Miniaturized Circular Array

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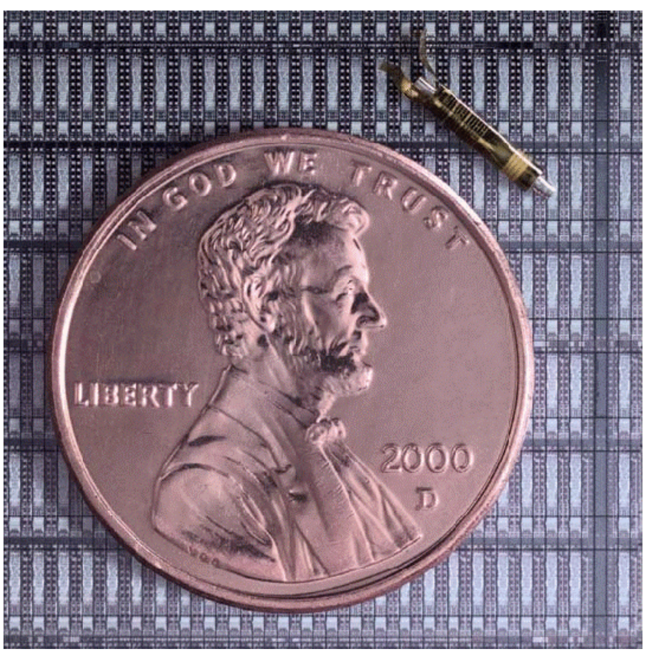
Intravascular ultrasound demands miniature transducers that can be guided through tiny blood vessels. Other applications in medicine and industry can also benefit from a highly miniaturized catheter based transducer design. The smaller the geometry the more useful and versatile the resulting device will be.

Design consideration of geometry versus performance tradeoffs, other acoustic properties in array design and the methods of synthetic aperture beamforming are well known to this audience. Therefore, we have focused our paper on the details and intricacies of manufacturing extremely small ultrasound arrays.



Although it is increasingly being used in other vessels of the body, intravascular ultrasound (IVUS) is mostly employed to assess the condition of coronary arteries in patients who are experiencing symptoms of coronary disease. That requires the diagnostic catheter to be as small as possible while still providing a reasonable image quality. The catheter must also fit the fairly restrictive medical reimbursement rates and since it is a single-use disposable the cost per device must be more than an order of magnitude lower than the cost of regular ultrasound transducers.

In the beginning EndoSonics had attempted to build up the array, the ICs and the interconnect traces around a machined ceramic carrier. In other words the structure was being built from the inside out. This scheme had worked well but its labor intensity and cost turned out to be prohibitive. A new scheme was devised where the array and five integrated circuits (IC) are assembled on a flat flexible circuit. This circuit contains all interconnect traces. During the first production stages the flexible circuit remains rigidly mounted onto a stiff plastic carrier which can be easily handled and loaded into production equipment. After mounting the PZT, dicing the PZT and placing the integrated circuits, the relevant part of the assembly is removed from the rigid plastic carrier, rolled up into a mold and baked out in order to create a circular array.

EndoSonics' 20 MHz circular array consists of 64 elements with an outer diameter of 1.2 mm. In order to support a synthetic aperture scheme with more than 100 firing combinations per vector the ultrasound system must perform more than four billion multiply-accumulate operations per second. Also, flow estimator hardware and

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software has been incorporated so that a cardiologist can estimate the open area of a vessel in an instant, without having to evaluate gray levels and speckle regions.

The Five-64 transducer got its name because of the 64 elements it features and the fact that five integrated circuits are needed to multiplex the array elements into a single signal channel at a time. The transducer is built on a flexible circuit which is then rolled inwards. The element pitch of 55 µm leads to challenges such as dicing the small kerfs between elements. These kerfs are about 20 µm wide and the cut must be all the way through 75 µm thick PZT and into the very thin flex circuit. However, the flexible circuit must not be cut through and this requires a precision of the saw and its blade beyond what is customary in the semiconductor industry. The cutting depth tolerance is ± 3 µm.

Another rather intricate task is the placement of the multiplexer ICs. Each one is 2.5 mm long and 0.4 mm wide, yet features 31 contact pads that must all successfully bond to the flexible circuit. The chips feature very small contact areas which are plated up for a reflow soldering process. The smallest pad pitch is 75 µm and the smallest contact area is 15 µm by 17 µm. Also, the ICs are lapped down to about 100 µm in thickness. That is required for two reasons. First, the whole assembly will in the end be rolled inwards and if the ICs were thicker than 100 µm their top corners would interfere upon inward rolling. Second, the solder reflow process requires a camera head to see through the ICs in order to identify the correct positioning of the contact pads over the corresponding pattern on the flex circuit.

In order to achieve secure IC bonding, all five chips have to be flip-chip placed with an accuracy of ± 5 µm in either direction. A single contact failure typically renders the complete assembly non-functional.

Extensive machine vision is utilized to ensure that the production of these miniature devices is economically feasible. The required dicing and bonding machinery is not available off-the-shelf and most equipment lacks optical pattern recognition gear. Therefore, almost all equipment has been custom built and fitted with camera systems and image process control software. Most of the processes are no longer manual and the main tasks are loading, unloading and maintenance of the production equipment.

After separating the diced and otherwise completed flat assembly from its rigid plastic carrier the flexible circuit is rolled inwards by pulling it into a mold which inner diameter narrows. Rolling occurs around a metal tube which then becomes the center “axle” of the transducer. This tube serves many purposes. It provides an electrical ground connection between front and back, it is radio-opaque which eases the visibility of the scanner in the x-ray based angiogram and it allows the attachment of the catheter shaft, a catheter tip, balloons or whatever else is needed. A washer on either end ensures the proper roll diameter and stability.

The washers exhibit recesses so that the backing material can be injected from one side while air escapes at the other washer. After completely filling the device it is placed in an oven and cured. Later the mold is removed and the scanner is ready for mounting onto a variety of catheters. Mounting requires very fine pitch electric wire connections.

Other solutions such as drive-shaft driven single crystals are technological alternatives to create similar imaging. However, these need to be flushed prior to use in order to provide acoustic coupling. Also, only electronically scanned transducers can be effectively combined with interventional therapeutic devices and allow reliable flow analysis.