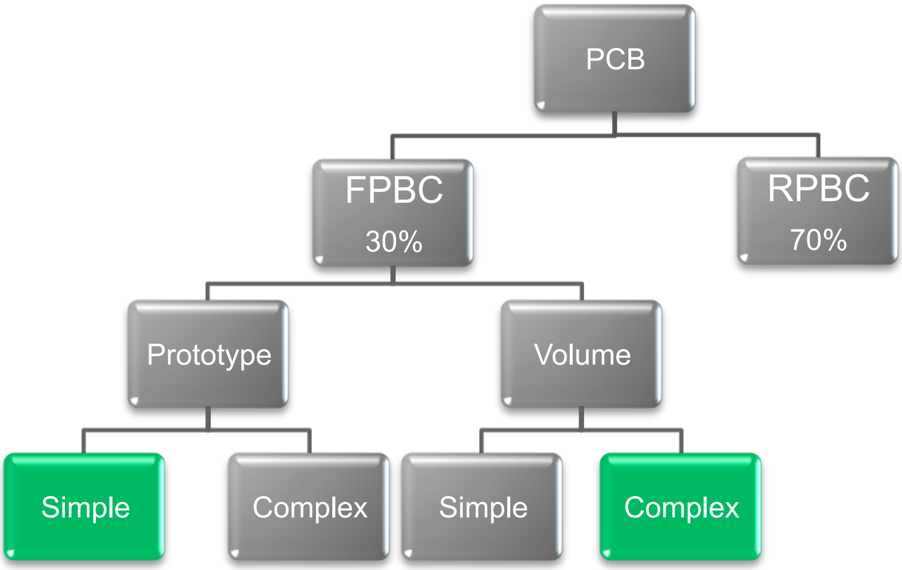


**Figure 3: Market segments**

Small companies in this industry want to have as broad a scope as possible. The small prototype manufacturers that may be interested in CMV are the once seeking expansion from simple PCBs into complex PCBs, without an investment in expensive lasers. The small companies already in the complex PCB business already have systems in place, and generally don't have a large enough volume to benefit from a technology change.

Large companies in this industry usually try to keep a more narrow focus than the small ones. This means that the high volume companies that are interested are the ones already in complex PCB, as this can increase production efficiency. Large-volume simple PCB companies are less likely to want to expand into complex PCB than small companies.

## Value chain


## Entry barriers

As a substitute in an existing market there are several practical entry barriers connected to PCB manufacturers switching costs. Based on contact with customers it seems that the most important barrier is not cost or adaptation, but whether or not the technology is reliable. An important aspect of the PCB industry is quality and consistency. This is due to a high quality demand from the PCB buyers. It is therefore of extreme importance that costumers don't see the CMV as a low quality solution despite its low price.

If the CMV technology is perceived as less accurate, less reliable, less controllable or as a low quality solution, there will not be any interest in a market demanding quality.

## Competitors

The main competitors to CMV are the current suppliers of alternative microvias production methods. Laser is the dominating technique, and is used in 94% of all PCB production. Other current methods of producing microvias is plasma and precision drilling.

The different competing technologies are compared in the table, with the dominating competitors in each segment listed at the bottom.

| | Laser | Plasma | Microdrilling | CMV |
|---|---|---|---|---|
| Throughput | - | - | - | + |
| Cost | - | - | - | + |
| Reliability | + | + | + | + |
| Resolution | + | - | + | + |
| Maintenance | - | - | - | + |
| Competitors | Hitachi | Continental | Hitachi | None |
| | Coherent | | | |
| | LPKF Laser | | | |
| | Mitsubishi | | | |

**Table 1: Competing techniques**

The competitors in the laser segment are mostly large companies with strong economy and strong focus on R&D. Despite the competitors strengths it may be possible for a small company like CMV to pass under the radar.

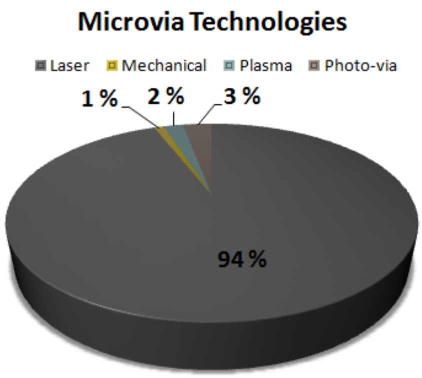


**Figure 5: Techniques used to create microvias**

## Suppliers

For large scale FPCB manufacturers it will be necessary with chemical spray machines to make the production line continuous. Possible suppliers include TenCC and Chemcut. For small scale manufacturer only low-cost, low-tech equipment is needed.

The chemicals needed in CMV are well-known and sold by many suppliers. For example the preferred method of creating the etching chemical is with water, ethylenediamine and potassium hydroxide, which are all widely used.

## Customers

The initial users of the CMV technology are manufacturers of flexible PCBs.

- *Small volume prototype manufacturers* want to start microvias production. Of these many haven't yet taken the step because of the high initial investment costs. Cirexx, All-flex Inc and Stevenage Circuits Ltd are three companies in this segment that have shown an interest in the technology.

- *Large volume manufacturers* benefit from the CMV technology since it will enable them to have a fully automated production line. A company that has shown interest in this segment is Korea-based Newflex.

These manufacturers are driven by industries like the mobile device industry, the hardware industry and other high-tech industries that at an increasing rate demand PCBs at higher complexity and smaller size.

### Customer value

The customer value can be divided into two main categories:

Small FPCB production facilities:

- Reduced maintenance cost for production equipment.
- Low initial cost leading to lower entry barriers to the microvia market.

Larger FPCB production facilities:

- Reduced maintenance cost for production equipment.
- Continuous production lines increasing efficiency and ease of handling.

### Purchasing criteria

The customers purchasing criteria is closely related to the process innovation and cost, and include:

- The quality of the holes must be either equivalent or better than the current methods
- High reliability and operability, minimum at the same level as conventional laser technology
- Technology needs to be accepted by end-user
- Environmental issues regarding the toxicity of the chemicals should not exceed issues presented by current methods
- Operational and maintenance costs should be substantially reduced
- Compatibility with the other stages in the production line is a prerequisite
- For small companies initial investment cost must be substantially lower than for laser

## Organization

### Idea owner

The CMV process was invented by CERN staff researcher Rui de Oliveira. de Oliveira works with development of electronic modules, and has invented several new technologies. This invention was made while working at CERN, and CERN is therefore the holder of the patents and the owner of technology. At CERN the technology is formally administrated by the Knowledge & Technological Transfer.

### Commitment and ambitions

The inventor is not interested in working in a start up commercializing the process. CERN is interested in the technology being commercialized and made available in as many markets as possible. This is something CERN usually enables through a licensing agreement.

Primarily CERN does not grant an exclusive license — however this condition can be relaxed if exclusivity is considered necessary to get the product to the market (Henning Huuse, 2009). In most cases CERN demands clauses to make sure the technology is getting out on the market.

## Entreprenørskolen's part

CERN is interested in Entreprenørskolen taking a part in commercializing CMV. The role Entreprenørskolen can have is heavily dependent of the choice of business model. In most cases a crucial role for Entreprenørskolen is starting a company based on the technology, and licensing the technology from CERN. Early on this might include working closely with KTT at CERN to find the best way of commercializing the technology. Later on business development, sales, marketing and other business related tasks are most likely.

## Business models

Three business models have been identified:

- **Licensing.** This requires the least amount of knowledge about the process, and is the method that is already used at CERN. In the seven years the technology has been available for licensing, it hasn't been licensed out at all. A possible business model could be a cooperation with CERN to actively license the technology, and take a percentage of the licensing fee. The licensing model has low entry barriers and low risks, and there is also a low initial investment needed.
- **Selling equipment and chemicals.** This involves becoming a link between suppliers of machinery and chemicals, and the manufacturers of PCBs. It will also involve licensing out the technology to the PCB manufacturer. The added value for a PCB manufacturer is being able to one stop shop the chemical microvias method, and thus only one player to relate to in terms of installation, training and support. This method has low initial investments and a low risk, but also implies that the company will have a higher responsibility towards the PCB manufacturers. Figure summarizes this model.
- **Becoming an FPCB manufacturer.** This involves setting up a complete production line, and therefore has the highest initial investment of the three models. It also requires the most amount of technical competence and knowledge. A positive side of this model is that it will encompass an additional step of the value chain, and therefore gives better control and possible earnings. A possible competitive advantage is that it is possible to produce FPCBs with microvias without the initial investments needed for laser equipment. A problem is that the primary differentiator will be price, and not quality or reliability.

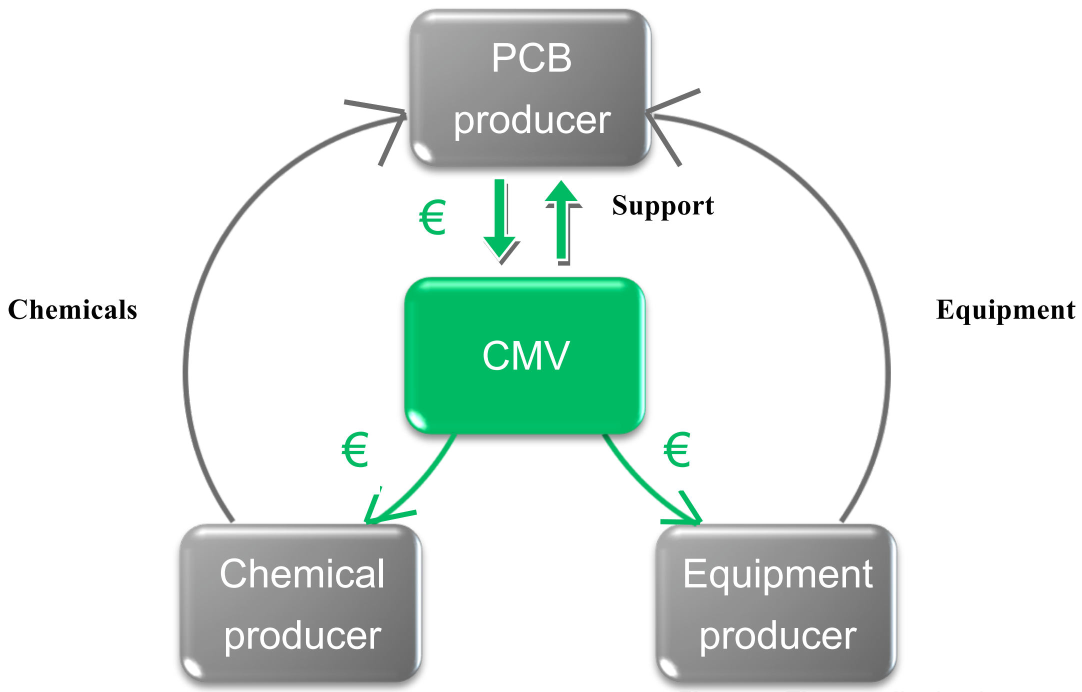


**Figure 6: The supplier business model**

Selling equipment and chemicals is considered to be the most attractive business model, but there are uncertainties:

- CERN has political guidelines for the technology they have developed, and these are difficult to follow up on when someone else has the ability to license out their technology.
- A company is focusing on maximizing profit, while CERN is only concerned with getting the technology to the market. Because of this they want to have as much control as possible over how their technology is licensed out.
- CERN has not had good experiences letting someone else license their technology.
- An exclusive license is very unlikely, as explained earlier.

The fact that CMV has been available for licensing for seven years without anyone licensing it, might be something that increases the likelihood of a company being allowed to license out their technology.

# Economy

## Economic potential

The total revenue of PCB sales in 2008 was €38 bn. About 30% of the total PCBs sold are FPCB and about 20% of those are microvias PCBs. This results in close to a €2.1 bn sales revenue in the production of microvia FPCBs. The cost of creating a microvias production line using a single laser system is about €400 000. The equipment required for a CMV production line is, in comparison, ranging from €10 000 to €75 000.

The pricing strategy for the license, the equipment and the chemicals should be different for the different market segments. For either segment, pricing will be subject for negotiation, although for the small-business market a stricter pricing template can be enforced. For this segment, low investment costs are important. Therefore, the license signing bonus and the markup on the equipment should be kept low. As these companies might not be using the technology for all of their orders, a high annual royalty might also be a limiting factor, and this should therefore also be kept low. This will be balanced by a relatively high running royalty and a significant markup on the chemicals.

For the mass production companies where margins are very important, a high signing bonus and relatively high annual royalty is sustainable as long as the running royalty is relatively low. The markup on the equipment, a one-time investment, can be significant, but the markup on chemicals should be low.

In table 2, an example pricing scheme is shown. In table 3 a sample income budget is shown for a situation with one large customer with an annual production of 50 million units investing in two high-end equipment packages, and five smaller customer, each with an annual production of 20 000 units and each investing in one mid-range equipment package.

| | Volume | Prototype |
|---|---|---|
| Signing bonus | €100 000 | €10 000 |
| Annual royalty | €20 000 | € 5 000 |
| Running royalty | € 0.05 | € 1.00 |
| Spray machine | € 200 000 | € 50 000 |
| Chemicals, per L | € 10 | € 20 |

**Table 2: Example pricing scheme**

| | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| **Large customer** | | | |
| Signing bonus | 100 | | |
| Annual royalty | 20 | 20 | 20 |
| Running royalty | 2500 | 2500 | 2500 |
| Equipment investments | 400 | | |
| Chemicals | 15 | 15 | 15 |
| **Small customers** | | | |
| | | | |
| | | | |
| Signing bonus | 50 | | |
| Annual royalty | 25 | 25 | 25 |
| Running royalty | 100 | 100 | 100 |
| Equipment investments | 250 | | |

| | | | |
|---|---|---|---|
| Chemicals | | | |
| **SUM** | 3460 | 2660 | 2660 |

**Table 3: Example income over 3 years**

It should be mentioned that these estimates are based on very conservative numbers.

### Funding requirements

The requirements for funding depend highly on the choice of business model. In a license case or a license-, equipment- and chemicals sales case the funding requirements are mostly administrative. Expenses for this model might be described as expenses for travels, contracting, active marketing and sales and other activities necessary for setting up necessary partnerships. The funding requirements in a licencing-tailor model will be relatively low, but it is important not to underestimate the costs tied to creating the commercial production line and getting the technology to the market.

### Financing

There are several ways to finance a start up. FFF might be a solution if available, but might not provide sufficient capital for the commercialisation phase. Angel investors and venture capital, depending on the business model, might not be that relevant for a start-up like this as there is a low added value.

Also indirect financing trough CERN via bootstrapping might be a possibility if one or more of the students in a potential start up team participates through the technical student program at CERN. This might be favourable as it also provides access to lucrative technology resources at CERN if necessary.

## Our recommendation

The technology is both ready for and needed in the market today. Both large-business and small-business segments can clearly benefit from the technology. The window of opportunity is open now, but considering patent expiration dates in the 2020s, it won't be open for very long. CERN has not managed to sell any licences yet, but several companies have expressed their interest during this acid test.

The economic potential is not very large, but the investments required are small, and the risk is therefore relatively low.

Our recommendation for ES depends on whether an agreement can be brokered with CERN. If a solution can be found that grants some degree of freedom as to licence sales, this would be a viable project for ES.

# Appendix

Technicalities

## Laser ablation process

First, a high-energy laser etches through the copper layer. Then a lower intensity setting is used to ablate the dielectric layer and the glue keeping to layers together. The laser doesn't stop the ablation process when it reaches the next copper layer, so it is usually stopped a bit before the glue is completely removed, and a plasma etch process is then used to clean away any residues.

## CMV

In this method, the microvias are first patterned on the copper (top) layer of the circuit. The via is then etched through the copper layer. This step is fairly standard in PCB production. The novelty of CMV follows in the next two steps. The dielectric layer under the copper layer is now etched using a chemical bath that only targets the dielectric material, resulting in an anistropic etch that stops at the thin layer of glue binding the dielectric to the lower copper layer. The thin glue layer is then etched using a different chemical bath that spesifically targets the glue, without etching into the copper layer below. After the etching has been completed, the via is metallized using any standard metallizing process.

Method steps:

1. Patterning of the copper layer using normal photolithographic processes (lamination of photoresist, exposure, development, copper etching and resist striping).
2. Lamination of solid glue or application of liquid glue onto the first layer of the circuit.
3. Lamination in a press machine of a copper-coated polyimide foil onto the first patterned layer using liquid or solid glue (Figure 2(a)).
4. Patterning the upper copper layer with holes (using normal photolithographic processes) to permit the etching of polyimide.
5. Etching the polyimide (Figure 2(b)).
6. Etching of the glue (Figure 2(c)).
7. Metallizing the microvia holes (Figure 2(d)).
8. Patterning the circuit on the upper copper layer.

## Patents

### Granted

| Extension in | Application Number | Patent Number | Issue Data |
|---|---|---|---|
| Europa | 02805373.4 | EP1457101 | 28.05.2004 |
| Russia | 2004 122 132 | 2 241 791 | 10.12.2004 |
| US | 10/499 365 | 015816/0808 | 18.06.2004 |
| France | FR20010016522 | FR2834180 | 12.03.2004 |
| Taiwan | 91136251 | 1233770 | 31.05.2005 |

### Filed

| Extension in | Application Number | Filed Date |
|---|---|---|
| Canada | 05286472 | 01.09.2004 |

| | | |
|---|---|---|
| Japan | 555 873/2003 | 18.06.2004 |
| South Korea | 7 009 732/2004 | 18.06.2004 |
| China | 00809453.5 | 20.06.2000 |