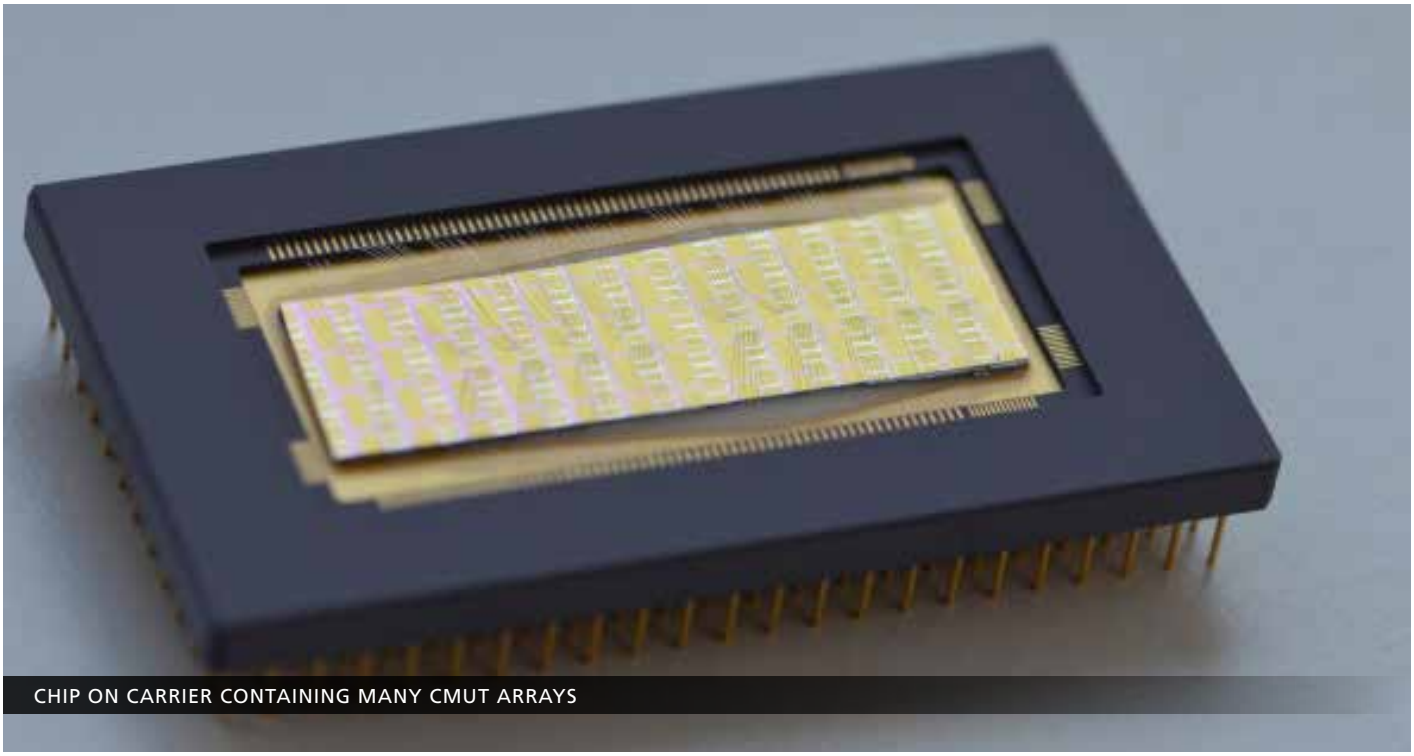
ACOUSTICS WITH MEMS: CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER (CMUT) FROM RESEARCH TO COMMERCIAL PRODUCTS



CHIP ON CARRIER CONTAINING MANY CMUT ARRAYS

Capacitive Micromachined Ultrasonic Transducers (CMUT) are MEMS based structures that can be used to generate and sense acoustic signals in the ultrasonic range. Interest on CMUTs is rising due to the quality of the acoustic signal they provide, ease of integration with CMOS and because their dimensional characteristics enable to broaden the applications of ultrasonics. At Fraunhofer IPMS we are working to shift CMUTs from a research to a commercial environment.

Ultrasonic transducers are present in everyday life in the form of level sensors, speed sensors and medical imaging systems among others. Current ultrasonic transducers are usually built using piezoelectric materials and have proven to do a great job. CMUT technology can however broaden the applications and fields where ultrasounds could be used, in addition to avoiding undesired materials (Pb) and allowing easy integration with CMOS integrated circuits.

The CMUT is essentially a MEMS structure comprising two electrodes facing each other, one of which is fixed and the other is movable. The two electrodes are separated by an insulating layer and an air gap. CMUTs can operate on transmit and receive mode, by converting electrical energy into acoustic energy or vice versa through the displacement of the movable electrode.

Over the last two decades, Prof. Khuri-Yakub's group at Stanford University and several other research groups have demonstrated the capabilities of the CMUTs, and have worked on all the different parts (MEMS, beam forming, drivers, read-out, etc.) required for the CMUTs to work. However, and although trials have been made to bring CMUTs to commercial products, there is still no product available in the European nor US market using this technology.

One of the issues that could explain this situation are the strict requirements presented for the new ultrasonic applications, such as homogeneity among transducer elements within large arrays and reliability of the MEMS, which is a difficult target to meet in a research fab.

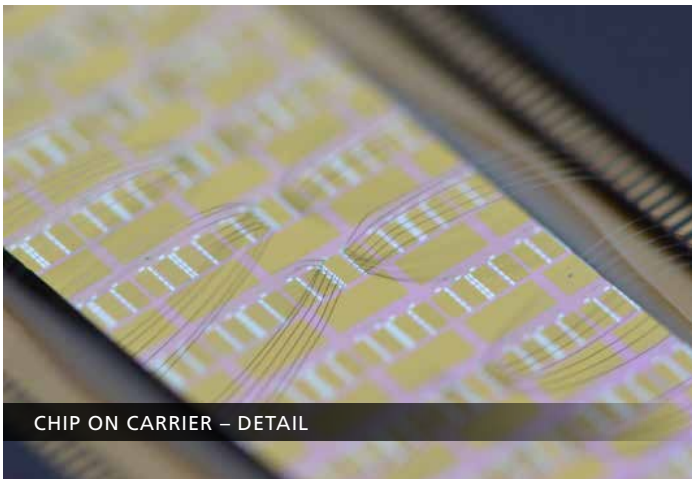
Fraunhofer IPMS can address this by making use of the in-house wafer fabrication facility. In this facility, the Spatial Light Modulator (SLM) product range is being produced with similar element homogeneity requirement as for CMUTs. Furthermore, an in-house developed CMOS process as well as experience on integrating MEMS on top of CMOS wafers are available at Fraunhofer IPMS, which can contribute to the CMUT project.

Fraunhofer IPMS started developing CMUTs in the last quarter of 2012, and since then, a committed team of engineers have completed several tasks. To start with, a "sacrificial release" process

was adopted for the fabrication of the CMUTs. This was preferred over the "wafer bonding" technique alternative, as many of the fabrication steps were already characterized over the last years during the SLM projects. At the same time, a complete process flow was specified, including materials and available film thicknesses.

Initial FEM models of the CMUT elements were built to explore the design space, and several CMUT designs were selected to obtain resonant frequencies in the range of 1 to 50 MHz. Dimensions of CMUT elements ranged between 10 and 100 µm, and are to be packed in groups of a few hundred, meaning that all these CMUTs operate as a single structure.

Even though many of the fabrication steps have previously been characterized for the SLMs, it was necessary to explore parameters, such as the deposition stresses and the release times for different number of release holes and CMUT dimensions in a wafer lot. As an extension to this experimental wafer lot, the cavities where sealed and electrical contact pads added, yielding the first testable CMUTs built by Fraunhofer IPMS.

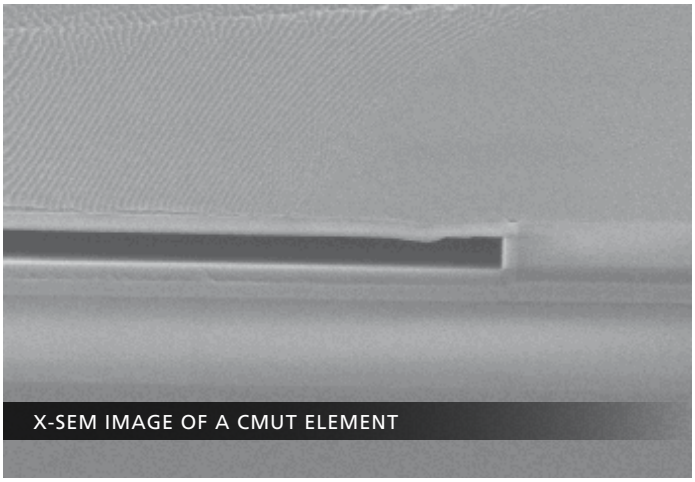


CHIP ON CARRIER – DETAIL

The first generation of Fraunhofer IPMS´ CMUT arrays is currently being characterized. In addition to the optical inspection and X-SEM images, white light interferometry was performed to check on the homogeneity of the CMUTs within CMUT group to wafer location dependency.

Electrical tests are also being performed on the first generation Fraunhofer IPMS CMUTs. Initial impedance measurements show a resonant frequency in the range of 9.1 MHz matching what the FEM models predicted. At the moment, several CMUT samples are being tested to create statistics and see the homogeneity on the resonant frequencies between elements within the array and array to array.

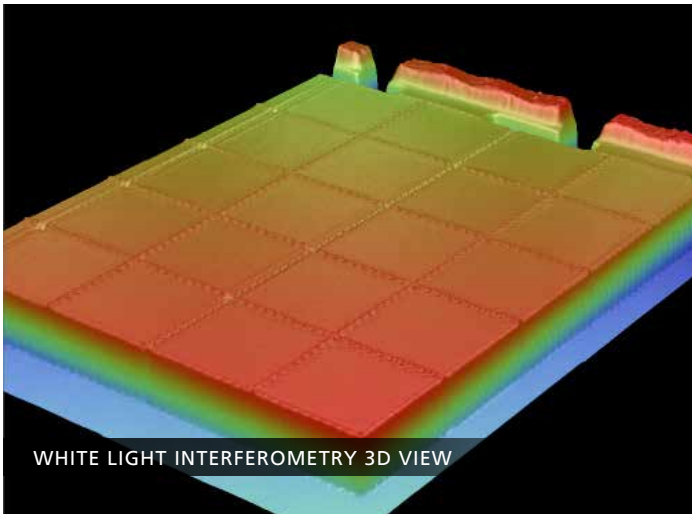
So far, the results obtained are very promising. The characterization activities are now progressing towards obtaining the first acoustic measurements using an hydrophone system.



X-SEM IMAGE OF A CMUT ELEMENT

In addition to the team, many of the CMUT experts around the globe have been approached, and all have shown their interest to support Fraunhofer IPMS with their expertise, which has already been useful and we really appreciate.

At this stage, we are looking into the requirements for different applications, ranging from medical to non-destructive testing applications, but more interestingly looking for new applications where CMUTs can provide a definite advantage over current ultrasonic transducers.



WHITE LIGHT INTERFEROMETRY 3D VIEW

In fact, the aim is to develop applications for customers that could benefit from this new technology. Therefore, we invite everyone interested on developing new ultrasonic applications to contact us to explore the possibilities of CMUTs.

INTERVIEW WITH ANARTZ UNAMUNO

Fraunhofer IPMS: "Since 2012 Fraunhofer IPMS is working on the development of CMUTs. How did this come about?"

Anartz Unamuno: "CMUTs have been researched for over 20 years now, but as with many other products, several hurdles need to be overcome to close the gap between research and commercial products. Fraunhofer IPMS has the fabrication facility as well as the knowledge required to fabricate CMUTs. In addition, the business model of Fraunhofer Institutes is to apply research to create products, which is what CMUTs need at this stage. I believe that Fraunhofer IPMS and CMUTs have met at the right time, and the outcome of this effort will yield in CMUT based commercial products in the next 2–3 years."

Fraunhofer IPMS: "What are the main benefits of CMUTs compared to piezoelectric transducers?"

Anartz Unamuno: "Piezoelectric transducers have done a great work so far in the ultrasonic field, and they do keep advancing with new technologies and materials. This is why CMUTs are not here to replace piezoelectric technology, they are here to complement and bring ultrasound technology to new applications. The main advantages of the CMUTs lay on the easiness to integrate them with CMOS, their manufacturability using microelectronic fabrication methods that allow repeatable results, and a better performance, regarding bandwidth, frequency range and dynamic."

Fraunhofer IPMS: "What will be the main challenge working on CMUTs?"

Anartz Unamuno: "Of course there are technological challenges that need to be addressed, but there are usually solutions available for them. I would bet that the largest challenge is in convincing the potential customers to use a new technology, CMUTs in this case, for their application. For this, the CMUT team at Fraunhofer IPMS has to generate enough evidence in form of performance and reliability results that demonstrate the strengths of CMUTs, and eventually we need to provide an individualized solution to each customer. Bringing a product into a new market is always challenging, but it is also highly fulfilling."

Fraunhofer IPMS: "What are the advantages of the CMOS integration of CMUTs?"

Anartz Unamuno received the Ph.D. degree from the University of Strathclyde (UK). Between 2006 and 2012 he worked on RF-MEMS for Cavendish Kinetics (NL). Since September 2012 he is leading the ultrasonics group at Fraunhofer IPMS.

Anartz Unamuno: "Many ultrasonic applications rely on so called phased arrays since they provide functionalities like steering and focusing of the ultrasonic wave. Technically, this is realized by individual scaling and delaying of the ultrasound pulses generated by the cells. Since piezos are always passive devices, only one-dimensional arrays are possible at the cost of complicated and expensive wiring. Two-dimensional arrays which enable numerous new applications for instance in non-destructive testing require CMOS integration which only can be achieved with CMUTs."

Fraunhofer IPMS: "Which applications could CMUTs be used for in everyday life?"

Anartz Unamuno: "In reality CMUTs could replace any other ultrasonic transducer in applications, such as level or speed sensors, medical imaging, non-destructive testing, etc. However, as mentioned before, the intention for CMUTs is not to replace the piezoelectric transducers, but to address new applications. Some of the applications where CMUT researches are working range from medical ultrasonic imaging systems mounted on a catheter for cardiac exploration, to gas flow sensor systems in harsh environments, to airborne ultrasound applications used for gesture recognition that could be used to replace the mouse and keyboard interface for gestures."

Fraunhofer IPMS: "Which will be the next steps?"

Anartz Unamuno: "So far, we have fabricated the first CMUTs at the IPMS fabrication facility, and we have done optical and electrical characterization of these CMUTs. We are now working on the setup required for the acoustic characterization and working to obtain the first acoustic performance measurements. In the next few months, we need to work on the drive and readout ICs and implementation of beam forming algorithms.
As you see, we have just started working on CMUTs. There is plenty waiting ahead of us! Probably as important is to focus on developing the right application for CMUTs and possibly win a key customer that could eventually lead to a commercialized CMUT based product."