Technology for Medical Human Implants

Vision Chip on Thin-film Multilayer

Dr. Alexander Kaiser
Karin Ruess
Dr. Bruno Holl
Josef Vanselow
Dr. Ernst Feurer

Reinhardt Microtech GmbH
Sedanstrasse 14
89077 Ulm I Germany
alexander.kaiser@cicor.com
A company of the Cicor Group

Dr. Liu Liu
Prof. Dr.-Ing. Albrecht Rothermel
University of Ulm

Andreas Möller
Multi Channel Systems GmbH
Reutlingen

Dr. Alex Harscher
Retina Implant AG, Reutlingen

Abstract

Increasing complexity of today's electrical circuits' lead to a growing demand for thin film "interface" substrates. Such substrates provide an important link between integrated electronics and peripheral accessories like amplifiers or signal processing units. Possible applications lie in the field of laser sub mounts with electrical connections for re-routing or even more sophisticated in the field of medical applications or implants. Whereas conventional thin film multilayer are mostly realized on stiff ceramic substrates (aluminum oxide, aluminum nitride), the extraordinary challenge with medical applications often comes from the required flexibility of the circuit. Biocompatibility and practical handling of the assembly play an important role in these applications.

This publication will show general aspects of the fabrication of thin film multilayer, stiff as well as flexible, and show the main differences which may appear, and be requested, in such systems.

A special focus shall be laid on an application for a retinal implant. In this application a vision chip, developed by the University of Ulm, is combined with a flexible thin film multilayer forming a human medical implant for regaining, at least partly, the eyesight for blind people. The special issues of the implantable chip are the low supply voltage and DC free external supply of the circuit.

The vision unit itself consists of a 40 x 40 pixels array with light sensors and electrode drivers, which are addressed sequentially to improve power consumption and spatial resolution of perception. This guarantees for a long-time operation and minimization of chemical reactions on the periphery

1 Introduction

Due to growing experience in the fabrication of multilayer substrates, which Reinhardt Microtech gained over the last years, the step from multilayer circuits on rigid substrate towards flexible circuits was a rather small one. First experiments showed the principle functioning of the technology and with the retinal implant application a first product was being developed.

The aim of the retinal implant is to help blind people to regain at least partially their eyesight. Unfortunately at the moment the retinal implants are no cure-alls. With the implant discussed here only humans suffering from Retinitis Pigmentosa can be helped.

Retinitis pigmentosa is a degenerative disease of the outer retina that can result in complete blindness. Part of the inner retina is still intact and electrical stimulation of this neural network has shown to elicit light sensations in blind patients [1]. With the so-called subretinal implants (which we have here) the intact inner retina is stimulated and the rest of the "natural" path as well as the optical system of the eye are still used.

A first clinical pilot study has been carried out and the detailed analysis of the data with 10 patients so far resulted in a redesign of the existing CMOS chip that is implanted in the subretinal space.

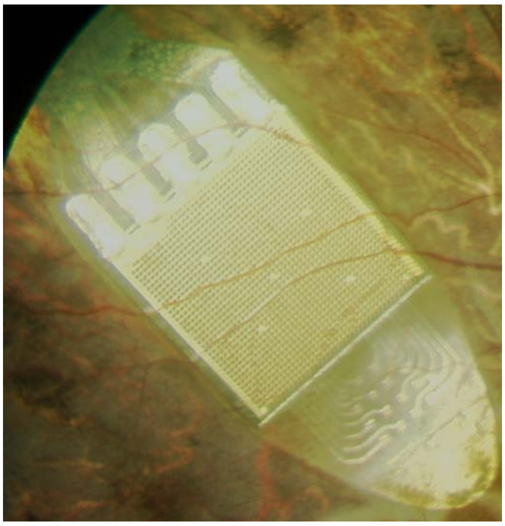

Fig. 1
Optical photograph of a human eye with the installed retinal implant.

Figure 1 shows an optical image of the implanted CMOS chip of the first pilot study. One can clearly see the chip itself as well as the connection with the attached flexible substrate.

Cicor Management AG
Gebenloostrasse 15
9552 Bronschhofen I Switzerland
Tel. +41 71 913 73 00
Fax +41 71 913 73 01
info@cicor.com

2 CMOS Vision Chip

The novel chip, which was designed based on results out of the first study, operates with a symmetrical supply voltage (±2V) and has all DC free terminals for long life wired operation. 40 x 40 pixel cells including photo diodes, amplifiers, control logic and electrode drivers are addressed sequentially to improve power consumption and spatial resolution of perception. Pad count is limited to 6. The 3 x 3.5 mm^2 design is fabricated in a 0.35 µm CMOS technology [2].

The block diagram of the silicon chip is shown in figure 2. The chip has six input pads, which have to be connected to the supply box.

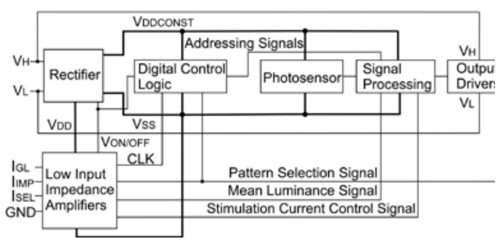

Fig. 2
Block diagram of retina chip

Three supply terminals are used for V_H, V_L and GND potentials. Three other supply terminals are used to provide control signals I_{GL}, I_{IMP} and I_{SEL}. On the chip, a rectifier generates internal DC supply $V_{DDCONST}$ and V_{SS} from the external AC supply V_H and V_L. Three control signals are required (brightness reference level I_{GL}, stimulation timing and amplitude limit I_{IMP}, operating mode I_{SEL}) to control the chip functions.

Low input impedance amplifiers are used to convert externally supplied control current to internal control voltage. The input voltages are clamped to levels below 300mV.

On the chip, each pixel cell includes a photo diode, an amplifier and an output driver. The pixels are addressed by the digital control logic sequentially to reduce chip power consumption. The photo diode current is read out by a standard logarithmic photo sensor which has highest dynamic range of incident light and corresponds to human perception of brightness.

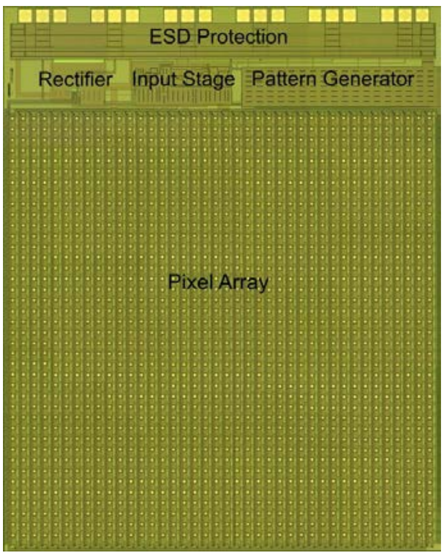

Fig. 3
Optical image of CMOS vision chip with photo diode array and input/output circuitry

The inputs of each differential amplifier are connected to local photo diode output and mean luminance signal, its bias current is determined by I_{IMP}. The amplifier DC output signal is converted to a biphasic output stimulation signal by the output driver. The driver output will be connected to TiN stimulation electrodes, which will then be able to stimulate the optic nerve layer. Figure 3 shows an optical image of the CMOS vision chip, also denoting its main parts. More details on the circuit's operational principles can be found in [2].

3 Thin-film Multilayer Substrates

As it has been for long years, the thin film technology nowadays is still settled in between the widely known PCB field and semiconductor circuits and device technology. Providing the ability of fine line patterning (down to 10 µm lines and spaces) and the use of nearly arbitrary substrate material, the advantage over PCB is obvious, whereby the high resolution of e.g. CMOS semiconductor circuits never will be achievable.

Main applications of thin film products lie in the field of RF circuits, like e.g. T/R modules, DC fan-outs or sub mounts for semiconductor devices. Various kinds of solutions for thermal management by

Dr. Alexander Kaiser
Karin Ruess
Dr. Bruno Holl
Josef Vanselow
Dr. Ernst Feurer

Reinhardt Microtech GmbH
Sedanstrasse 14
89077 Ulm I Germany
alexander.kaiser@cicor.com
A company of the Cicor Group

Dr. Liu Liu
Prof. Dr.-Ing. Albrecht Rothermel
University of Ulm

Andreas Möller
Multi Channel Systems GmbH
Reutlingen

Dr. Alex Harscher
Retina Implant AG, Reutlingen

Cicor Management AG
Gebenloostrasse 15
9552 Bronschhofen I Switzerland
Tel. +41 71 913 73 00
Fax +41 71 913 73 01
info@cicor.com

using thin film substrates and comparison with conventional technologies have been developed and described intensively [3, 4, 5].

Especially in the area of sub mounts for optical devices a strong increase has been noted over the last years. Principal differentiations hereby can be seen in the requirements for thermal management (in such applications normally thick Cu plays an important role) or relatively high pin-count to the ‘outer world’. The second option normally will require several layers of metallization to provide the desired connectivity between circuit parts.

3.1 Rigid Multilayer

Due to the increased demand on such circuits, Reinhardt Microtech started to develop a technology for the production of such multilayer substrates. Figure 4 gives a schematic cross section of a rigid multilayer circuit in thin film technology.

Rigid multilayer circuits most commonly start with a base metallization put directly on the substrate. Hereby the substrate may be glass, alumina, and silicon or aluminum nitride for improved thermal properties. Due to customers demand and required current transportation capabilities, the metal layers in the stack can be just sputtered metal or also strengthened by electroplating.

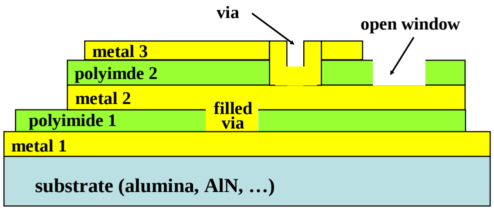

Fig. 4
Schematic cross section of rigid thin film multilayer substrate (3 metal layers, 2 insulator layers, base sub-strate).

In contrary to what people may know from CMOS semiconductor processing, where normally insulator layers are made of silicon oxide, oxynitrides or similar which is deposited e.g. by CVD[1], these materials normally cannot be used in thin film manufacturing. Especially when using electroplated metal lines, a certain kind of planarization and covering capability is necessary. For this reason often polyimide insulators are the material of choice, as these can be deposited in sufficient thickness.

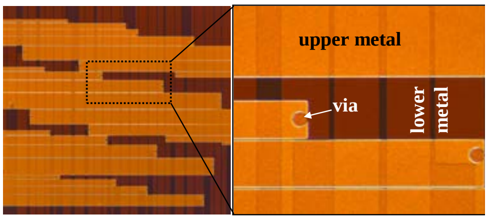

Fig 5
Test substrate with 2 metal layers and 1 insulator layer (left: overview; right: detailed view of metal lines and via, brown layer: polyimide insulator).

Figure 5 shows a test substrate for a two story multilayer chip. Hereby two electroplated Au line layers are separated by a polyimide insulator layer. Electrical contact between the two layers is realized by fabrication of via interconnects between the different metallization levels.

Different methods for the via drilling in the insulator layer are possible. One can think e.g. about using laser drilling, which is a well-established technique for producing holes in ceramic substrates. Another method is the use of photosensitive polyimide and the fabrication of holes by photolithography. If this is not possible, also a dry etching process can be used for patterning of the holes. This method tends to be suitable for moderate polyimide thicknesses below 10 - 15 µm. Common parallel plate reactors with gas mixtures mainly containing O_2 can be used for etching of the polyimide insulator.

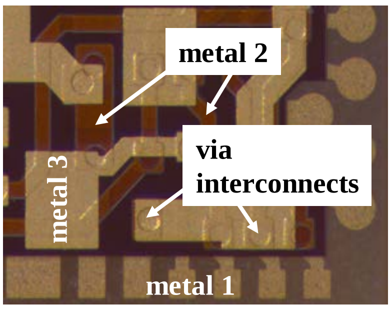

Fig. 6
High volume multilayer product: detail with 3 metal layers, 2 insulator layers, via interconnects between metal layers.

Figure 6 shows a detail of a rigid multilayer incorporating 3 metal layers and 2 layers of polyimide insulator. One can easily recognize the surface topology which is resulting when having several layers of electroplated metal, separated by the polyimide, above each other. This issue even becomes more important during the fabrication of flexible multilayer substrates.

[1] **CVD**: **C**hemical **V**apour **D**eposition

Dr. Alexander Kaiser
Karin Ruess
Dr. Bruno Holl
Josef Vanselow
Dr. Ernst Feurer

Reinhardt Microtech GmbH
Sedanstrasse 14
89077 Ulm I Germany
alexander.kaiser@cicor.com
A company of the Cicor Group

Dr. Liu Liu
Prof. Dr.-Ing. Albrecht Rothermel
University of Ulm

Andreas Möller
Multi Channel Systems GmbH
Reutlingen

Dr. Alex Harscher
Retina Implant AG, Reutlingen

Cicor Management AG
Gebenloostrasse 15
9552 Bronschhofen I Switzerland
Tel. +41 71 913 73 00
Fax +41 71 913 73 01
info@cicor.com

3.2 Flexible Multilayer for Medical Applications

In comparison to thin film multilayer substrates for fan-outs or sub mounts, where the material selection in principal is totally free, there are some restrictions for medical applications. The choice of the metals one can use is mainly limited to e.g. Ti, Au, Pt, or TiN for electrodes and lines, and also not every insulator material can be used. This fact also puts some limitations on the usable processes in the development of medical multilayer substrates.

An additional point is the flexibility of the ready-made circuits. Thus, the carrier which is normally needed to support the whole structure during processing is temporary. The manufacturer needs to have appropriate processes to guarantee this property.

Due to the final flexibility, unlike to the rigid multilayer, the flex multilayer processing normally starts with a polyimide layer of specific thickness which supports the whole structure after release from the carrier. Mechanical, electrical and handling aspects in the later application have to be taken into account when choosing polyimide kind, thickness and processing parameters.

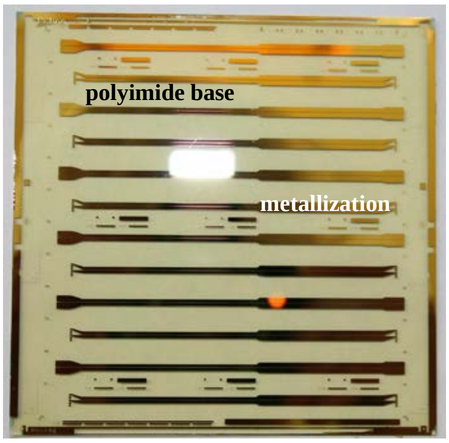

Fig. 7
Flexible medical multilayer on 4" rigid glass carrier substrate, first metal layer deposited.

In figure 7 one can find a 4”-sized glass substrate carrying the first polyimide and metal layer of the retinal implant multilayer. This substrate is designed to provide re-routing and connectivity of a CMOS vision IC to the attached periphery while being implanted in the human eye.

The completed flexible substrate then consists of three polyimide layers (one carrier layer and two insulator/ passivation layers) and two metal layers for control signals and power supply.

The complexity of the flexible multilayer substrate can also be seen in figure 8. A detailed view of a contact pad shows the various layers of the finished substrate. Contact windows hereby are opened by using a plasma dry etching process.

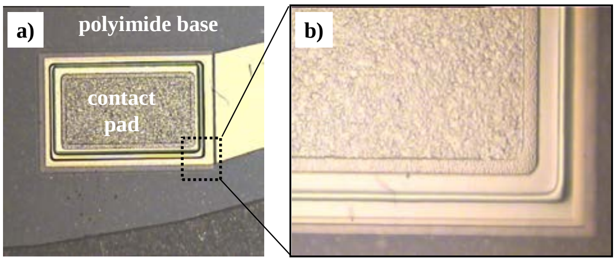

Fig. 8
Detailed view of contact pads:

a) overview

b) detail of metal and polyimide insulator stack

Figure 8(b) shows the stack of materials which make up the multilayer: 1st polyimide, 1st metal, 2nd polyimide, 2nd metal and the polyimide cover layer. Clean surfaces and proper process control are required to fabricate reliable substrates for medical implants.

4 Combination of System Parts

Figure 9 shows the whole retinal implant. It is made up of the three main parts: the CMOS vision chip, which provides the fundamental function of image sensing and signal processing; the flexible substrate which carries the CMOS chip and goes round the eye; and the RF power supply which enables DC free operation of the system. Due to this, the chemical interaction of the implant with the periphery (human body) can be minimized.

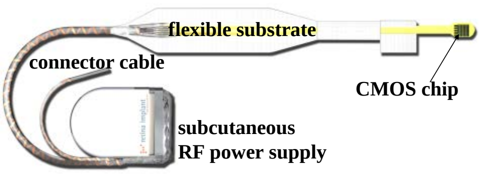

Fig. 9
Retinal Implant with RF power supply, showing the combination of the different system parts being implanted in the human body (subcutaneous = below the skin).

Dr. Alexander Kaiser
Karin Ruess
Dr. Bruno Holl
Josef Vanselow
Dr. Ernst Feurer

Reinhardt Microtech GmbH
Sedanstrasse 14
89077 Ulm I Germany
alexander.kaiser@cicor.com
A company of the Cicor Group

Dr. Liu Liu
Prof. Dr.-Ing. Albrecht Rothermel
University of Ulm

Andreas Möller
Multi Channel Systems GmbH
Reutlingen

Dr. Alex Harscher
Retina Implant AG, Reutlingen

Cicor Management AG
Gebenloostrasse 15
9552 Bronschhofen I Switzerland
Tel. +41 71 913 73 00
Fax +41 71 913 73 01
info@cicor.com

cicor

Dr. Alexander Kaiser
Karin Ruess
Dr. Bruno Holl
Josef Vanselow
Dr. Ernst Feurer

Reinhardt Microtech GmbH
Sedanstrasse 14
89077 Ulm I Germany
alexander.kaiser@cicor.com
A company of the Cicor Group

Dr. Liu Liu
Prof. Dr.-Ing. Albrecht Rothermel
University of Ulm

Andreas Möller
Multi Channel Systems GmbH
Reutlingen

Dr. Alex Harscher
Retina Implant AG, Reutlingen

The electrical connection of the chip with its flexible carrier is realized via gold wire bonding onto each of the six 3-fold contact pads (see figure 10). Utilizing these connections, the electrical supply and the control of the CMOS chip is realized.

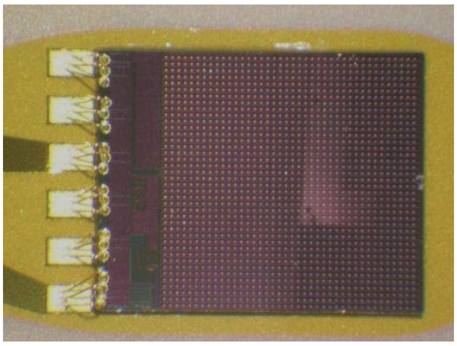

Fig. 10
CMOS Chip on multilayer with electrical connections used for supply and control
.

Encapsulation of the chip with silicone and connecting it to a subcutaneous hermetically sealed RF power supply via a flexible cable (see also figure 9) has proven to be feasible.

Attachment of the silicone cable to the flexible multilayer is realized by wire bonding on the flex substrate side and welding of Au wires onto the silicon cable. This guarantees for a strong and reliable connection between the single parts.

5 Results

First tests with the new redesigned multilayer substrates showed good and promising results. Important properties hereby are the electrical resistance of the lines, which has to be kept small to minimize losses. Another critical point, as the power supply is DC free, is the cross coupling capacitance between the single lines, which also has to be kept on a minimum. This topic has to be addressed by proper design and control of thicknesses of insulators and metal lines.

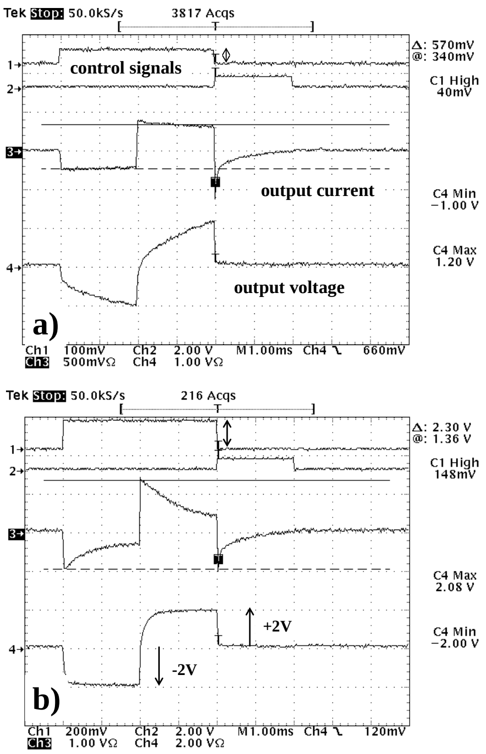

Fig. 11
Output stimulation waveforms of CMOS vision chip applying different input conditions: (a) current limit of I_{IMP}: +7µA / -5µA; (b) current limit of I_{IMP}: +28µA / -20µA.

Another point which seems to be very trivial is the ability to do wire bonding on the connection pads. But due to reliability issues of such implants this has to be considered as an important parameter. Flexibility also has to be taken into account when characterizing such systems, as this is important during the implant surgery as well as in the later use inside the human body.

Examples of output stimulation waveforms with RC-load models are shown in figure 11. These fundamental tests were performed under ambient light condition to prove the functioning of the CMOS chip. The discussed design enables charge-balanced biphasic output signals, which shall be able to couple to the biological interface in the eye and activate the intact cells. Hereby the response of retinal cells to electrical stimulation depends on the charge injected per impulse. The stimulation timing and amplitude of the chip's output can be adjusted by the control signal I_{IMP}.

Cicor Management AG
Gebenloostrasse 15
9552 Bronschhofen I Switzerland
Tel. +41 71 913 73 00
Fax +41 71 913 73 01
info@cicor.com

As the polarities of the stimulation voltage and currents change as can be seen in figure 11, at the end of the stimulation phase the total charge injected can be adjusted to be zero. This is very important to avoid chronic accumulation of electric charge in the nerve layer. In detail, in a first phase a negative charge is injected, followed by a positive charge injection designed to be as large as possible with the given voltage constraints, and finally a third negative charge injection completes the stimulation cycle, with the sum of all three charges being close to zero.

Different conditions were used for testing the principal functioning of the circuits. In figure 11(a), due to a relatively small stimulation current the output voltage approaches a triangular waveform. Hereby the stimulation intensity is determined by the stimulation current amplitude.

In figure 11(b), the output voltage reaches the level of the maximum voltage relatively fast. Subsequent increase of I_{IMP} will not lead to increased stimulation intensity, as the output voltage is limited by the supply voltage amplitude of ±2V.

6 Conclusions

The described technology for flexible implantable multilayer substrates provides new possibilities in the field of medical implants. One first application is demonstrated with a retinal implant, used for helping people regain a certain portion of visual perception.

For this a new CMOS chip has been developed which is able to operate DC free to minimize the interactions with the human body. Special attention was laid to design for long lifetime and high stimulation efficiency to improve the vision of the patient as much as possible.

A promising system with new and outstanding technological attempts was described, which hopefully will be able to help a lot of blind patients in their future life.

7 Acknowledgement

The authors would like to thank the staff of Cicor at Reinhardt Microtech GmbH and Retina Implant AG for support on the technological development and the management for the possibility of publishing this work. Additional thanks are to Volker Burger at EADS Ulm for assisting with the attachment of the Au wires.

8 References

[1] E. Zrenner: “Restoring neuroretinal function: new potentials”, Doc Ophthalmol, pp. 56 - 59, 2007

[2] A. Rothermel, V. Wieczorek, L. Liu, A. Stett, M. Gerhardt, A. Harscher, S. Kibbel, “A 1600-pixel subretinal chip with DC-free terminals and ± 2V supply optimized for long lifetime and high stimulation efficiency”, IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, pp. 144 - 145, Feb. 2008

[3] E. Feurer, B. Holl, J. Vanselow, K. Ruess, A. Kaiser, “Advanced Thin Film Substrates in Cu-AlN Technology”, Proceedings EMPC 2007 European Microelectronics and Packaging Conference, June 17 – 20, 2007, Oulu, Finland, pp. 522-525

[4] A. Kaiser, J. Kusterer, K. Ruess, B .Holl, J. Vanselow, and E. Feurer, “Improved Thermal Management in High Power Applications by utilizing novel “Filled Via” Thin Film Substrate Technology”, Proceedings IMAPS 2007. The 40th International Symposium on Microelectronics, McEnery Convention Center - San Jose, California, USA, November 11-15, 2007

[5] A. Kaiser, J. Kusterer, K. Ruess, B .Holl, J. Vanselow, and E. Feurer, “Solid Filled Via: Improved Interconnects for DC and RF Thin Film Applications”, Proceedings IMAPS/ACerS 4th International Conference and Exhibition on Ceramic Interconnect and Ceramic Microsystems Technologies (CICMT), Holiday Inn City Centre, Munich, Germany, April 21–24, 2008

Dr. Alexander Kaiser
Karin Ruess
Dr. Bruno Holl
Josef Vanselow
Dr. Ernst Feurer

Reinhardt Microtech GmbH
Sedanstrasse 14
89077 Ulm I Germany
alexander.kaiser@cicor.com
A company of the Cicor Group

Dr. Liu Liu
Prof. Dr.-Ing. Albrecht Rothermel
University of Ulm

Andreas Möller
Multi Channel Systems GmbH
Reutlingen

Dr. Alex Harscher
Retina Implant AG, Reutlingen

Cicor Management AG
Gebenloostrasse 15
9552 Bronschhofen I Switzerland
Tel. +41 71 913 73 00
Fax +41 71 913 73 01
info@cicor.com