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Noble Metal PCB Manufacturing for Direct Implants

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The market of active implantable devices requires new strategies in designing and manufacturing the relevant components (e.g., the electronic modules). The request for continuously smaller devices to achieve improved patient comfort with even higher functionalities asks as well for further miniaturization on PCBs (Figure 1). Combining existing PCB manufacturing technology with technologies from the thin film industries allows integration of new functionalities while reducing the footprint and the number of components.

DYCONEX AG has demonstrated the use of PCBs in in-vivo applications without additional sealing or housing by applying noble metals as conductors on biocompatible PCB materials. For short-term implants the use of gold-plated copper traces has proven good results in several clinical studies. For long-term implants the market requests completely copper-free structures (Figure 2).

These copper-free substrates have been manufactured by combining standard PCB processes with thin film deposition methods as used in the MEMS industry. Using thin film technologies, resolutions within the nanometer range can be achieved by combining the know-how between standard PCB and semiconductor industry. As an example a typical high-density

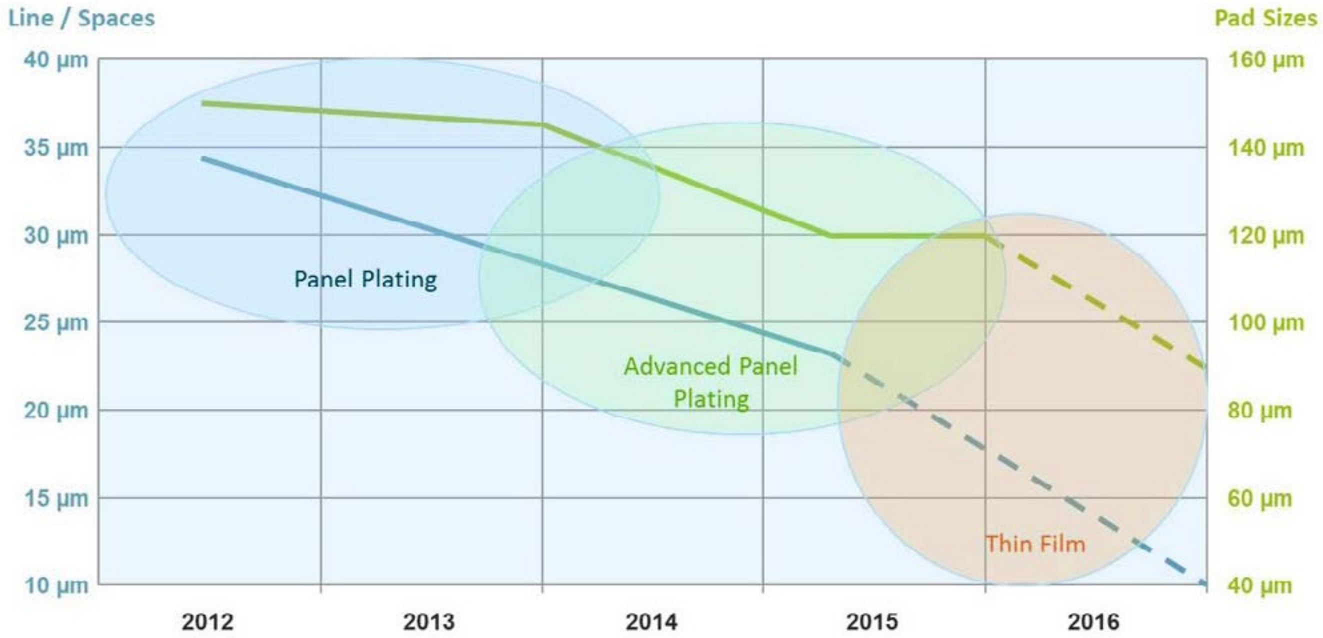


Figure 1: Decrease of the lines, spaces, and pad sizes within the last few years.

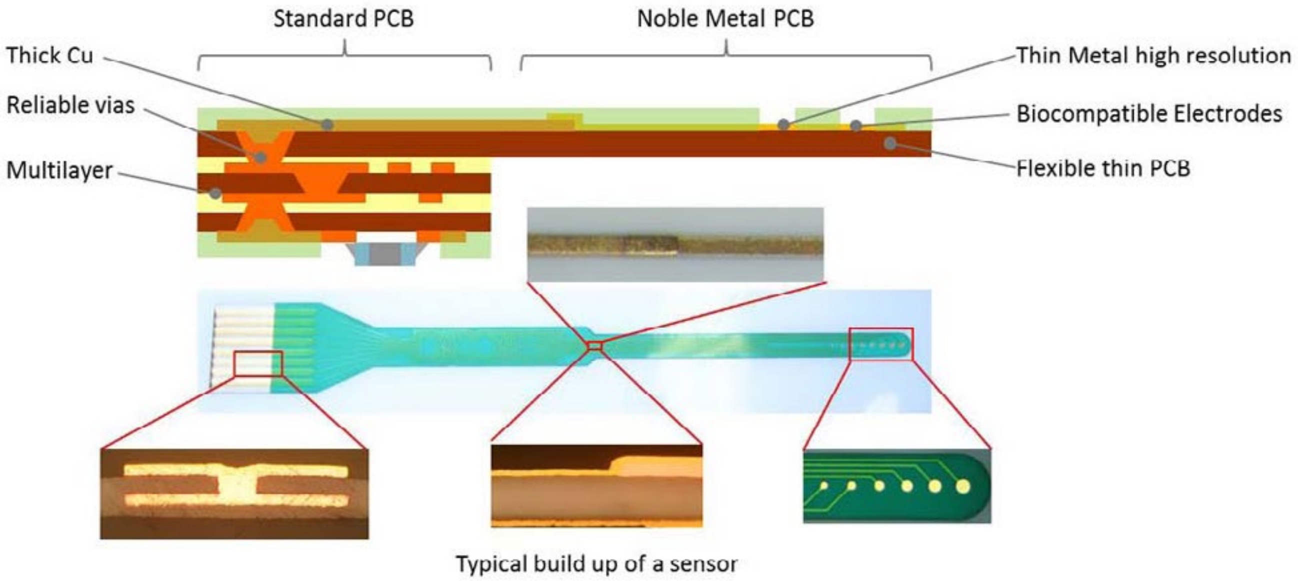


Figure 2: A hybrid PCB combining standard PCB with noble thin film material technology.

PCB has lines and spaces down to 25 µm for signal paths in compare to an ASIC within a 40 nm range. However, the fabrication size in the semiconductor industry is restricted to 12”, while the PCB world manufactures in 12 x 18” large panel sizes. The substrates were structured using standard PCB surface cleaning, activation, photolithography and chemical wet-etching technologies. For the noble metals (Au and Pt), gas phase deposition methods were applied. The material is heated within a high vacuum chamber up to its boiling point. Clusters of atoms evaporate and deposit on the substrate forming a noble metal layer structure. If neces-

Figure 3: Assembling of different Pi layer made by adhesives (left); several LCP layer thermally bonded (right).

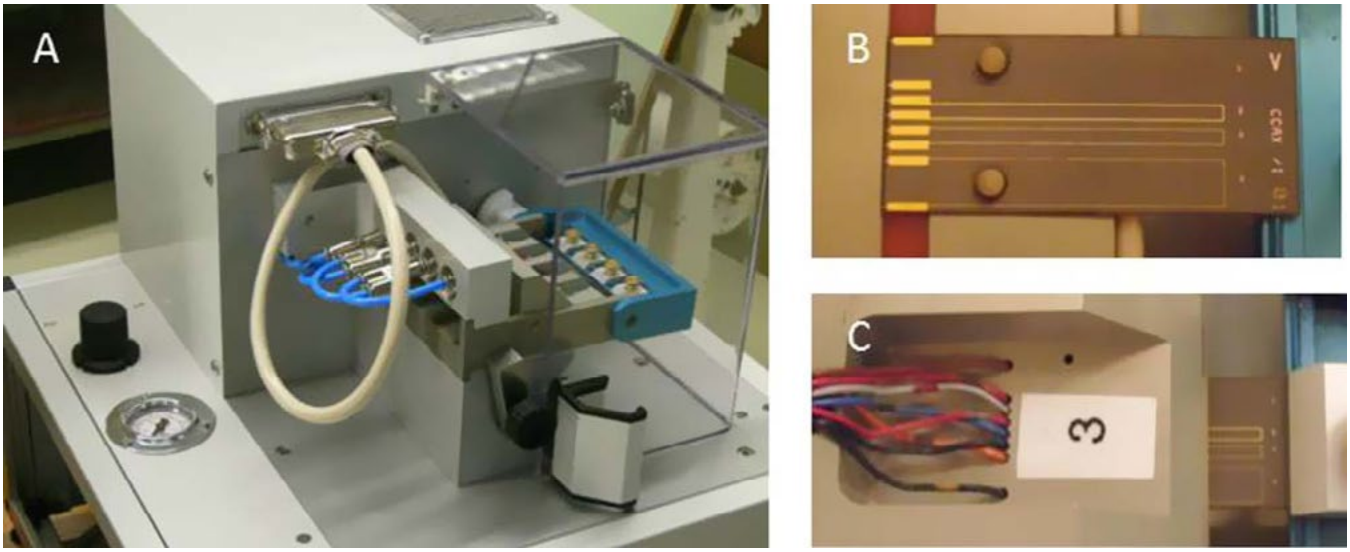


Figure 4: (a) Overview of the bending test machine; (b) test structure; (C) structure under bending including electrical testing.

sary, the noble metal thickness can be increased to several micrometers by electroplating according to the desired properties (ohmic resistance or conductivity). The desired feature sizes and fine lines and spaces (< 25 µm) were achieved by implementing novel technologies like laser direct imaging and drilling with corresponding step and repeat registration as well as new auxiliary materials for thin films.

As a base several bio-inert substrate materials are available. For flexible applications polyimide or LCP (liquid crystal polymer), for rigid applications glass, PEEK or a flexible material with a rigid stiffener can be used. Especially capable are the properties of LCP, a very flexible thermoplastic base material with its biocompatible nature. LCP shows very low water absorption (0.04%) in comparison to standard acrylic adhesives (8%), a temperature stability of up to 190°C (Tg > 280°C, Td > 320°C), excellent high-frequency properties ($\varepsilon R = 2.9$, $\tan\theta = 0.0025$) and low weight (3.2 g/cm^3). For multilayer applications no glue is needed due to its thermoplastic properties (Figure 3).

For applying the pure noble metals on the dielectric base material adhesion is a key feature. To achieve good adhesion adequate surface preparation has to be chosen or an additional adhesion promoter has to be applied. The manufactured PCBs have passed the tape test in accordance with IPC-TM-650 2.4.1. Furthermore the noble metal substrates have undergone a bending test by using a test coupon built up as a resistance loop (Figure 4).

The traces are placed on a 100 µm single sided polyimide. Cracks in the noble metal traces are detected on the first occurrence of resistance changes.

Bend R = 1 mm	**Trace width**			
Au metal thickness: 0.5 µm	20 µm	50 µm	60 µm	100 µm
Cycles [k = 1000]	N/A	2.5k	6k – 12k	> 40k

Table 1: Examples of bending test results.

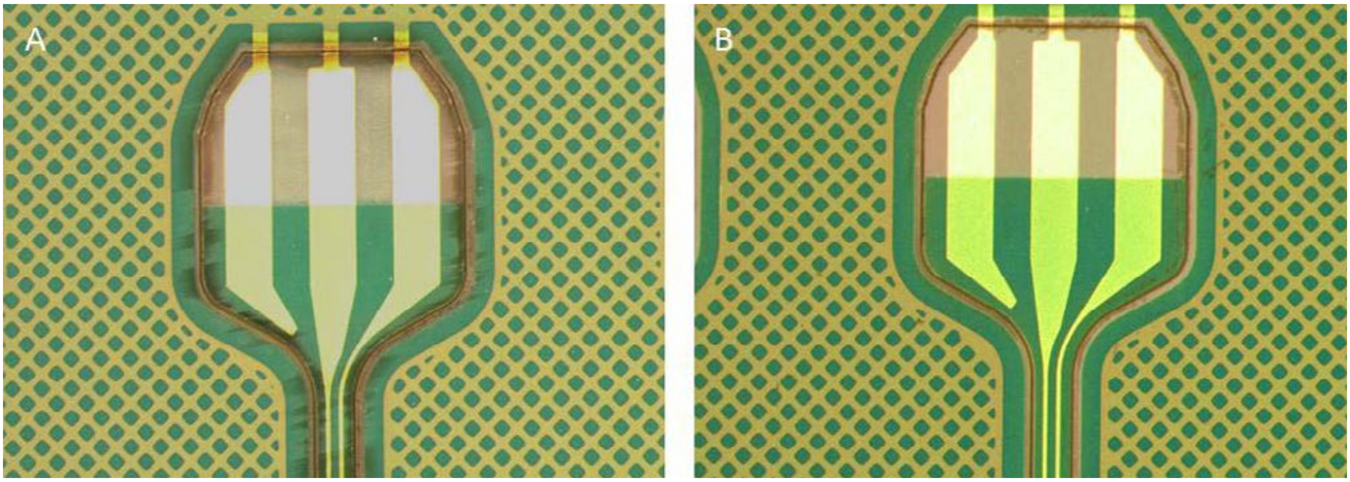


Figure 5: Laser residues on print after final routing (left); print after laser routing including cleaning procedure (right).

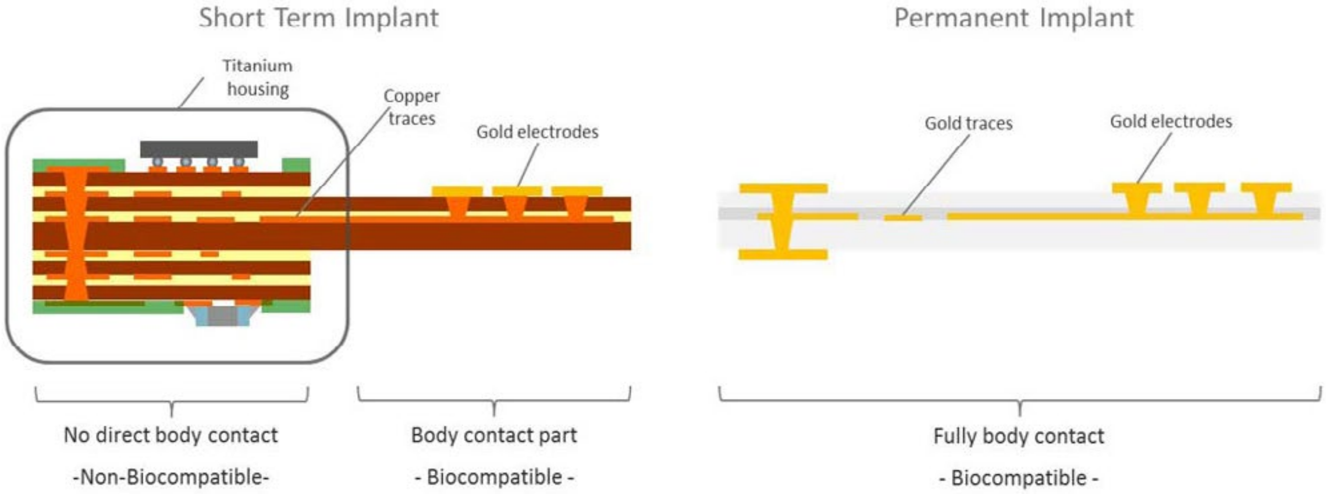
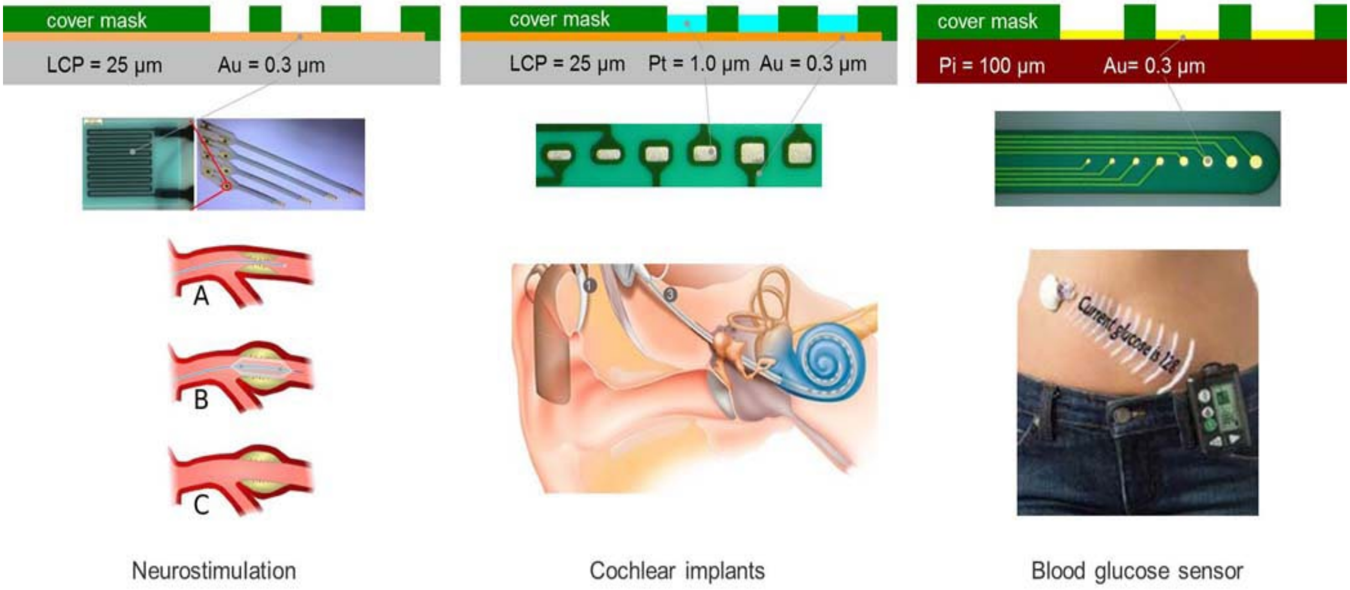


Figure 6: A comparison of a hybrid PCB layout for short term implants and a fully biocompatible layout acting as a permanent implant.

The substrates were bended ± 90° and survived 2,500 cycles at a trace width of 50 µm and more than 40,000 cycles at a trace width of 100 µm (Table 1).

On the final structure a special cleaning procedures to remove laser residues originated by a laser cut for the final outline was used (Figure 5). These residues may cause shorts along the



Neurostimulation Cochlear implants Blood glucose sensor

Figure 7: Examples of implantable PCB layouts and their corresponding application.

traces and may contaminate the electrode pads. To guarantee biocompatible PCBs a final cleaning is mandatory. The substrates have been successfully tested according to ISO 10993-5 for in vitro cytoxicity, a standard for evaluating biocompatibility.

The combination of conventional PCB processes and the use of noble metals allows for the manufacturing of directly implantable structures (Figure 6). For short term implants (< 30 days) a hybrid of the already established copper technology for parts without direct body contact and noble metals for body contact parts may be used. For permanent implants (> 30 days) the substrates need to be completely biocompatible by implementing noble metals only. A detailed description of necessary tests for surface devices, external devices or implantable devices can be found in the regulation ISO 10993-1:2009 + Cor 1:2010.

Such devices have been successfully fabricated for short term implants like blood glucose sensors, balloon catheters and diagnostic catheters as well as for permanent implants like cochlear and neurostimulating applications (Figure 7).

Achieving more complex artwork architectures and connectivity in the Z axes using pure noble metallization is under further investigation, as are ongoing activities focusing on long term reliability, especially with daisy-chained patterned, interconnect stress test designs that accomplish the biocompatible noble metal components. **PCB**

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