Research in Ultrasonic Imaging Laboratory

National Taiwan University

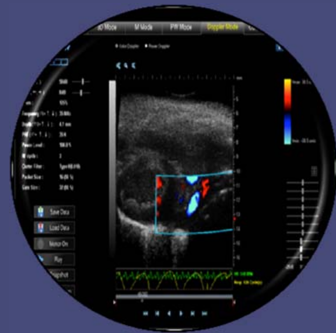
Ultrasound Technologies for Biomedical Applications

Physics

- Wave propagation
- Ultrasound
- Photoacoustics

Systems

- High frequency imaging
- Functional imaging
- Customized Sensors

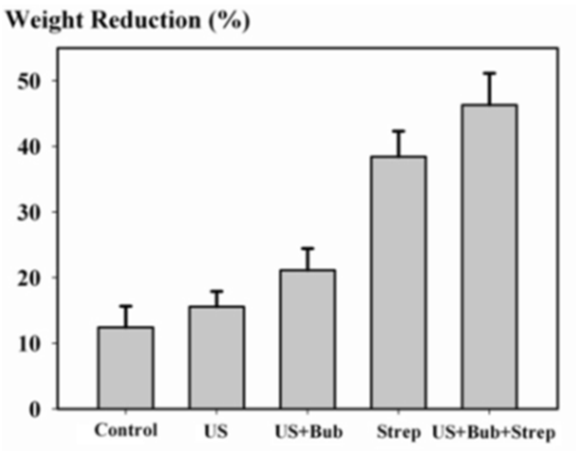


Signals

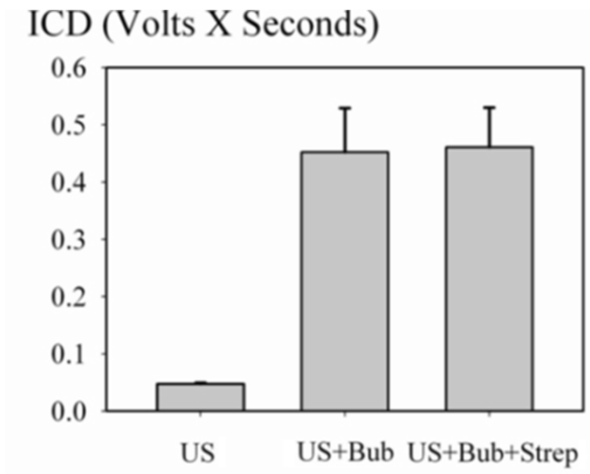
- Adaptive imaging
- Software imaging
- Quantitative assessment

Ultrasound-assisted Thrombolysis

- Goal: Find a better detection technique for sonothrombolysis.
- Hypothesis: Combining ultrasound, microbubbles and thrombolytic agent can be a promising method for sonothrombolysis.



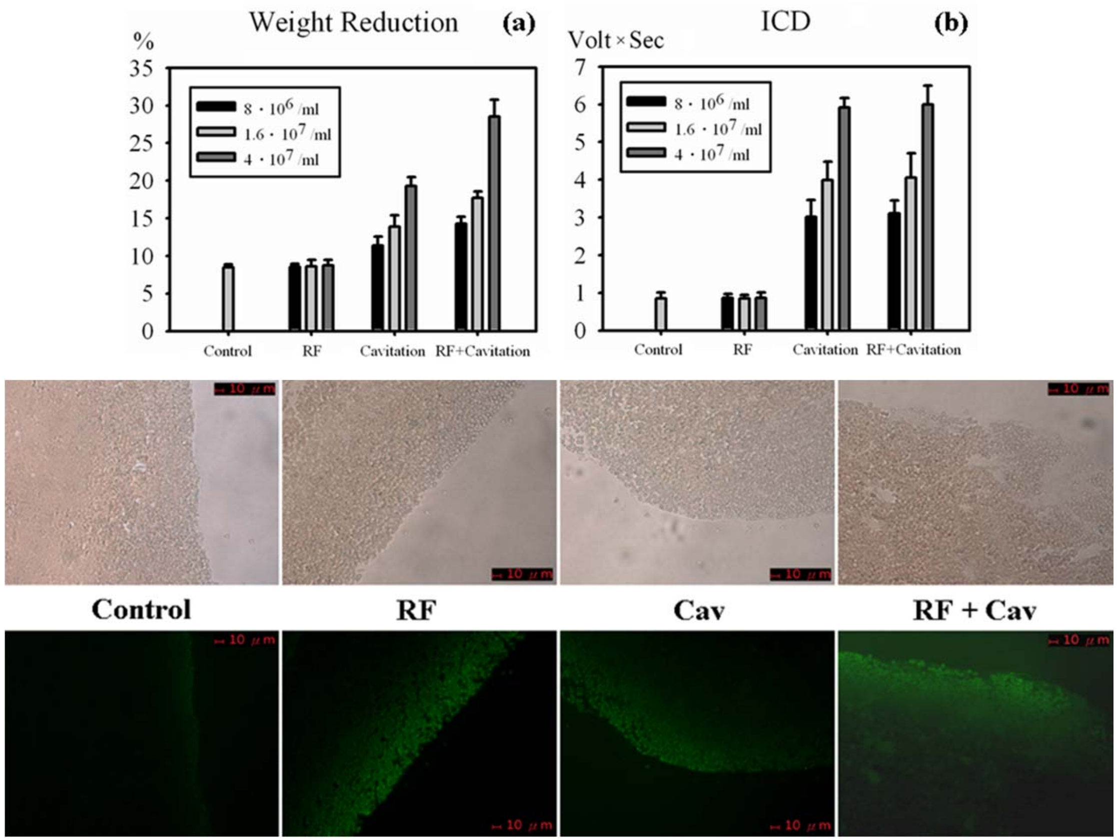
(a)



(b)

Cavitation (especially inertial cavitation) probably underlies ultrasound-enhanced thrombolysis. The ICD (inertial cavitation dose) we proposed was proved to be a useful indicator of thrombolysis.

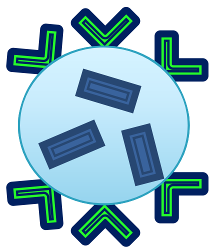
- Hypothesis: Acoustic radiation force helps the targeting of microbubbles on blood clots for subsequent treatment.



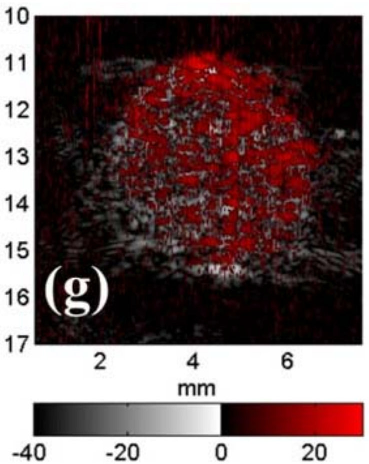
Combining targeting microbubbles, radiation force, and cavitation effects of ultrasound have been shown as a promising method for sonothrombolysis. Alternative application of radiation force and cavitation provides better effects in sonothrombolysis relative to radiation force or cavitation alone.

AuNP-MBs for Multimodality Theragnosis

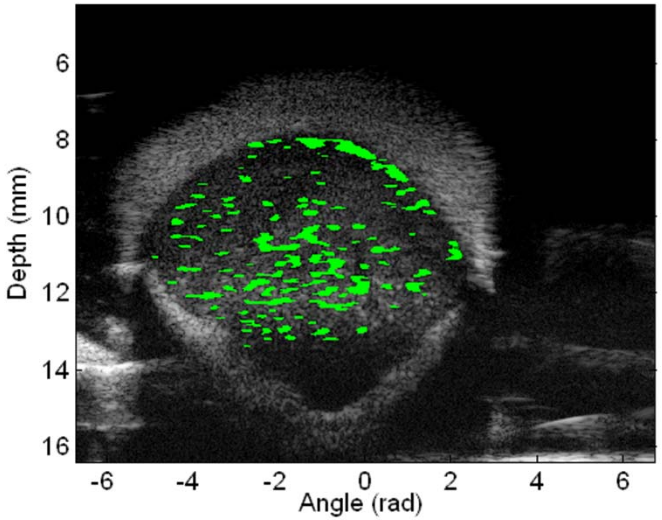
- Goal: A photoacoustic-ultrasonic dual modality contrast agent for theragnosis
- Hypothesis:
  - <u>Gold nanorods (AuNRs)</u> provide optical absorption for photoacoustic and photothermal enhancement.
    →Observed by optic method and provide cellular level information
  - <u>Microbubbles (MBs)</u> are an ultrasound contrast agent and drug carrier.
    →Enhanced delivery by acoustic mediated method and molecular targeting.



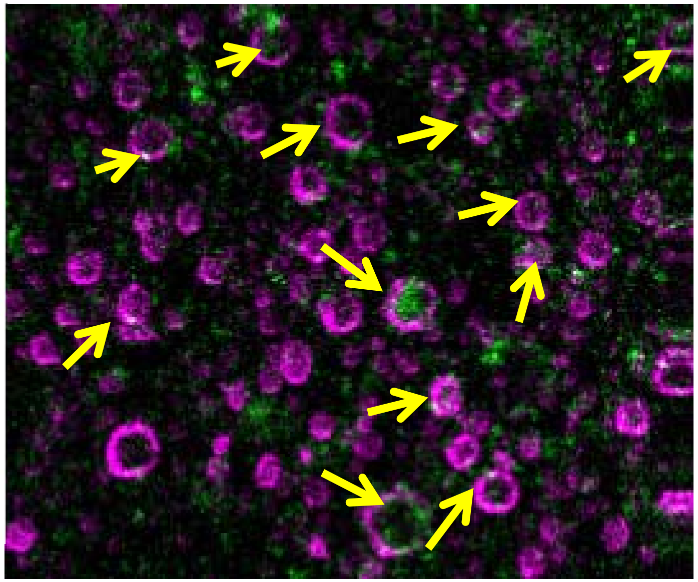
- Representative Figures



US/PA dual-modal image of AuMB



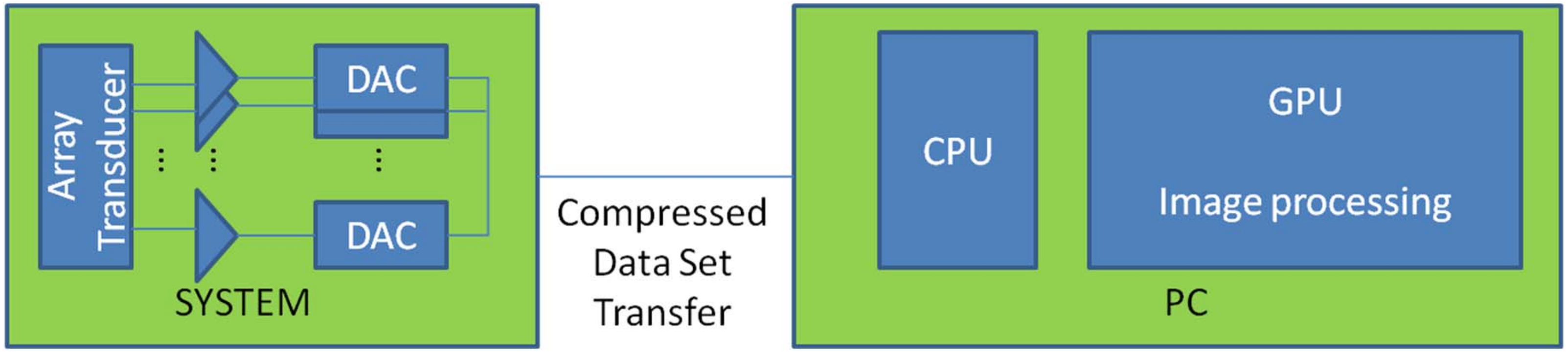
Targeted MBs extends the retention period for therapy and enhances the effect at the targeted site.



Overlaid 2PF(AuNRs) and THG (MB shell) image of AuNR-MBs

Channel Data Compression for SW Imaging (1)

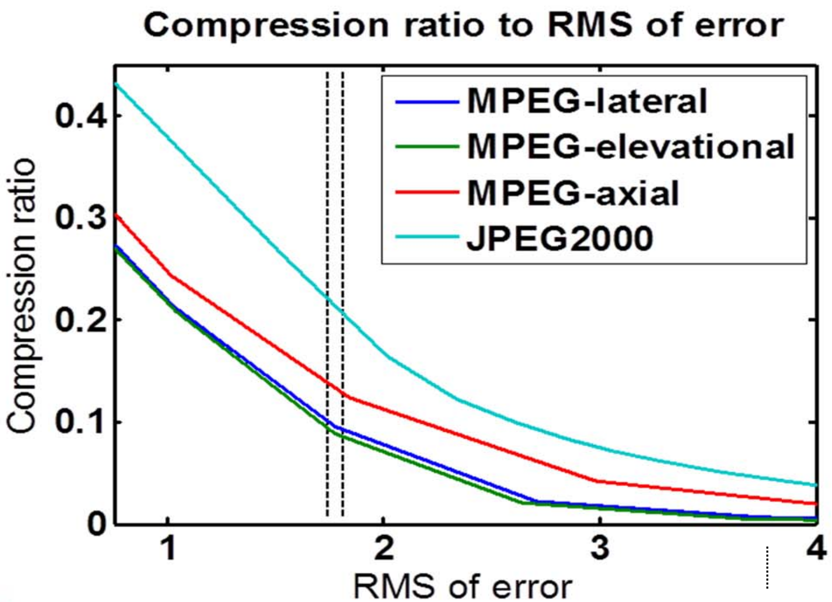
- Goal: Overcome data transfer bottleneck in software based imaging



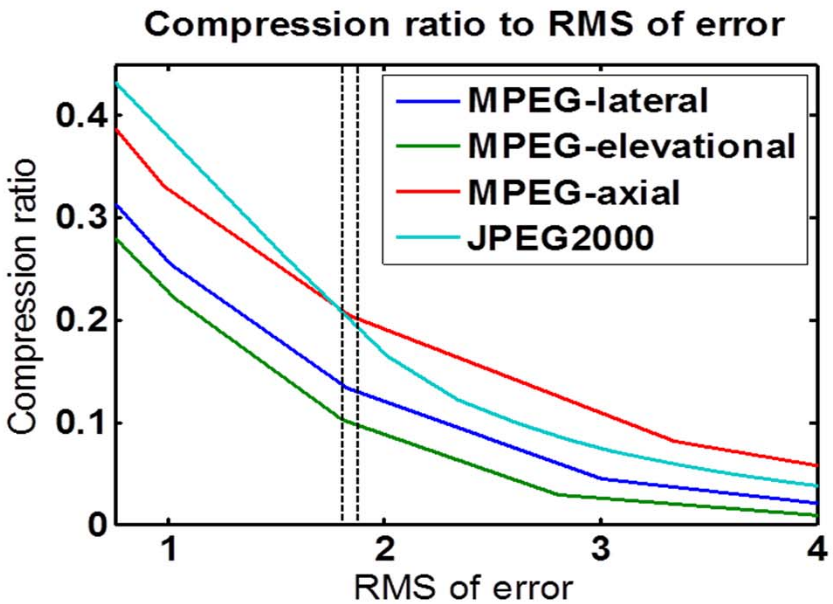
- Hypothesis:
  - Data compression can be performed to significantly reduce data size with an acceptable image quality degradation.

- MPEG compression efficiency
  - Different between motions in different directions
  - Dependent on the frame-to-frame correlation
  - Better than JPEG in most cases

5 µm



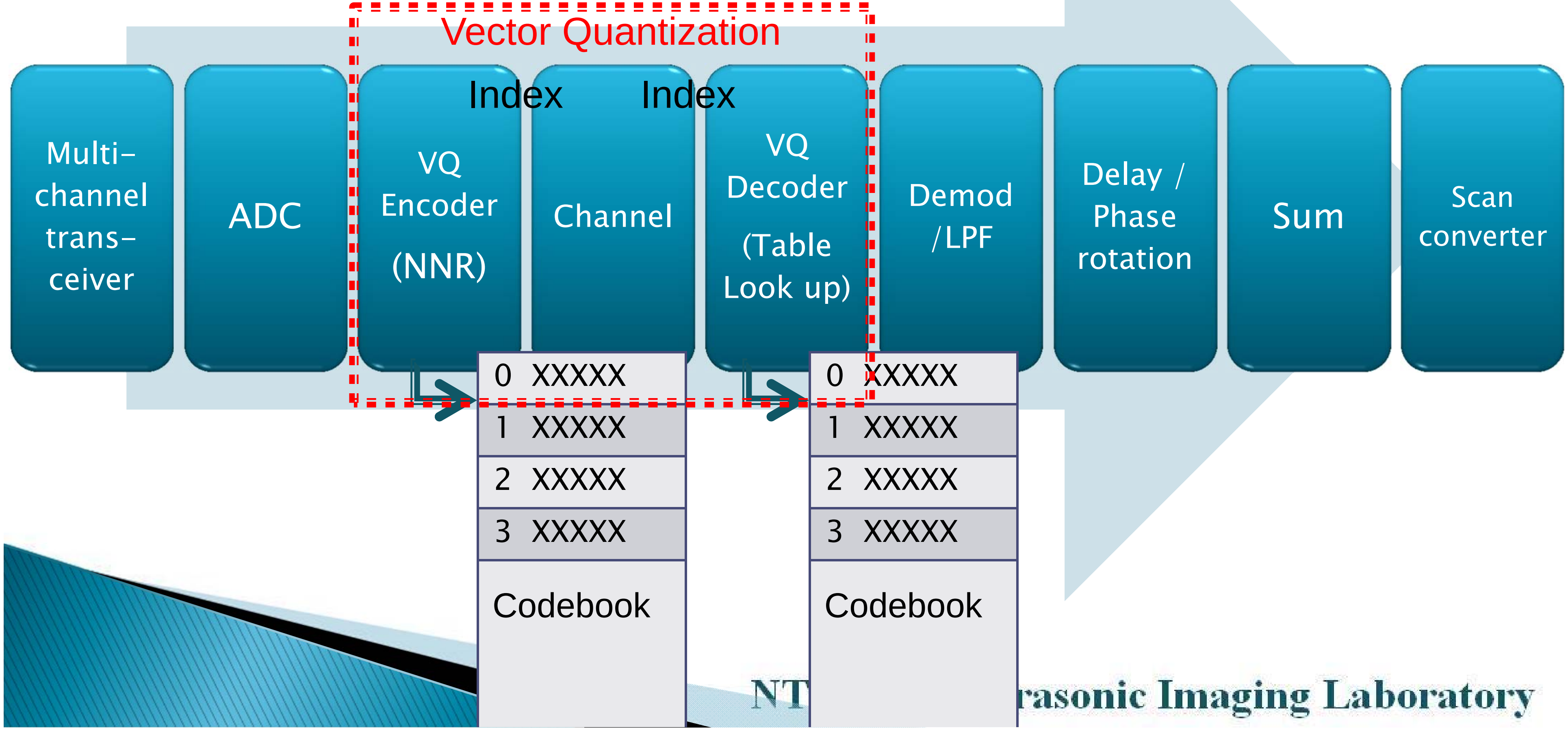
40 µm



crf = 15

Channel Data Compression for SW Imaging (2)

- Goal: Using vector quantization (VQ) to compress ultrasonic raw data and keep the image quality satisfactory.
- Hypothesis: The channel data received by adjacent elements are correlated, this will be good for VQ. By VQ method, the channel data can be compressed effectively with acceptable image quality.



- Result:
  - In this study, we use three code book size, which are 1024,512, and 128.
  - Vector dimensions are chosen to be 2D,4D,and 8D.
  - Under the same codebook size, root mean square error will increase when vector dimension changes from 2D to 8D and when codebook size decrease from 1024 to 128.
  - The image quality is still adequate when compression ratio is about 0.08.

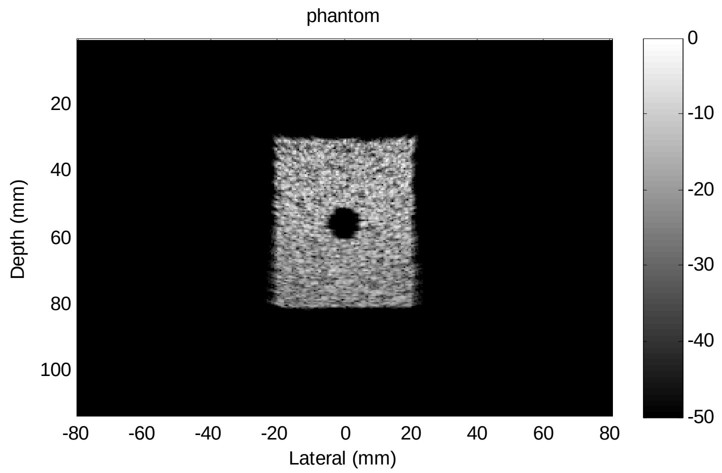


Fig1. Original image

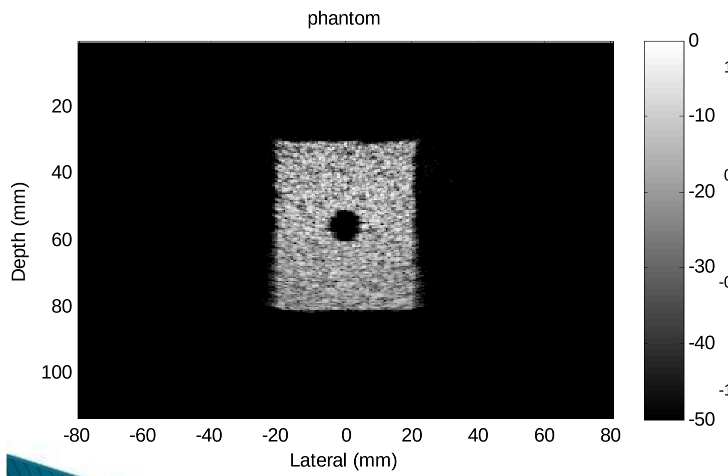


Fig2. After VQ

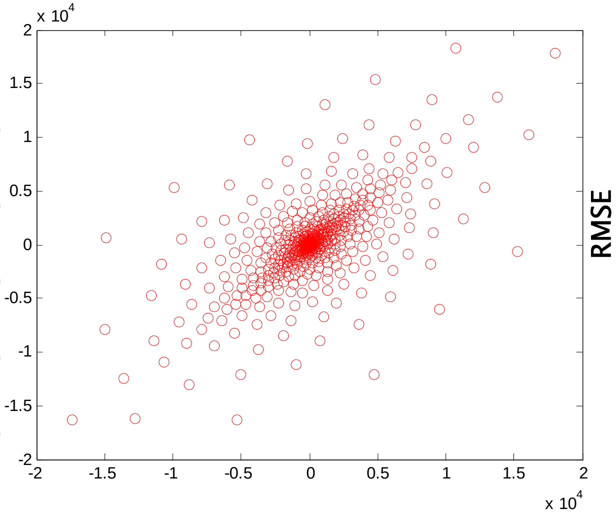


Fig3. 2D codebook with 1024 code vectors

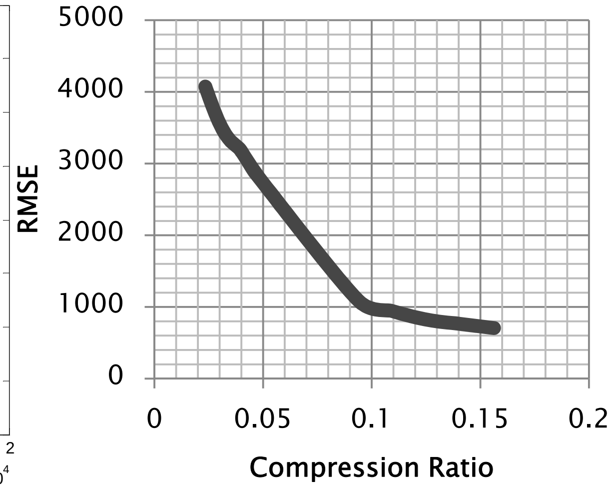


Fig4. RMSE vs. CR

Intravascular PA Imaging

- Goal: To develop a high frame rate IVUS/IVPA imaging system for cardiovascualr disease diagnosis

- Hypothesis:
  - IVUS: To see locations and morphologies of atherosclerotic lesions
  - IVPA: To provide composition contrast of atherosclerotic lesions
  - High frame rate imaging can reduce the diagnostic time to prevent the risk of interventional procedure.

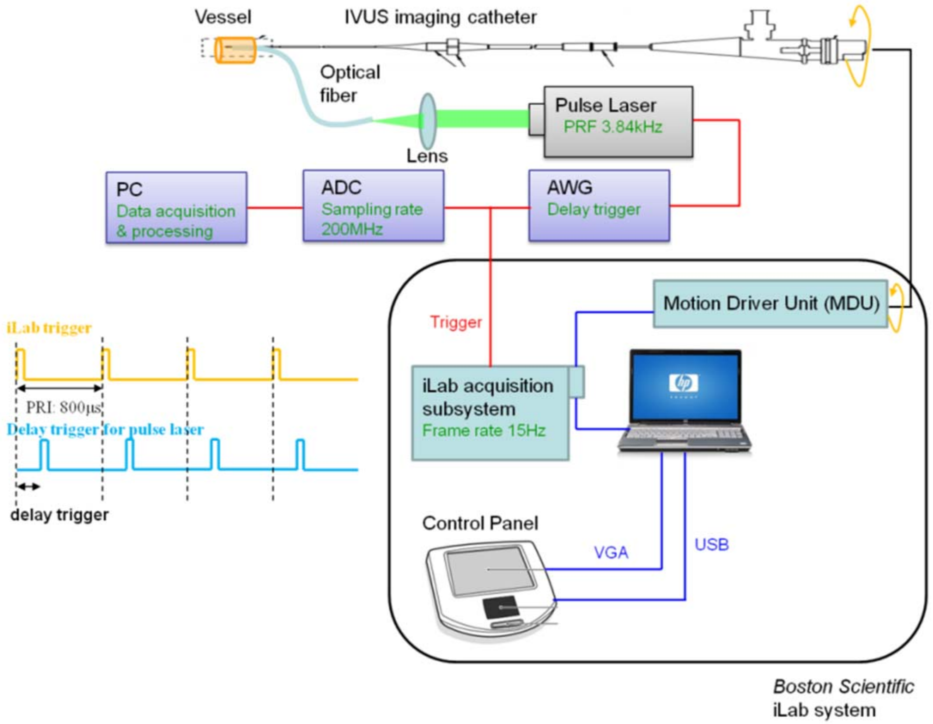


Fig.1 High-frame-rate IVUS/IVPA imaging system (frame rate= 19fps).

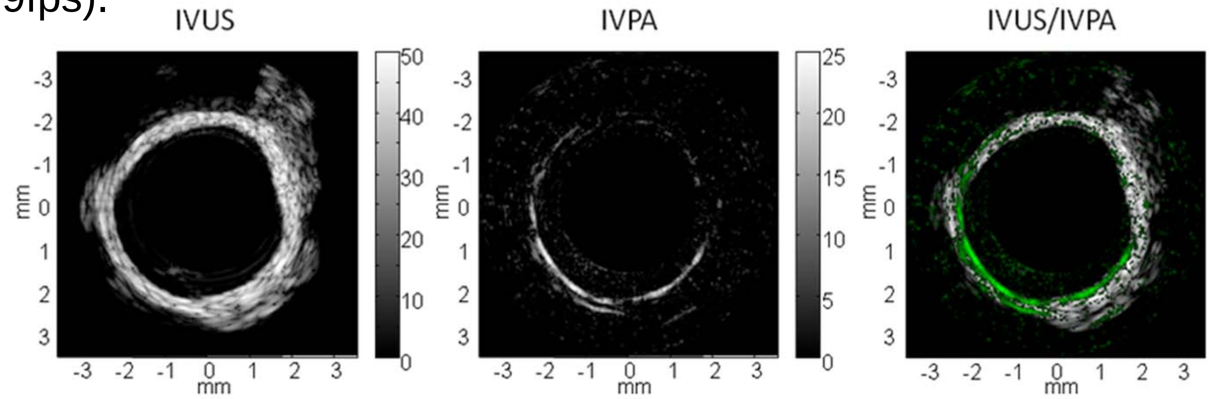


Fig.2 Rabbit's atherosclerotic aorta images

All-Optical US/PA Imaging Probe

- Goal: To develop an all-optical integrated US/PA transducer
- Hypothesis:
  - All-optical US/PA scanhead has a potential to be developed for high resolution and high frame rate intravascular imaging because of its simple configuration and scanhead containing no electronics.
  - Structural and optical contrast information can be retrieved by this all-optical imaging scanhead.

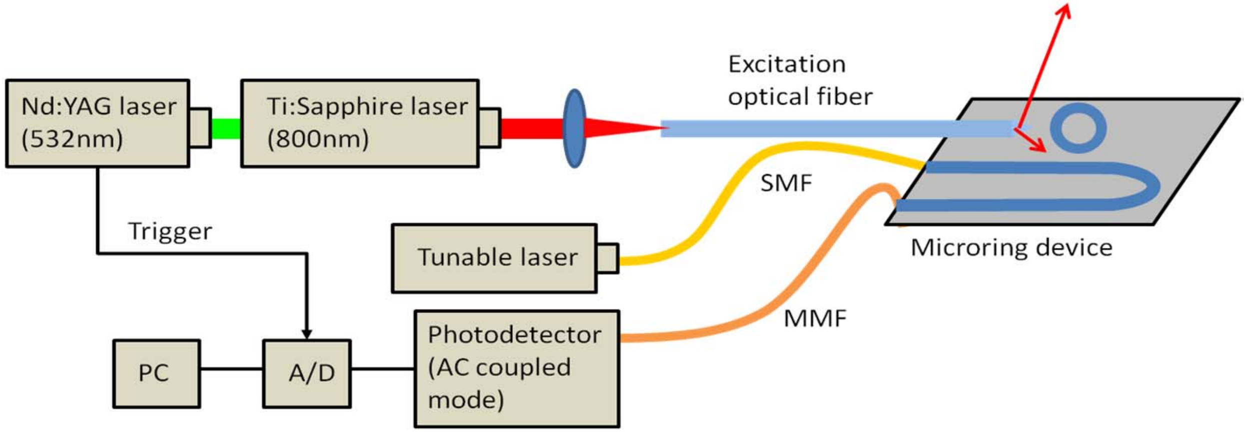


Fig.1 All-optical US/PA imaging transducer/system

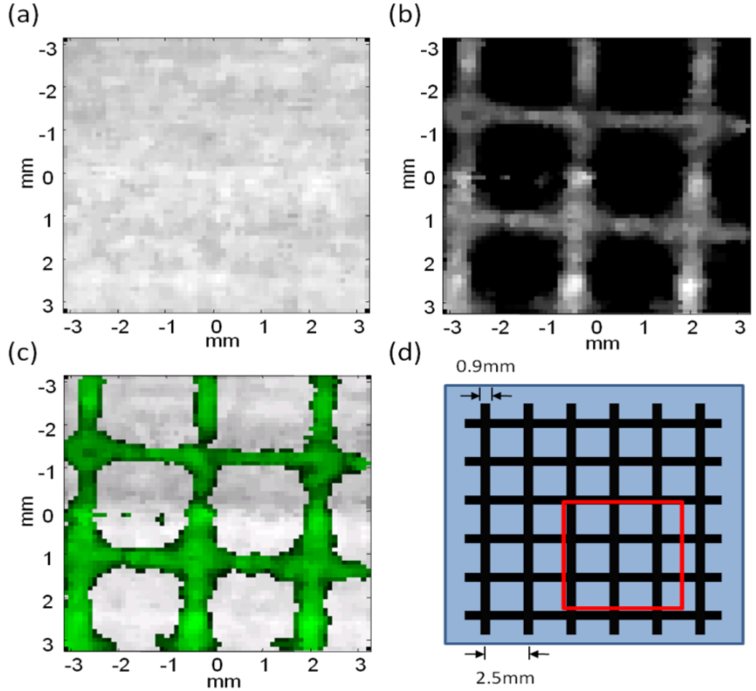


Fig.2 (a) US, (b) PA, (c) fusion image, and configuration of the grid phantom

Ultrasonic Shear Wave Elasticity Imaging

- Goal:
  - To create a new ultrasonic shear wave elasticity imaging (SWEI) platform for quantifying the elasticity property of tendon.
  - To develop an effective therapeutic strategy based on the high intensity ultrasound for tendon diseases.

- Hypothesis:
  - Tendon elasticity property will be altered by tendinopathy, which can be measured and detected by use of SWEI modality.
  - High intensity ultrasound can be an effective therapy for tendon diseases.

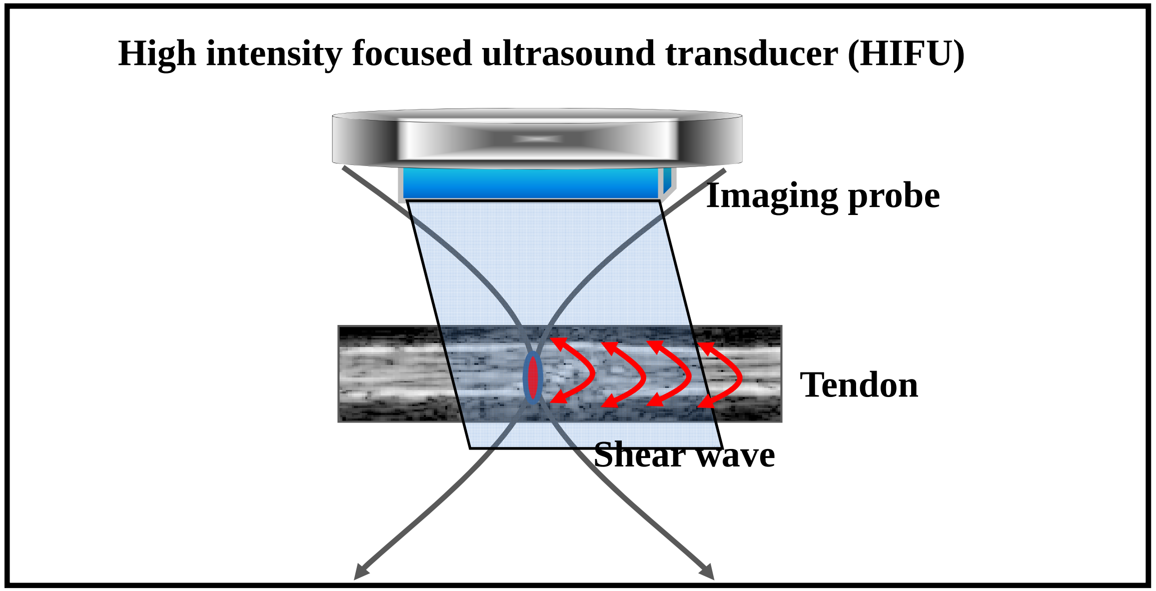


Fig. 1. Schematic of combined SWEI platform and HIFU system

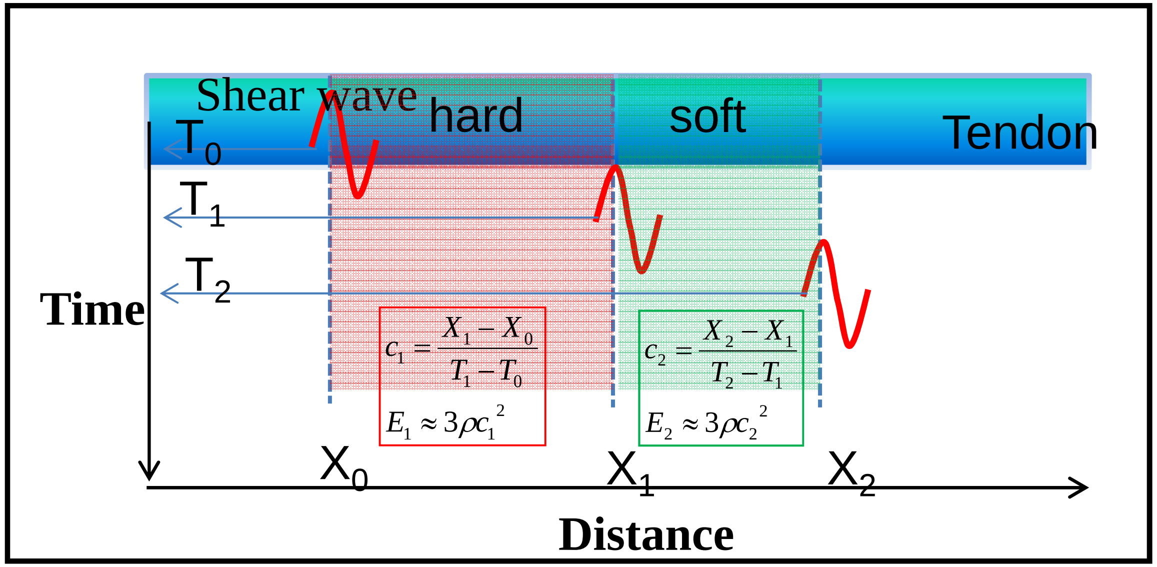


Fig. 2. Schematic of the shear wave reconstructing process

Improving Depth of Focus for Single Element Annular Transducers

- Goal:
  - Using transmit focusing technique improving the depth of focus (DOF) and axial resolution for single element annular transducer (SEAT). (Fig.1)
  - Using receive focusing technique to improve the penetration depth.
- Hypothesis:
  - Transmit focusing: By designing the chirp-coded signals (Fig.2) as the transmit signals, which corresponds to the center frequencies of the sub-rings of the SEAT, the focused delay profile will be changed and consequently affecting the DOF.
  - Receive focusing: The dynamic focusing can be achieved and improving the image quality by applying filter-based receive focusing technique that utilizes the band pass filter corresponding to the frequency response of each ring in the SEAT device.

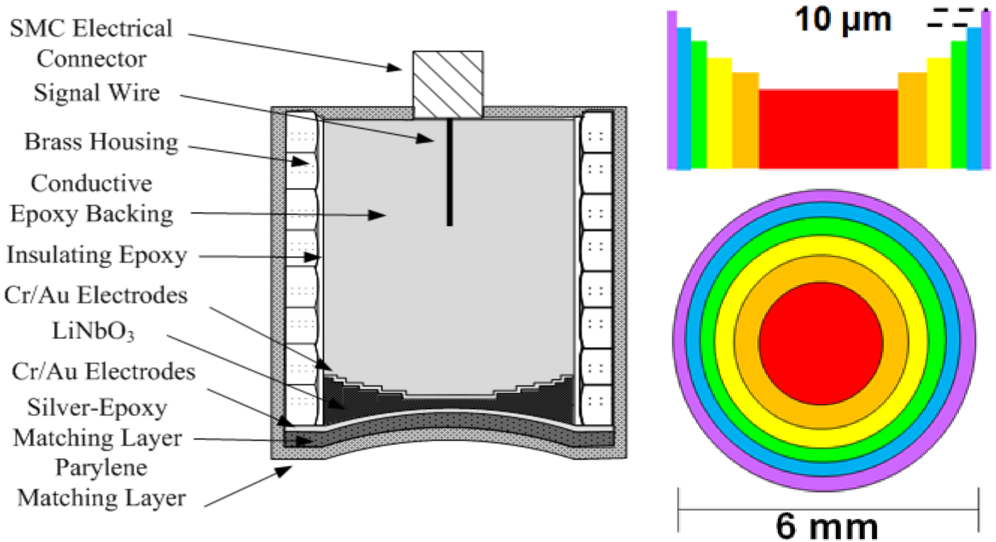


Fig.1： Schematic diagrams of the SEAT

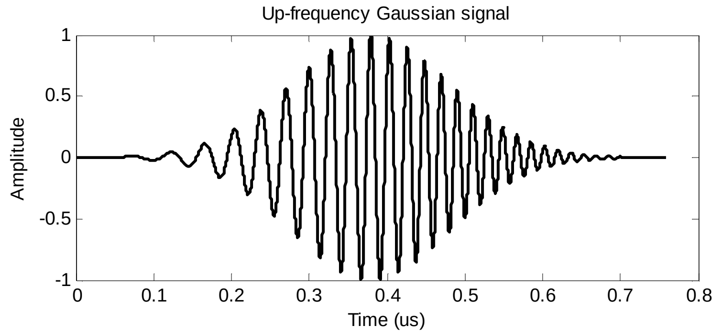


Fig.2： chirp-coded excitation signal

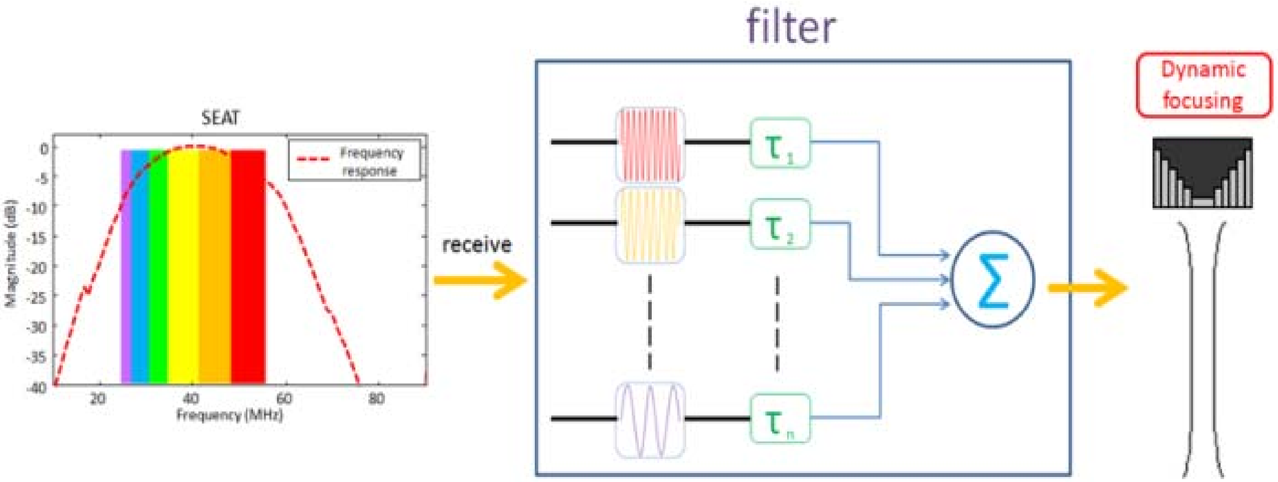


Fig.3： receive focusing block diagram

Cardiac Function in Mice Using 40MHz High Frequency Ultrasound System

- Goal:
  - To determine the echocardiology measurements between wild type mice and ligation surgery mice by 40-MHz high frequency ultrasound imaging system.
  - To test the contrast echocardiology for myocardium between wild type mice and ligation surgery mice by 20-MHz high frequency ultrasound imaging system.

- Hypothesis:
  - High Frequency Ultrasound System helps to diagnose the significant difference of cardiac function between with and without ligation surgery mice in long term.

Representative Figures

After surgery 4weeks	Sham_Average	Sham_SD	Ligation_Average	Ligation_SD	P-value
Number	3.00		4.00		
Heart rate (BPM)	444.00	50.97	387.00	64.20	
LV end-diastolic dimension (mm^2)	12.12	0.81	22.99	3.31	0.00
LV end-systolic dimension (mm^2)	7.35	1.85	17.44	3.47	0.01
Anterior wall_ED_thickness(mm)	0.47	0.01	0.28	0.10	0.02
Anterior wall_ES_thickness(mm)	0.66	0.12	0.43	0.13	0.05
Inferior posterior wall_ED_thickness(mm)	0.52	0.01	0.31	0.11	0.02
Inferior posterior wall_ES_thickness(mm)	0.66	0.06	0.44	0.06	0.00
Septal wall_ED_thickness (mm)	0.53	0.02	0.32	0.11	0.02
Septal wall_ES_thickness (mm)	0.63	0.05	0.42	0.11	0.02
Posterior lateral wall_ED_thickness (mm)	0.56	0.09	0.39	0.09	0.04
Posterior latera wall_ES_thickness (mm)	0.65	0.07	0.51	0.05	0.02
Short axis_Fraction Shortening(%)	35.91	3.31	18.20	8.61	0.02
Short axis_Ejection Fraction(%)	66.69	4.77	36.68	15.75	0.02
Short axis_Stroke Volume(microL)	28.77	8.16	38.69	10.20	0.15
Short axis_Cardiac Output(ml/min)	12.05	4.13	14.28	2.41	0.24
Long axis_Fraction Shortening(%)	37.45	0.68	19.86	7.68	0.01
Long axis_Ejection Fraction(%)	68.77	0.92	39.88	13.60	0.01
Long axis_Stroke Volume(microL)	30.21	5.46	41.40	6.66	0.05
Long axis_Cardiac Output(ml/min)	13.20	1.51	15.62	0.64	0.03

Figure 1. The echocardiogarphy measurements between Sham and Ligation after surgery 4 weeks by pair T-test.

	Sham surgery 4wk_Average	Sham surgery 4wk_SD	Ligation 4wk_Average	Ligation 4wk_SD	P-value
ICT+IRT	27.23	2.65	28.98	1.16	
ET	47.91	2.18	36.51	3.01	
Tei Index	0.57	0.04	0.80	0.07	0.00
	Ligation 2wk_Average	Ligtion 2wk_SD	Ligation 4wk_Average	Ligation 4wk_SD	P-value
ICT+IRT	24.93	1.91	28.98	1.16	
ET	38.85	4.45	36.51	3.01	
Tei Index	0.65	0.05	0.80	0.07	0.01

Figure 2. The Tei index between Sham and Ligation after surgery 4 weeks by pair T-test.

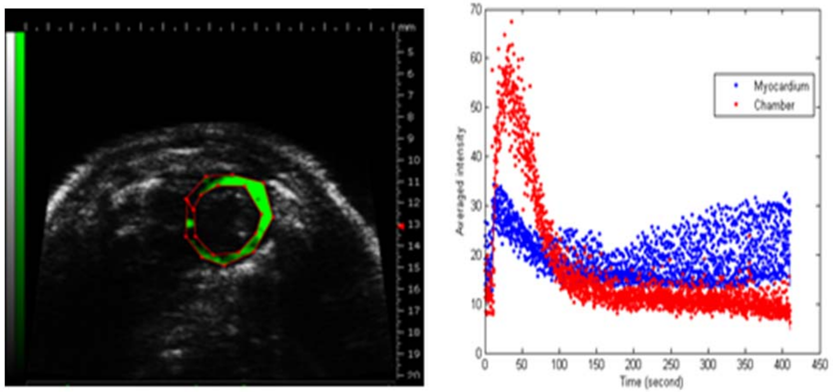


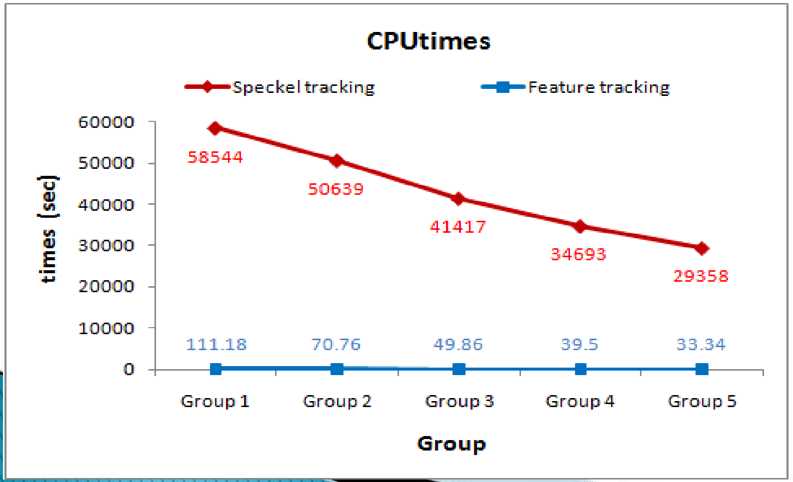
Figure 3a. The enhanced myocardium by Sonovue MB. 3b. The time intensity curve of myocardium and chamber.

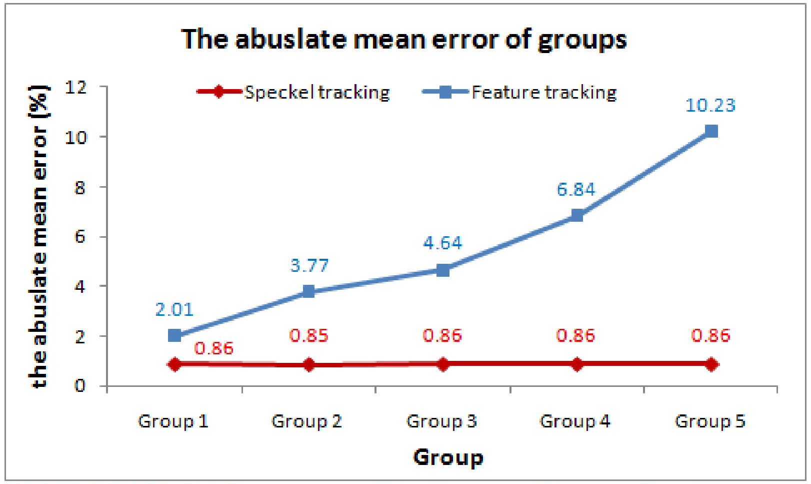
Myocardium	Mean transit time	Peak time	Chamber	Mean transit time	Peak time
M1	196.02	20.20	M1	145.17	30.20
M2	179.55	7.40	M2	140.86	31.60
M3	178.53	11.20	M3	166.21	23.60
M4	193.54	4.60	M4	163.03	21.80
M5	185.12	22.20	M5	164.00	16.80
Average	186.55	13.12	Average	155.85	24.80
SD	7.13	6.95	SD	10.62	5.47

Figure 4. The Mean Transit Time and Peak Time of Myocardium for Wild Type mice.

3D Cardiac Strain Imaging Using Plane Wave Excitation and Feature Tracking

- Goal: To achieve accurate evaluation of cardiac deformation with ultrasound in real-time 3D imaging using plane-wave excitation and feature tracking.
- Hypothesis:
  - Plane wave excitation can significantly increase the image frame rate to achieve real-time imaging.
  - Feature tracking can speed up computations drastically compared to conventional speckle tracking in 3D image.

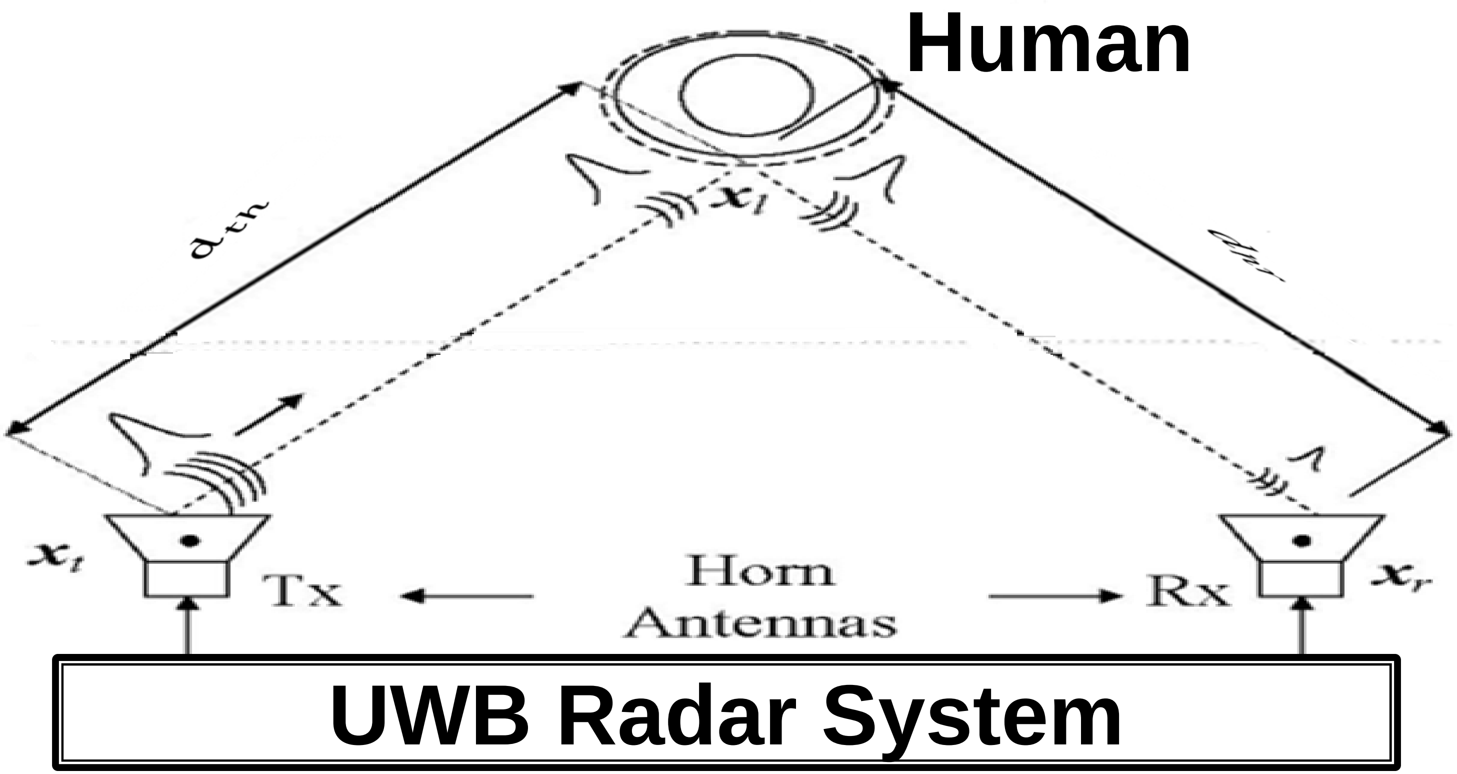




Ultra-Wideband Home Care

- Goal
  - Using ultra-wideband radar (UWB) to detect human respiration motion.
- Hypothesis:
  - Using signal processing techniques on the received ultra-wideband signal, small range variation between the object and the UWB radar may be estimated.
  - The variation of distance between the human body surface and the UWB radar can be determined by signal processing the received signal, and it may be a representative of human respiration motion.

- Representative figure
  - Measuring human respiration motion with UWB radar.

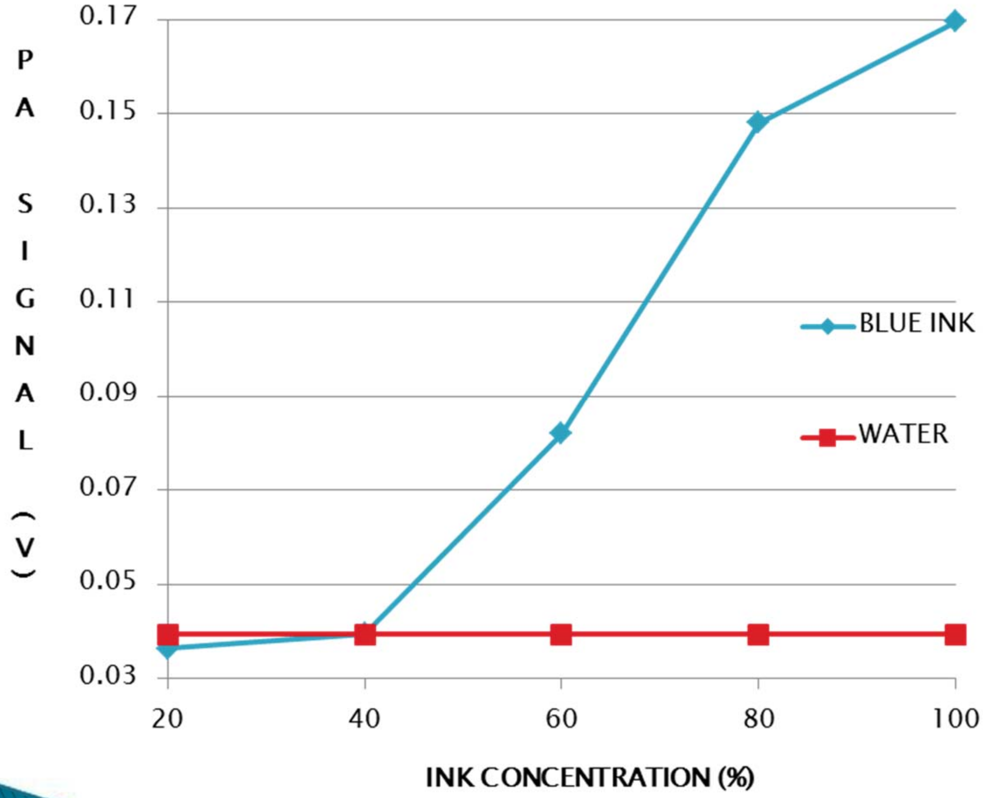


Estimation of Blood Oxygen Level Using Photoacoustic Signal

- Goal: To investigate the sensitivity and accuracy of detecting blood oxygen level using photoacoustic signal.

- Hypothesis:
  - Oxyhemoglobin and deoxyhemoglobin vary in absorption spectrum, and this difference can be detected by examining the photoacoustic (PA) signal intensity.
  - Other than hemoglobin concentration, PA signal intensity is also affected due to laser energy variation, which can be diminished by averaging or normalizing the signal.

- Difference between high(Fig.1) and low(Fig.2) concentration of ink phantom



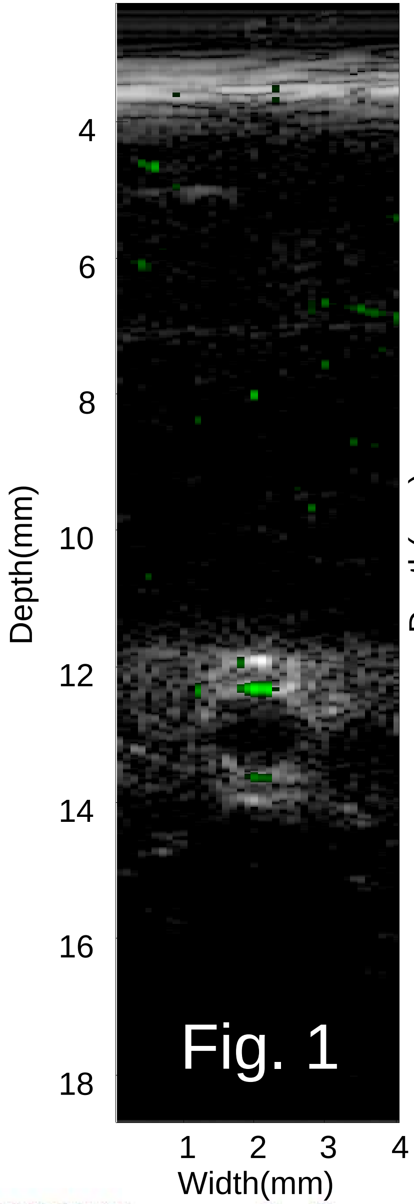


Fig. 1

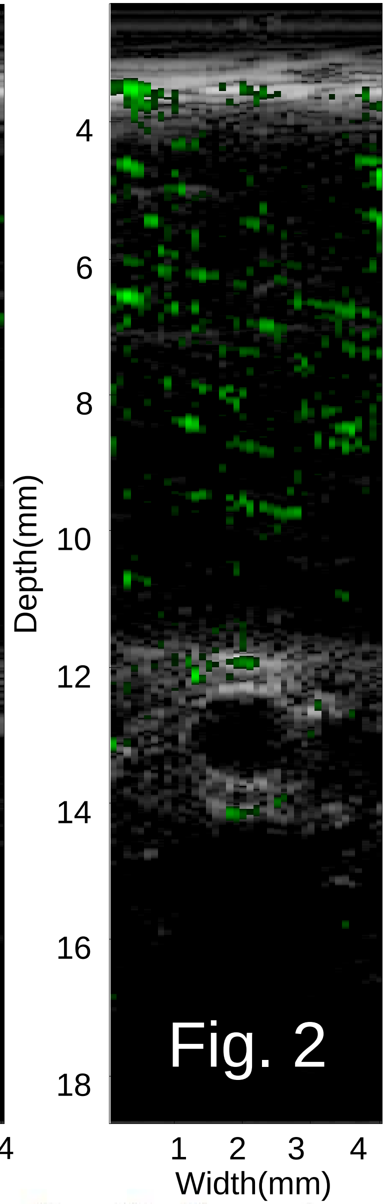
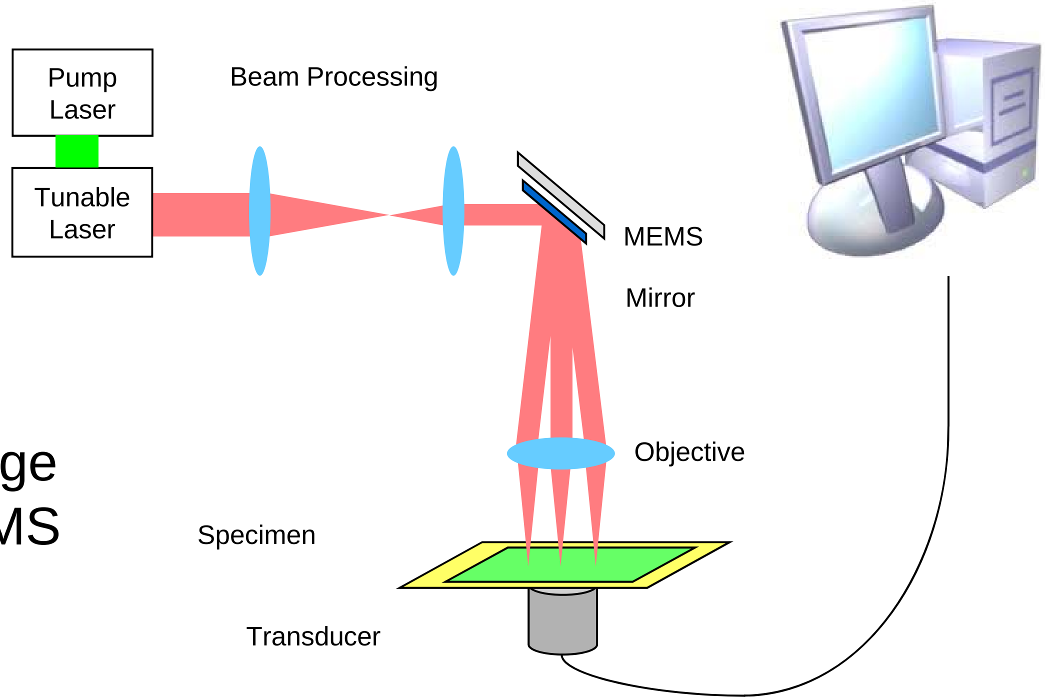


Fig. 2

Photoacoustic Microscopy

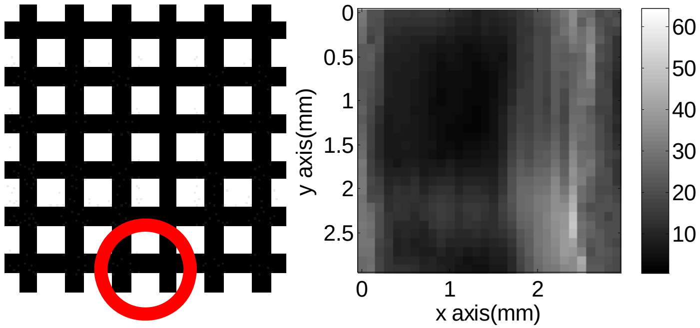
- Goal:
  - To perform biomedical photoacoustic imaging at high frame rate and diffraction-limited resolution with proposed photoacoustic microscopy

- Hypothesis:
  - Diffraction-limited resolution can be realized by near-field detection configuration
  - To achieve real-time image acquisition by using MEMS optical scanning

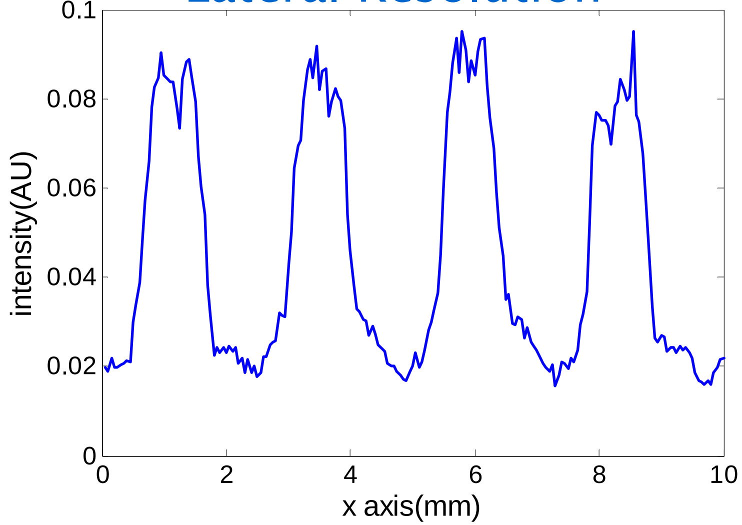


- Representative Figures

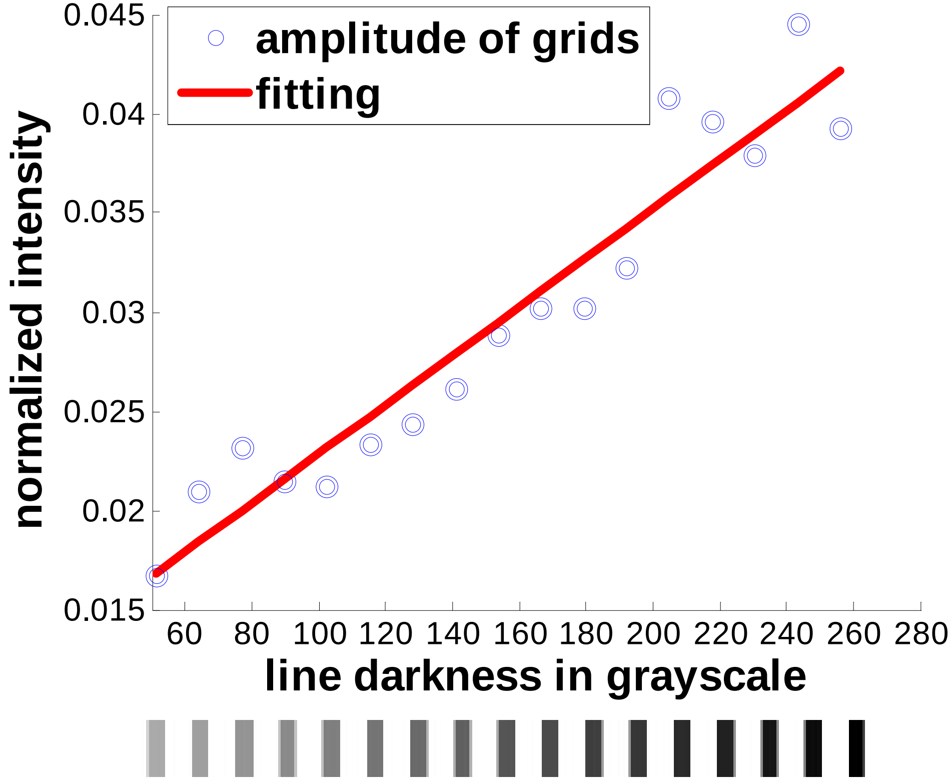
2D Imaging



Lateral Resolution

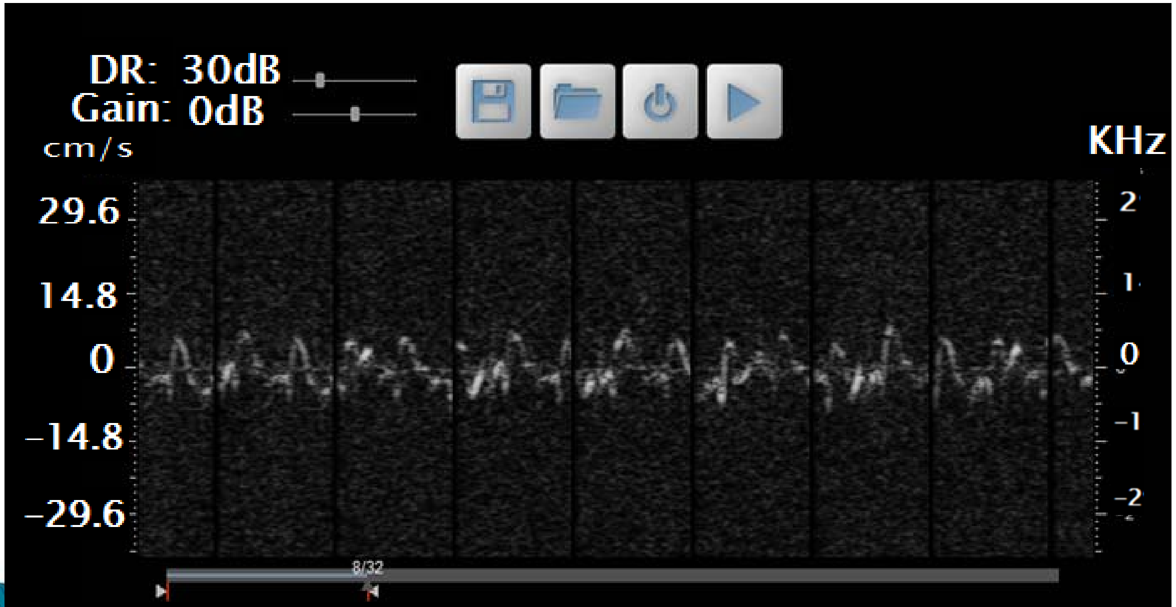


Contrast

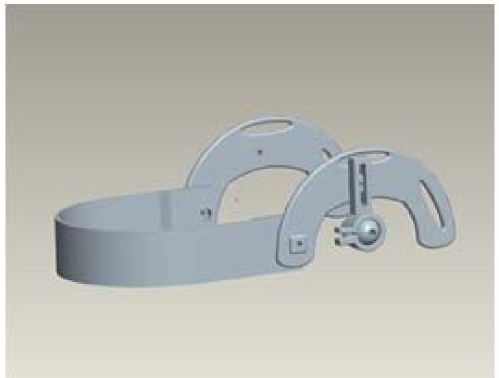


Real Time Wireless Transcranial Doppler Ultrasound System

- Goal: Construct a Wireless Transcranial Doppler Ultrasound system.
- Hypothesis: Real time display of blood flow velocity at different levels with depth detection algorithm.



Pulse Wave Doppler Display



Transcranial Headset

Low Bias Voltage of CMOS CMUTs

- Goal:
  - Using TSMC CMOS MEMS.35 process to fabricate the Capacitive Micromachined Ultrasonic Transducers (CMUTs).
  - Decreasing the bias voltage of CMOS CMUTs.
- Hypothesis:
  - Designed and fabricated a CMUTs' structure in CMOS MEMS process to integrate the electronic circuit and the transducers for yield improving.
  - In order to decrease the bias, the sacrificial layer was changed to cut down the membrane thickness and the structure gap height. Therefore, they can be suitable for human body detection than the traditional CMOS CMUTs.

- Representative Figures

Table 1 Comparison Table

	Traditional CMOS CMUTs	New CMOS CMUTs
Sacrificial layer	Metal	Polysilicion
Membrane thickness	1µm+1µm	1µm
Gap height	6400 Å	1800Å
Resonant frequency	2M Hz	2M Hz
Bios voltage	240 V	20V

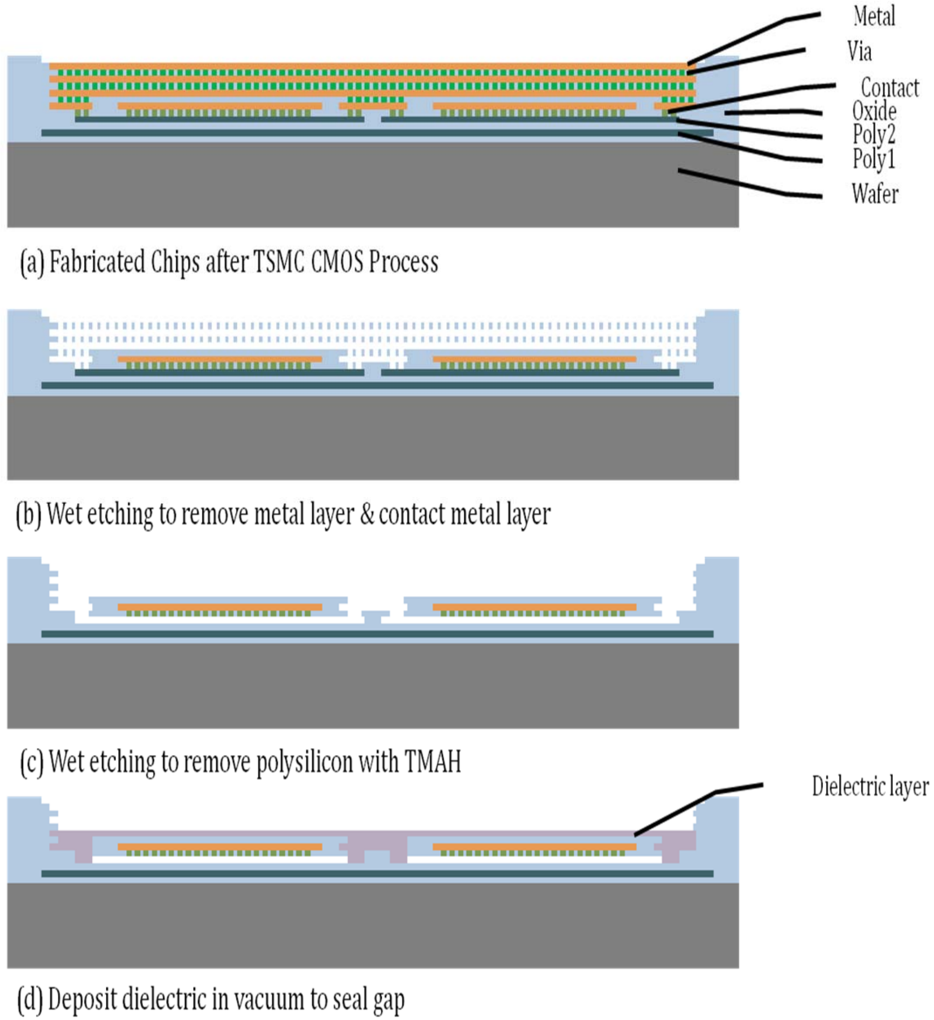


Fig.1 Fabrication Process

Thank You!