A 20 MHZ λ-SPACED LINEAR ARRAY WITH A REALTIME SYNTHETIC APERTURE BEAMFORMER

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Abstract

High frequency arrays working with frequencies up to 20 MHz are essential in high resolution and real-time imaging in industrial and medical applications. Especially in catheters and other small integrated devices they will deliver a diagnostic advantage.

Two major engineering tasks have to be solved in such systems. The electrical interconnection of the single elements of a fine pitch array and the beam forming electronics with the capability of real-time imaging. Fraunhofer MICROFLEX (MFI) technology is used to connect the transducer acoustically invisible. As a beam forming device an 8 channel 20 MHz Digital Phased Array System (DiPhAS) is used. To achieve best results in scan conversion a modified M-SAFT synthetic aperture method is used.

In this presentation the concept of a high frequency 110 element transducer array and its interconnection with a spacing down to 75µm using the MFI technology and a low-cost extendable beam forming system will be shown. The MFI technology allows a high flexibility in the design and shape of the transducer and the DiPhAS allows beam forming in a huge variety.

This paper concentrates on the key points in manufacturing and driving the HF array. First results have been shown with several test specimen.

Introduction

MICROFLEX-technology (MFI) is a multilayer process invented by Fraunhofer to achieve very thin flexible circuit lines. With this technology the capability of mounting small electrical and acoustical devices together is possible. The connection of electrodes of arbitrary shape and size is the aim of this approach. In micro systems technology die packaging and fine pitch bonding are very common techniques to mount devices on printed circuit boards. In acoustics high frequency transducer arrays for acoustical imaging use a pitch down to 75 µm. The flexible circuit is used to connect both worlds.

Although ball bonding technologies are very common to interconnect electrical parts they have not been used to connect thin electrodes on PZT-ceramics. The low adhesion between the ceramic material and the electrode can be simplified with this approach.

To use the linear array in an application a Digital Phased Array System (DiPhAS) is used. This device allows nearly arbitrary beam forming and focusing techniques. The system can run probes up to 20 MHz center frequency and adapts synthetic aperture focusing techniques like SAFT and M-SAFT.

MFI Process technology

The process to achieve the flexible circuit is performed in a clean room class 100. The fine pitch of the transducer array should not exceed 75 µm so photolithography was used to achieve the electrode structures. The approach is based on polyimide which is spin coated on a silicon wafer and is dried afterwards. The thickness of the polymer layer has to be a compromise between flexibility and mechanical stability. After appliance of this 5µm thick polymer carrier material it is activated by a plasma process to ensure the adhesion of a thin film metal layer which is used to form interconnection lines and pads. The structures are formed by a photolithography process. To achieve multilayer flexible circuits the polyimide spin coating is repeated as well as the metallization and the photolithography. Additional layers influence and deteriorate the flexibility of the circuit.

The achieved flexible circuit offers the possibility to connect other metal surfaces through via holes which are produces in a last plasma step. The flextape is coated with an Al-layer which works as an etching mask. The vias are produced then by oxygen plasma.

Microflex Interconnection

As in common wire bonding technologies a gold ball is bonded to a gold pad. This principle is adapted to MFI. The gold ball is achieved by electrically melting the bondwire with a diameter of 17 µm and then welded to the pad by ultrasound with a semiautomatic standard bondig device. In the MFI the substrate to be bonded onto is placed under the via holes and the gold ball is welded trough the hole with a small neck capillary at a temperature of 140°C. After lifting the capillary the bond ball remains on the surface connecting the substrate through the hole.

As a result for the fine pitch array circular pad sizes of 60 µm with a hole of 35 µm have been achieved (see Figure 2). The heated PZT ceramic is held with vacuum while the flextape is adjusted to the substrate with a micro positioning tool. After the bonding process an epoxy filling material is used to fix the connection between the tape and the electrode. For further reference of MFI technique and properties refer [1] and [2]. An schematic overview of the fabrication steps of the Mircroflex ribbon cable (two layer example) is described in Figure 1.

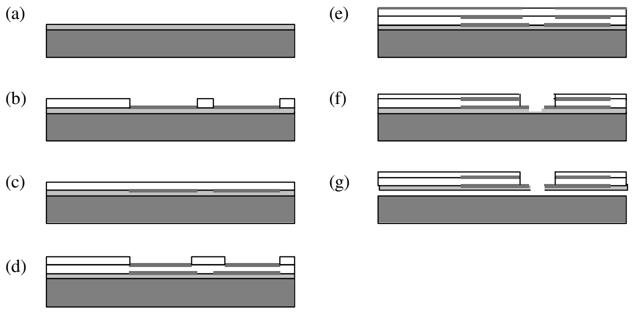

Figure 1: MFI Process

(a)	Spin process of Polyimide carrier layer to Si-wafer
(b)	Lift off technique with first metallization layer (bond pad)
(c)	Covering with second Polyimide layer
(d)	Second lift off process with second metallization layer
(e)	Aluminum pattern for etching process
(f)	Etching of Polyimide tape
(g)	Lifting off tape from substrate

Electrical properties

Overall thickness	10 µm
Thickness of conductors	0,5 µm
Width of conductors	50 µm / 150 µm
Resistance (length)	20 Ohm to 100 Ohm
Inductance (length)	10 nH
Capacitance (to ground)	2 pF
Capacitance (cross)	3 pF
Dielectric constant (1kHz)	2,9

A 20 MHz λ-spaced transducer array

To achieve the connection of the flex tape to the ceramics several approaches has been taken. To prove the fine pitch connectivity of the MFI the first effort was to place a 75µm pitch flextape on a gold sputtered Si-wafer. Because of the good adhesion between the gold layer and the silicon and the mechanical stability of silicon the bond ball stands after lifting off the bond capillary. The MFI connected flex tape to the Si-wafer. These results encouraged to apply the flexible circuit to a conventional gold coated Motorola PZT (3202HD). There the bond ball broke out after lifting the capillary and left a hole in the PTZ’s gold electrode. This lead to the conclusion that the lift up force of the capillary was too strong through the small area of the via hole of the flex tape.

To control the influence of the thickness of the gold coating the conventional electrode was removed by a fine lapping process. Best results have been achieved after preparing the Piezo ceramic to a surface roughness of 3µm and an intensive cleaning of the surface with acetone and isopropyl alcohol. An own electrode with a chrome adhesion layer was used as a basis. As a good combination 10 nm Cr and 700 nm Au was used. To maximize adhesion between Cr and PZT the ceramic had to be activated with Argon plasma, which leads to a better reactivity of the surface. After the deposition of the gold layer it was possible to place simple bond balls on the plain surface without the flextape. So the first attempt of connecting the flexible circuit to the electrode of the PZT was to create a pattern of simple bond balls on the surface in the same geometry of the bond pads of the flex tape. This is a very tiresome work because of its need for a placing mask in the same pitch. Another disadvantage is the thickness of the bond balls and the mask layer which cannot be removed.

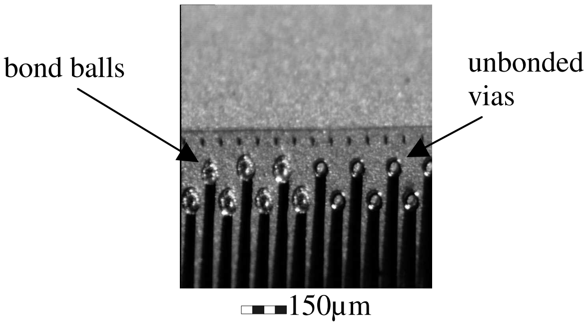

Figure 2: Bonded and not bonded via holes on PZT

Galvanic

To minimize the force of the capillary an additional galvanic layer of gold should spread the force evenly in the gold electrode.

In the galvanic process the surface roughness of the PZT played an important role, because it is responsible for the achievable area the gold ball can be applied to. Another important parameter was the speed of galvanization. At a low galvanization current gold lays down evenly on the surface and maximizes the area for the bond balls adhesion. High galvanization current leads to worse results because gold is not distributed evenly and this lead to uneven surfaces. Low current increases the process time of the galvanic

Post Processing

After achieving the connectivity between the flextape and the gold electrode the ceramic had to be structured with a dicing process. Therefore the flexible circuit has to be fixed with the backing material to avoid the lift up of the bond balls during the dicing process. Dicing of the PZT with applied backing and matching layer was successful with a pitch of 75 µm and a kerf of 18 µm. Backing was a PZT-powder filled Epoxy (DURALCO) with a Impedance of 6 MRayl. Matching was achieved with an Al2O3-filled Epoxy (Epotec 301) with an impedance of 4.04 MRayl. To avoid electrical cross coupling between the elements via the coupling medium an insulation with a “Parylen C” layer with a thickness of 2 µm was applied.

Probe Specifications

center frequency	20 MHz
Bandwidth	60%
No. of elements	110
Pitch	75 µm
Matching layer	1
Insertion loss	40 dB
6 dB opening angle	40°
6 dB focus width	180 µm (simulated M-SAFT)

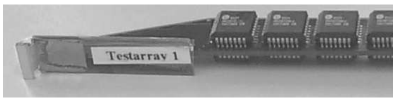

Figure 3: Acoustical block (l.) adapted to an ordinary printed circuit board and to a Multiplexer.

Digital Phased Array System (DiPhAS)

Ultrasonic digital phased array systems are used to control the sound beam transmitted into a test object (tissue in medical applications, material in non medical applications). For a given aperture the parameters that determine the form of a beam are: center frequency, wave form, amplitude-weighting (apodization), delay (steering and focusing) and number of beams (multibeam).

To use such a system as a research interface for ultrasonic applications several conditions have to be fulfilled. The parameters of the beam-former should be freely programmable to enable different scan strategies and support arbitrary transmit signals (e.g. coded excitation). An application specific modification of the system should be possible to support simple imaging as well as different modalities (Doppler, Color Flow, etc.) or pure RF-data acquisition. The adaptation of different types of probes (linear phased array) should be supported and an unrestricted access to the RF-data coming from the test object should be provided.

Figure 4: Diphas system with 8-channel synthetic aperture capability

Specifications of the Research Interface

One of the most important conditions for advanced research and development in ultrasonic phased array imaging is to have the full control of the parameters that determine the form and temporal behavior of the beam. Each single element should be addressable concerning the following settings:

- individual waveform (e.g. encoding),
- amplitude weighting (apodization),
- delay (steering and focusing, dynamic focusing),
- individual time gain control (dynamic fading),
- free configuration of the scan strategy (multibeam, synthetic-aperture-strategies like SAFT or MSAFT),
- adaptation of the impedance (matching to different transducers),
- adaptation of the sample frequency (e.g. 4 times the center frequency for imaging or 10 times the center frequency for time shift estimation) and
- sufficient resolution in AD-converting to reduce the digitization noise.

The digital phased array system DiPhAS that we have developed during the last few years meets these requirements. It is scalable in steps of 16 channels and supports probes up to 20 MHz. In its standard configuration it has 64 transmit-receive channels with a center frequency of 10 MHz. Using a multiplexer, probes with up to 256 elements can be driven. The transmit waveform is bipolar rectangular and arbitrary series can be programmed to form pulses, bursts or special code-sequences. Its amplitude can be controlled to a peak-to-peak-level of 160 Volts. With an internal system-clock of 120 MHz the resolution for the delays is 8.3 ns and a maximum value of 62 µs can be programmed for each channel. Dynamic focusing and dynamic aperture are supported to improve the resolution. The maximum scan depth is 60 cm at 7.5 MHz. The TGC-range is up to 72 dB and the received signal is converted by a 12 bit wide AD-converter. The system is connected via the PCI-bus to an external PC to transmit the RF-data with a speed of 40 MHz and a resolution of 16 bit. In its actual implementation the system is programmed through the PC's printer port (EPP-mode). The hardware of DiPhAS is partly implemented in FPGA-technology which enables a flexible adaptation to different application specific configurations (filter, control, scan strategy, etc.). The operating system of DiPhAS is programmed in simple modules (C-code), an object oriented implementation for the user interface and the control of the system is work in progress.

Synthetic aperture beam forming

The combination of the test array and the 8 channel DiPhAS is achieved with a 8:110 Multiplexer which allows to sweep an 8 channel subaperture in 5 steps over an 40 element aperture. A synthetic aperture of 40 transmit and receive channels can be build.

Since in the original synthetic aperture focusing technique (SAFT) only a single element is excited on each measurement, the acoustic power delivered to the body can be very small. For increasing acoustic power in multi-element synthetic aperture focusing technique (M-SAFT) a group of elements is transmitted and received simultaneously. In M-SAFT every sub aperture transmits parallel to its own acoustical axis. In our model every transmit aperture is focused in the focal point as a little phased array. Then the aperture is shifted. In the transmit case the single sound fields are added concerning the different time delays because of their round trip time. The elements on the edge need more time than the ones close to the axis.
The simulated focus is about the size of 180 µm which is also the estimated size of a complete 40 element aperture.

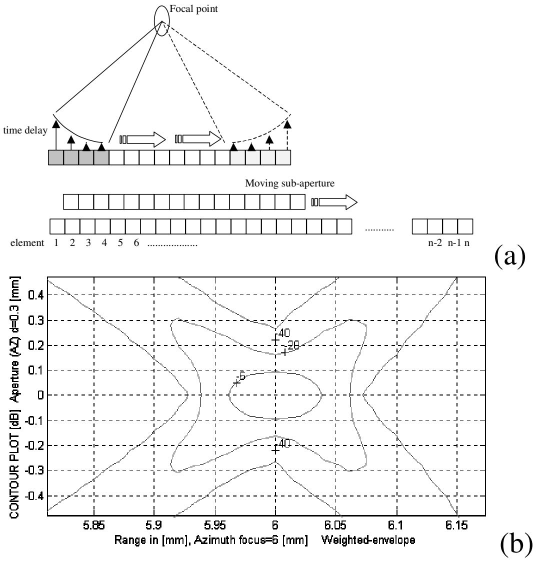

Figure 5: (a) adapted M-SAFT synthetic aperture technique
(b) simulation results of transmit focus 6mm in front of the aperture

Preliminary Results

To test the capabilities of the Beamformer with the array a phantom of 5 threads with a thickness of 130 µm and a pitch of 500 µm was created and a images were created. With the applied M-SAFT technique the frame rate of the system was adjustable between 10–20 Hz. All structures can be located and separated. The frame rate decreases with increasing number of transmitting and receiving subapertures.

Conclusion and Outlook

With Fraunhofer Microflex technology the miniaturization of high frequency transducers can be achieved very easily. Direct combination between electrical and acoustical parts is possible. Individual solutions in transducer array development in almost any kind of medical and technical application of ultrasound are possible.
A 110 element λ-spaced transducer array with a 75µm pitch was achieved with the possibility to adapt it into catheters an other small acoustic devices. To maximize imaging capabilities in future the adaptation of an acoustical lens is planed. For further miniaturization the actually used printed circuit board will be replaced by a flat fine pitch cable or other conventional flexible circuits.
Actual image results look promising and have the capability to be improved by implementing coded signals and correlation methods. Signal to noise ratio can be minimized in using more than 5 subapertures.

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