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# A demonstrator for a flexible active microelectrode array with high electrode number

**Abstract:** The integration of dies is a possibility to reduce the number of conducting tracks within electrical active implants. For passive microelectrode arrays the number of conducting tracks limits the number of electrodes. By embedding an array of small dies (250 μm edge length) employed to amplify and multiplex the signals of 25 electrodes each into a flexible foil we create a flexible active microelectrode array with more than 1000 electrodes. A fabrication process was developed containing a transfer process for the dies as well as an embedding procedure. Here a non-functional Dummy-System is presented as a demonstrator proving the feasibility of the proposed microelectrode array.

**Keywords:** microelectrode array, die embedding, die assembly

## 1 Introduction

The realization of flexible active implants is challenging due to several issues, most of them concerning long-time stability [1]. Another subject that can cause serious problems is the "complexity" of active systems as it can result in a high number of conducting tracks. If these conducting tracks end in another part of the implanted system this might cause no difficulties, but there are also applications where the ends of the tracks have to be outside the body. Reasons can be energy or data transmission either from outside (e.g. cochlea implant) or to the outside (e.g. for the control of a prostheses). As wireless energy or data transmission is very limited, there has to be a plug [2, 3]. However there are no plugs for higher number of leads [4, 5].

To avoid problems due to the high number of tracks in an active system additional circuitry and chips can be added to the desired system. This circuitry can multiplex and digitalize signals and thus reduce the number of tracks.

However, not only the number of tracks that has to leave the system can be a limiting factor. For microelectrode arrays the number of tracks within the array limits the electrode density and the electrode number.

In passive microelectrode arrays every electrode requires a separate conducting track connecting it to a contact.

Thus, for an array where all conducting tracks have to leave the array on one side, the tracks to all electrodes of the $n^{th}$ row have to pass between the electrodes of the $n^{th}$ and $(n+1)^{th}$ row in the first column of the array.

With the electrode spacing $d$ and a required space $s$ for a track (the width of the track itself plus the spacing to the next track) there is space for $d/s$ tracks and thus there can be $d/s$ electrodes in one row. If the array is meant to be a square array this results in $N = (d/s)^2 = k/\rho$ electrodes with the electrode density $\rho = 1/d^2$. The parameter $k$ is then a measure for how many electrodes can be realized for given electrode density $\rho$ in a square array with all tracks leaving on one side.

For a passive microelectrode array $k = 1/s^2$.

We are developing a new active flexible microelectrode array consisting of an array of small CMOS-dies embedded into a flexible foil. The dies developed within the project are 250 μm × 250 μm in size and provide multiplexing and signal amplification to 25 electrodes each.

In this paper we present results on the fabrication of a non-functional Dummy-System out of a 7 × 7 array of tiny die-dummies demonstrating the feasibility of such a microelectrode array with more than 1000 electrodes.

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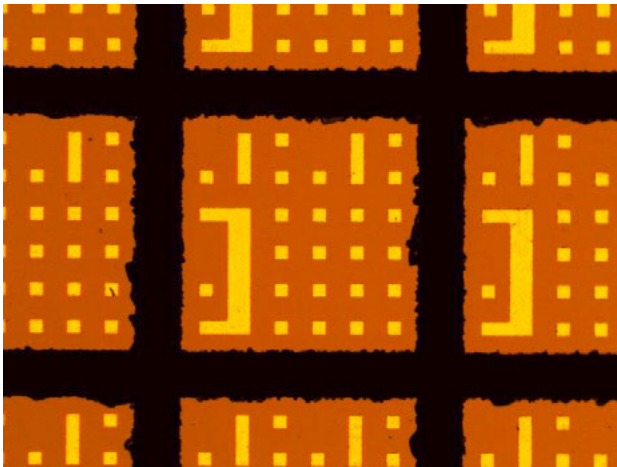
## 2 Materials and Methods



**Figure 1:** Picture of the used die-dummies. The small aluminum contacts are 15 μm × 15 μm in size and are arranged with a 40 μm pitch.

For the dummy-system non-functional die-dummies are used as dies. They were prepared by fabricating aluminium contact-areas on top of a 210 μm thick double-side polished silicon wafer (see Figure 1). The contact areas are (15 μm)² in size with a pitch of 40 μm. Some of the areas are connected to allow resistive measurements on the complete dummy-system. The contacts are repeated every 300 μm on the wafer.

The wafer with the dummy-contacts was separated into individual die-dummies, each dimensioned to about 240 μm × 240 μm using wafer dicing on the UV-curable dicing tape Adwill D-841 (Lintec, Japan). After UV-exposure and a mechanical bending step to loosen the dummy-dies, a selective transfer step was performed transferring all 49 dummies for one array to another substrate. As only every third die-dummy of each column/row was transferred the distance between neighbouring die-dummies was increased to a pitch of 900 μm in the array.

The transferred array was then turned upside down before it was cast in PDMS. After the PDMS was cured the sample was turned again, releasing a flat surface of the dies and the surrounding PDMS. As insulating layers both on top of the dies and between the two layers of conducting tracks 3 μm of parylene C were used. For the conducting tracks, a stack of titanium, gold and titanium was deposited.

Structuring was done using photolithography and dry etching. As the first photomask had to be aligned on the contacts of the dies the negative resist AZ 15nXT (MicroChemicals GmbH, Germany) was used in combination with a bright-field mask. After structuring the resist the parylene C was etched using an oxygen plasma. Then the remaining resist was removed using DMSO.
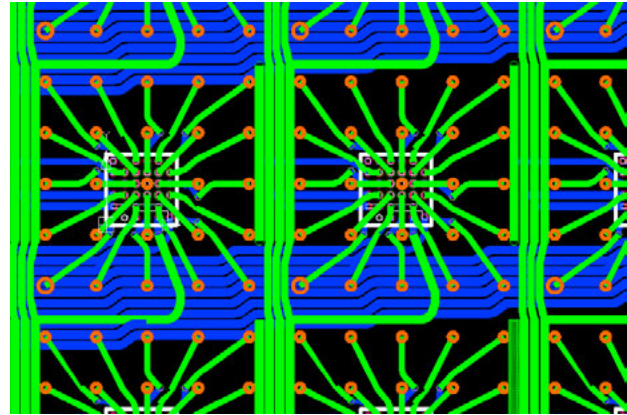


**Figure 2:** Excerpt of the layout showing how the electrodes (orange) are spread from the dies. The lower conducting layer is drawn in blue, the upper conducting layer is drawn in green.

The metallization for the conducting tracks was structured using the positive resist AZ ECI 3027 (MicroChemicals GmbH, Germany).

The dummy-system was designed in a way making it as similar to a microelectrode array based on the dies developed within the project as possible, but also allowing electrical measurements for process control. This means that each die-dummy is connected to 25 electrodes spread around the die with an electrode spacing $d$ of 180 μm. Then every die is connected to four conducting tracks running through the whole array representing lines that are equal for all dies (e.g. power supply) and two conducting tracks that are separated for every die – representing the data line for every die - allowing resistive measurements for checking if the process was successful in contacting the dies.

## 3 Results

For the fabrication two layers of conducting tracks are essential for spreading the 25 electrodes from the die forming one cluster. This electrode spreading also results in a very high wire density on top of the dies limiting the width of the conducting tracks to 20 μm and the spacing to 5 μm within one layer.

It is possible to guide these tracks in a way, that $3 \cdot d$ of space in the lower conducing layer and one $d$ of space in the upper conducting layer are available between two rows of clusters for those tracks leaving the array.

Hence for the system with 7 × 7 clusters all those conducting tracks being separate for every die could be guided in the lower conducting layer in a way leaving the array on side. However,
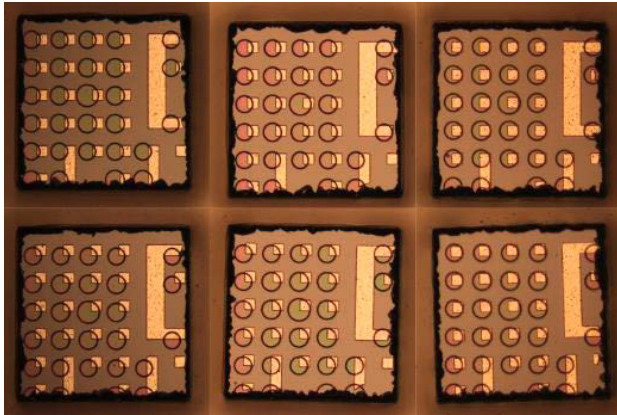
**Figure 3:** Picture of six die-dummies of an array with the structured parylene on top. The holes in the parylene overlap with all contacts of the shown die-dummies.

the space only allowed for tracks with a width of 30 μm and a spacing of 7.5 μm.

All other conducting tracks were guided in the upper conducting layer perpendicular to those of the lower conducting layer. So they were leaving the array on the two neighboring sides (see Figure 2). As a result the array had one side, were no conducing tracks left the array at all and two sides where only few tracks left the array.

The transfer of the dies worked reliable and the embedding resulted in a sample surface with only few micrometers of topography. Photoresist with a resist thickness of about 8 μm could be processed on the surface.

The photomask in the first lithography step for opening the passivation on top of the dies contacts unveiled the accuracy of the die positions within the array. While there were aberrations from the ideal positions these aberrations were less than 20 μm for almost all dies of an array allowing the alignment of the photomask on the dies (see Figure 3). However, this alignment must be a best-fit procedure aiming for overlap of the structures on the mask with the corresponding contacts for as many dies as possible. This means that for most of the dies there is no full overlap.

## 4 Discussion

The built dummy-system is a proper demonstrator for an active flexible microelectrode array with 1225 electrodes based on an array of 49 dies with an edge length of only 250 μm each. The question if such a device can be built and how large it can be made depends on the number of conducting tracks in the array and the spacing of the dies (correlating with the electrode spacing by a factor of five).

While the real dies require five conducting tracks being equal for all dies in the array ($V_{DD}$, $V_{SS}$, GND, clock, and reset), the presented system includes only four such lines. Instead the dummy-system includes two conducting tracks that have to be separate for each die, while the system with functioning dies would only require one for the data readout.

Though, these are the lines limiting the size of the array, as they cannot be merged. So the number of conducing tracks in the dummy-system is at least as high as in a system with functioning dies. The aberration from the authentic situation was tolerated to allow resistive measurements in the complete dummy-system.

Considering the insights from the layout of the dummy-system the number of electrodes $N$ for the system with the functioning dies can be determined. It is 25 times the maximum number of dies in the array $(3 \cdot d/s)^2$ and thus $k = 225 \cdot 1/s^2$. This means that this array can have 225 times as much electrodes as a passive microelectrode array with the same electrode density $\rho$.

The designed layout however only limits the number of columns, meaning that the number of rows can be increased. Also the array can be mirrored forming an array of twice the size with the tracks leaving on all sides of the array.

The transfer process worked reliable and selectively transferred subgroups of dies increasing the distance of neighboring dies in an array. This is essential in order to be cost efficient, as wafer area is precious and for such small dies up to 50% of the wafer area are lost for separation.

The transfer process also introduced only low deviations in the relative die positioning. However for some few dies of an array also larger deviation or rotation occurred, so that the photomask cannot be aligned on them leading to a gap in the electrode array. This would however not affect the functioning of the remaining clusters.

## 5 Conclusion

In summary it was shown that it is possible to build a flexible active microelectrode array with more than 1000 electrodes and an electrode density of more than 20 electrodes/mm² by embedding an array of tiny dies each providing multiplexing to 25 electrodes. A fabrication process was developed and tested building a non-functional demonstrator.

Based on the obtained insight in the design of such an array a square array, with the tracks leaving the array only on one side, with 1600 electrodes ($\rho = 25$ electrodes/mm², $s = 70$ μm) seems possible.

However, when submitting this paper the demonstrator had not been built completely, so no statement on the contact resistances within the system was possible.

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