REAL-TIME 3D SHAPE MEASUREMENT OF MICRO DROPLET USING DIGITAL HOLOGRAPHIC MICROSCOPY

USHIO

Lighting Edge Technologies

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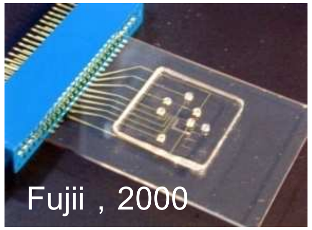
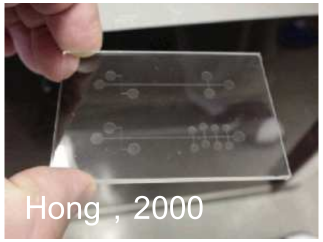
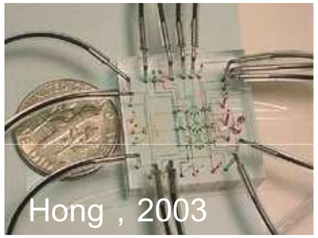
Droplet based microfluidic device

Microfluidic device

- Biochemical assay
- Cell manipulation
- Drug discovery
- Diagnosis

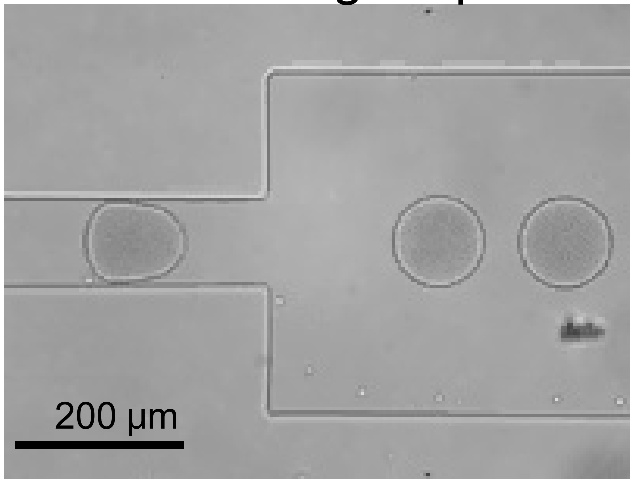






Example

Device using droplets



- Use of the droplet for the fluid transport
  - Droplet size pL ~ nL (10 ~ 100 μm)
  - Transportation sample or reagent

- Advantages of using droplet
  - Less dead-volume.
  - Short analysis time
  - Improvement of analysis precision

> Continuous flow

Importance of understanding
the droplet generation
for the controlled transportation

➢ **Droplet shape and its deformation**

Shape measurement methods

Current shape measurement methods

Confocal microscope
（ OLYMPUS ）

Commercial product	Measurement method	Measurement time
Laser displacement sensor	Spot scanning ⇒ 3D data reconstruction	A few minutes
Confocal laser microscope	2D scanning by Nipkow disk & Z scanning by piezo stage	A few seconds ~ A few minutes
Interferometric microscope	Single Exposure 2D fringe pattern & 3 Fringe scanning for phase calculation	Sub-second

Only for static object / Invalid for dynamical phenomena

Requirement for 3D & real-time(time-series) measurement

Purposes

- 1. Development of the real-time and 3D shape measurement technique of microscopic droplet

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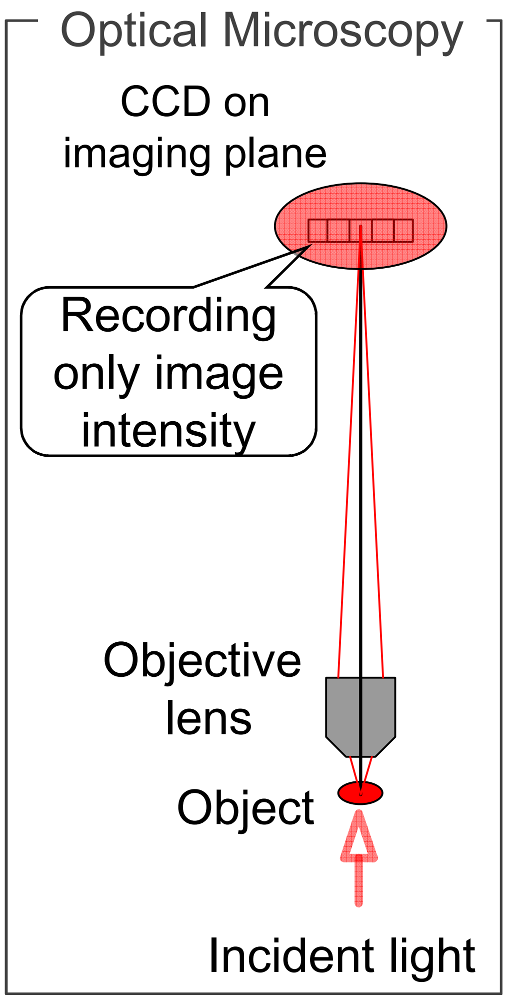
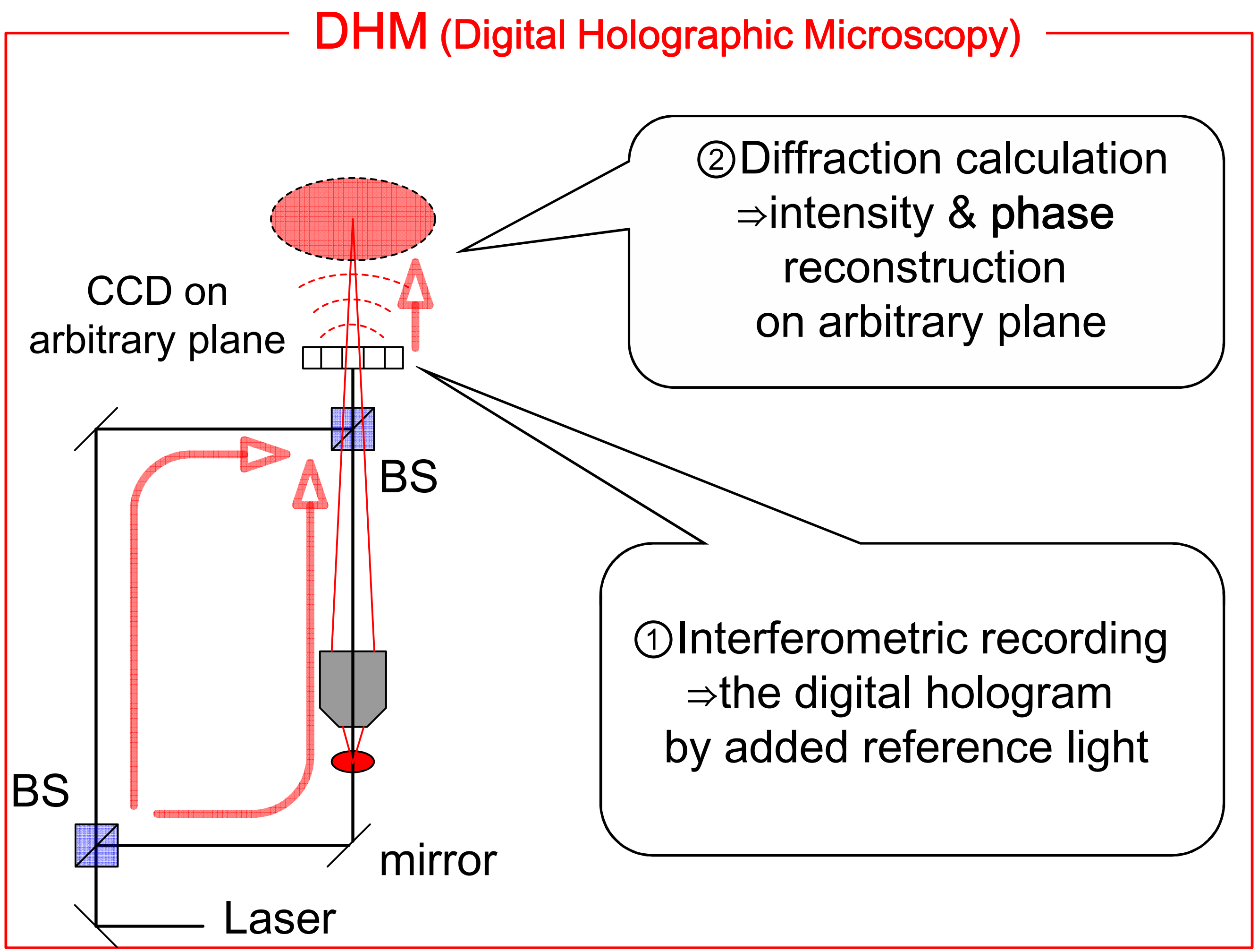
- 2. Demonstration of effectiveness of the developed technique for 3D shape microscopic droplet

Our approach

Use of Digital Holographic Microscopy (DHM)
because of its micro-second measurement time
(depended on camera's exposure time)

The principle of the DHM

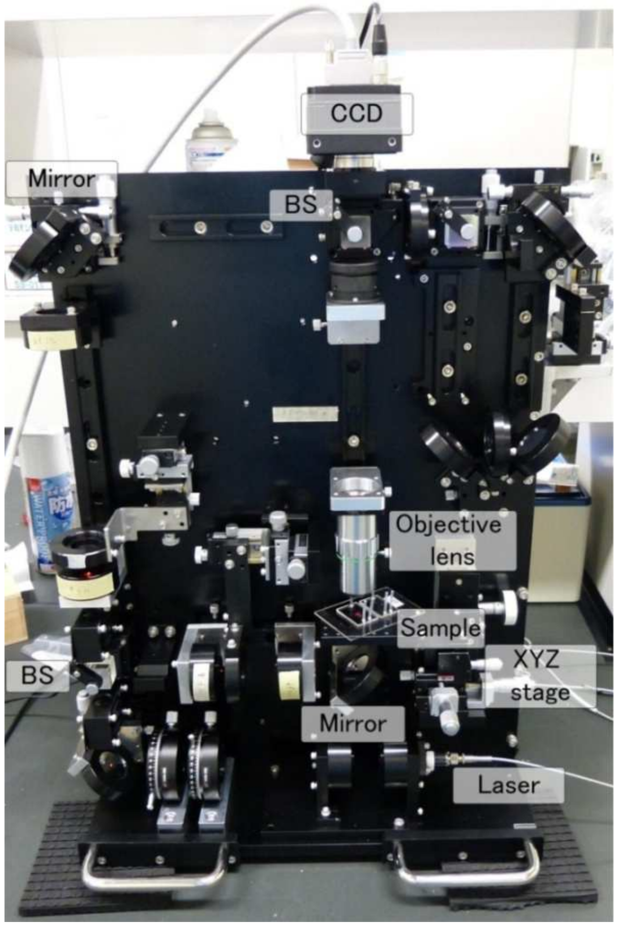




- DHM = Optical microscopy + Interferometer
  ⇒ Intensity & Phase

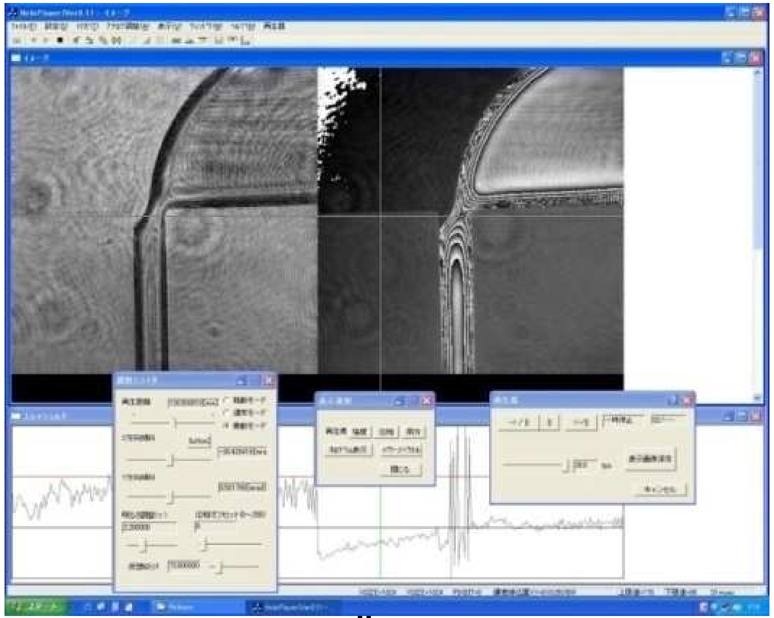
Developed system

①Table-top DHM microscope
➢Real-time measurement (scan free) by the off-axis formation



W540 x H640 x D240 mm, 15 kg

②Analysis software
➢Real-time observation(over 30fps) Using the GPGPU



Personal Computer

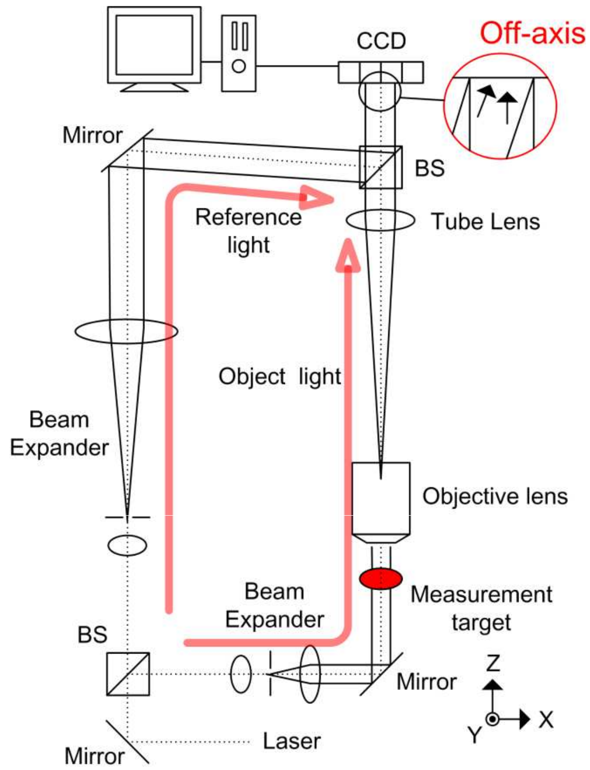
Real-time measurement

Off-axis formation

Holographic method that the reference wave plane is slightly tilted relative to the objective wave plane.

Feature

1. Need only a single shot hologram for a single measurement.
2. By the effect of the 0-order beam and the conjugate image rejection, object phase is measurable quantitatively.

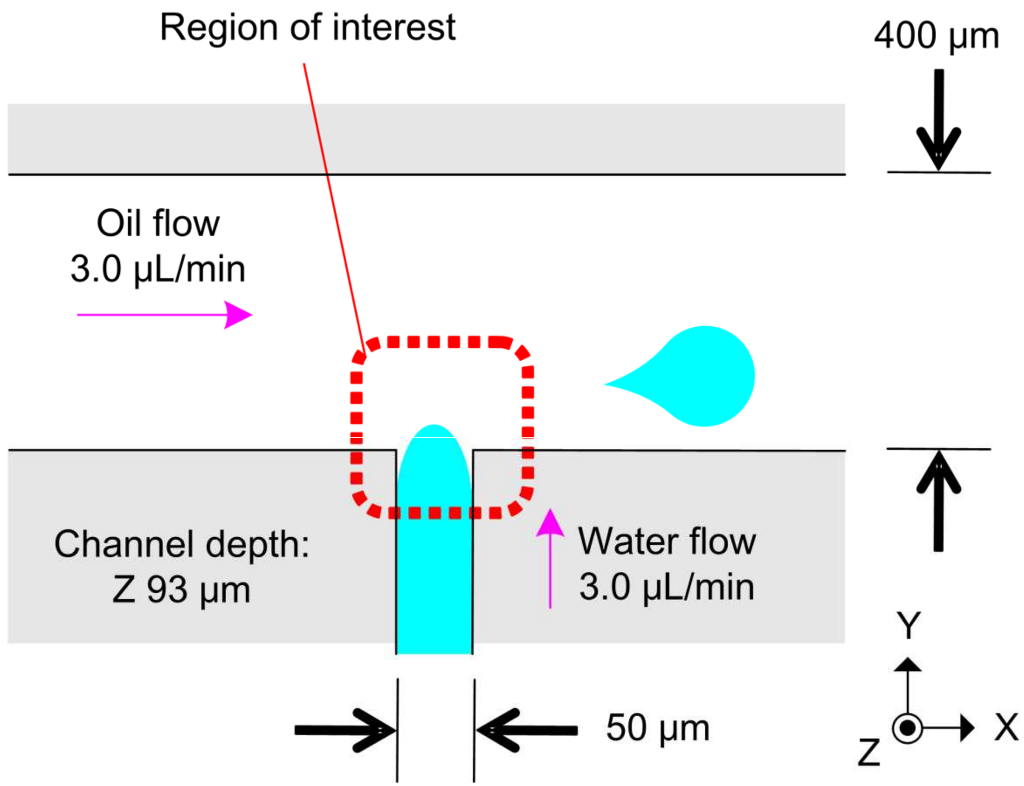


Schematic of the optical system

➢We adopt the off-axis formation which enables the real-time & quantitative phase measurement

Demonstration

①Measurement target



T-shaped microchannel for droplet formation made from PDMS, hydrophobic nature

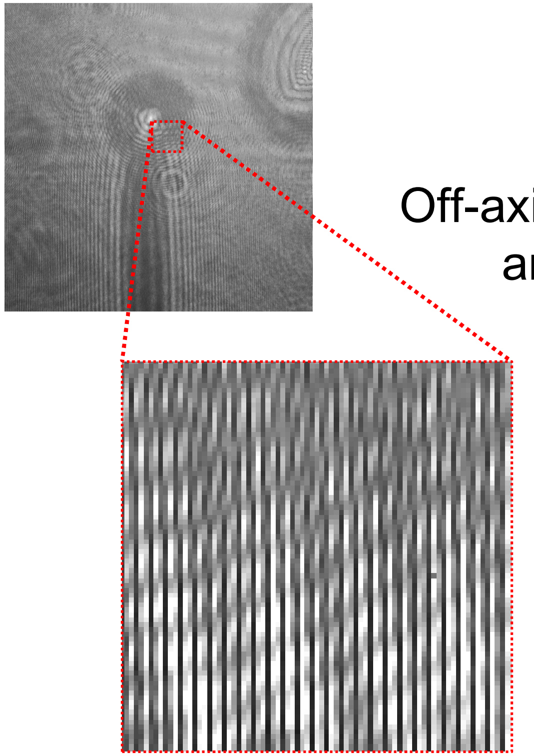
Working fluid:
water(droplet), silicone oil

②Measurement condition

Magnification	10 X
Measurement area	XY: 563×563 μm Z: 986 μm
Resolution	XY:1.1 μm Z: 0.062 μm
Frame rate	60 fps
Exposure time	1 ms
Light source	HeNe laser 633 nm
Illumination	Transmission

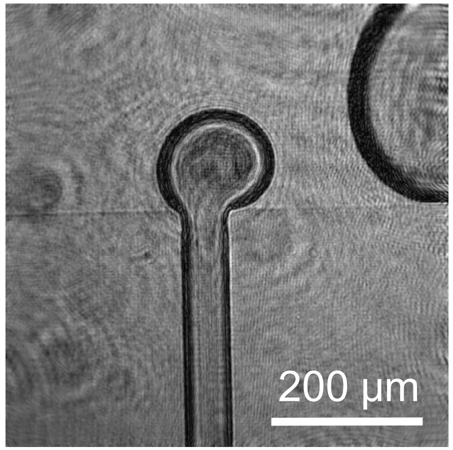
Analyzing process for the digital hologram

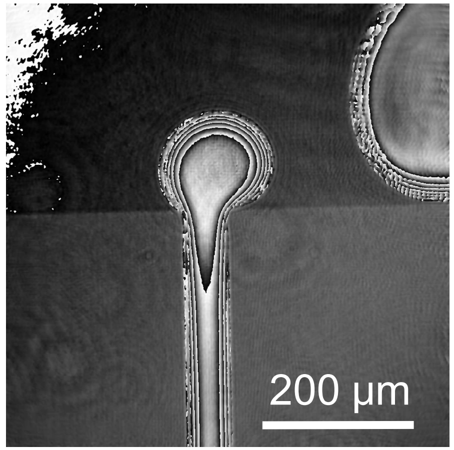
Hologram of the droplet



Off-axis hologram analysis

Complex amplitude distribution
on imaging plane





Reconstructed intensity

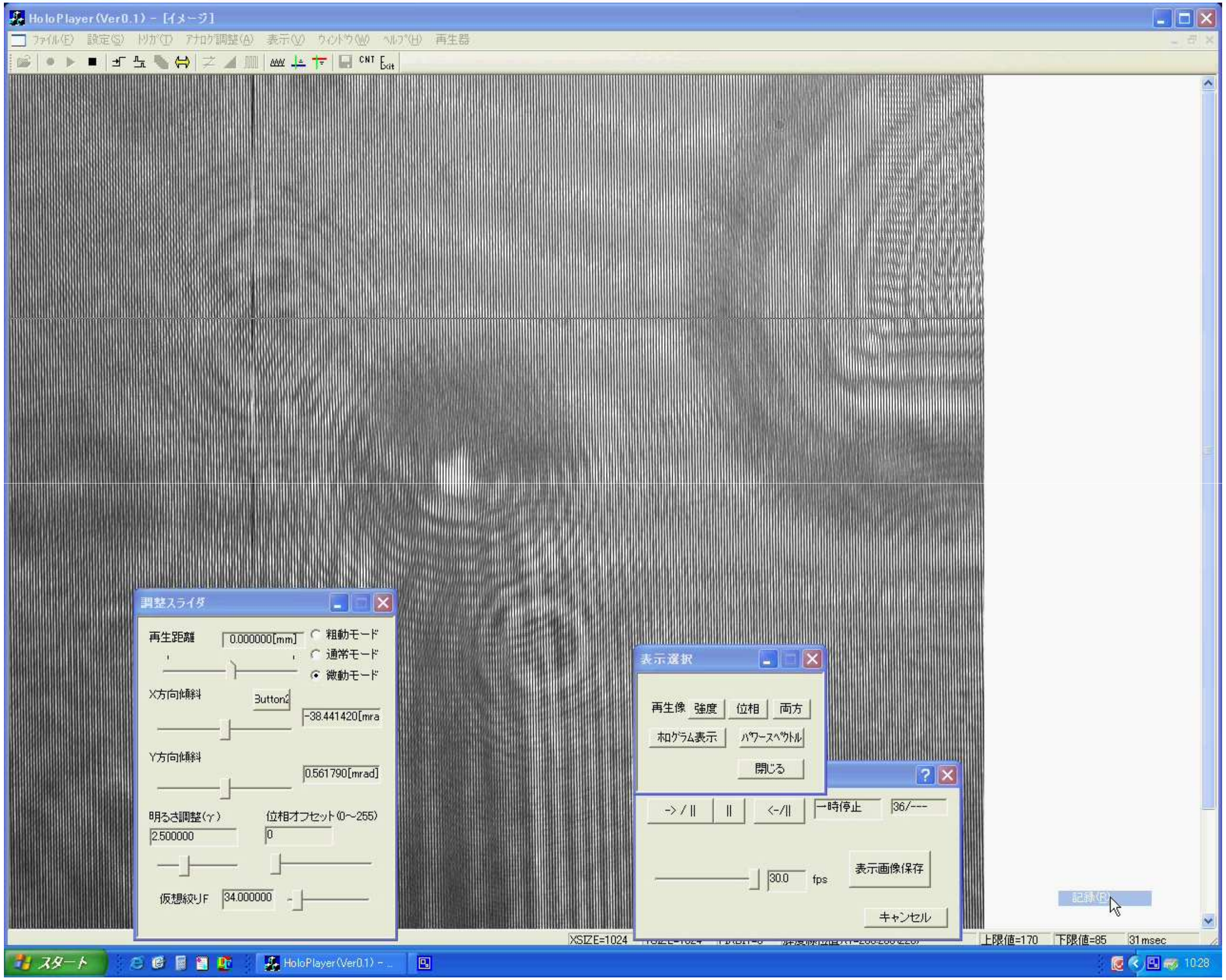
Reconstructed phase

Fringe pattern

a fringe tone ~ Amplitude
a fringe pitch ~ Phase

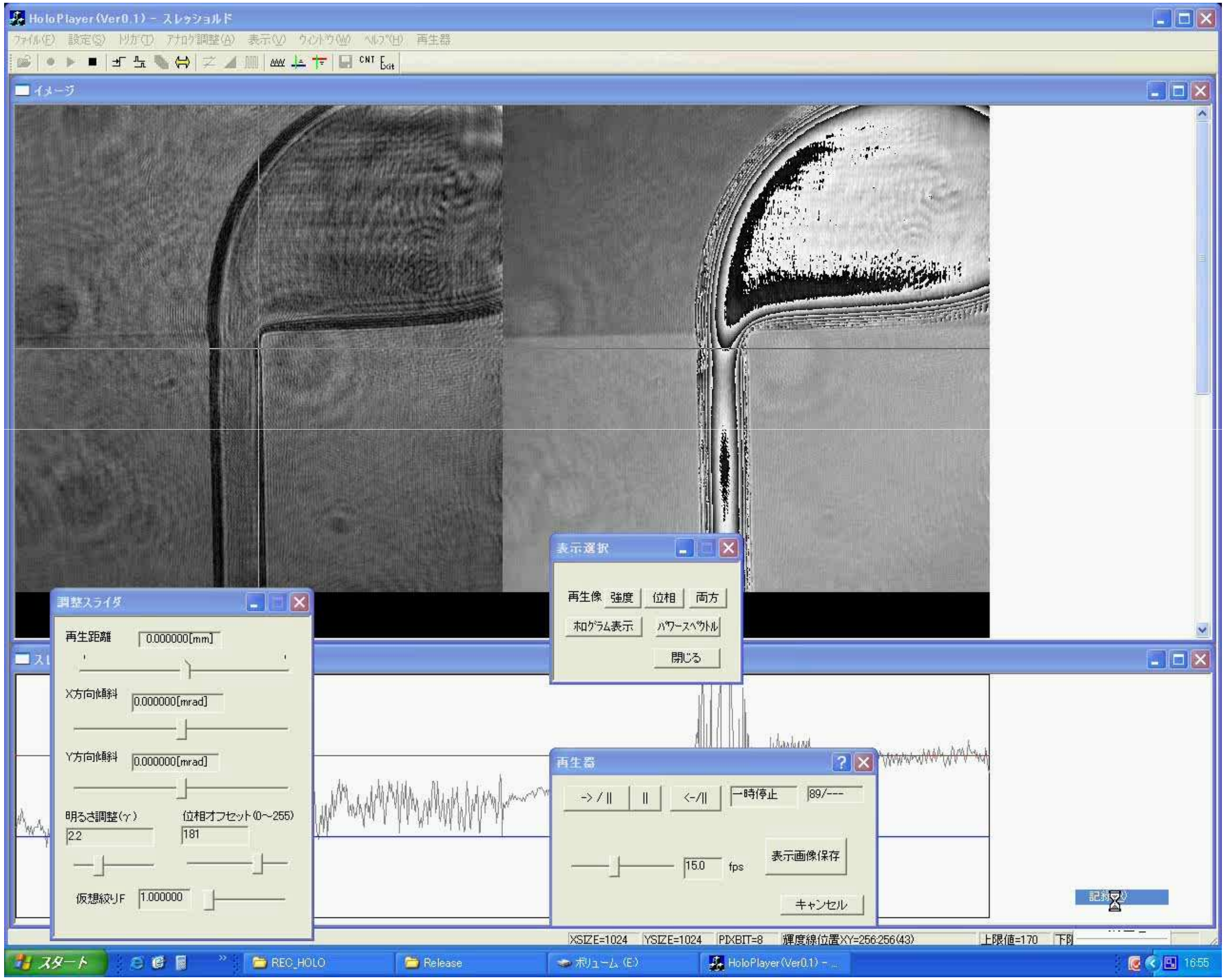
➢ **Hologram reconstruction of droplet using only a single shot**

Hologram images (raw CCD images)



Reconstructed images

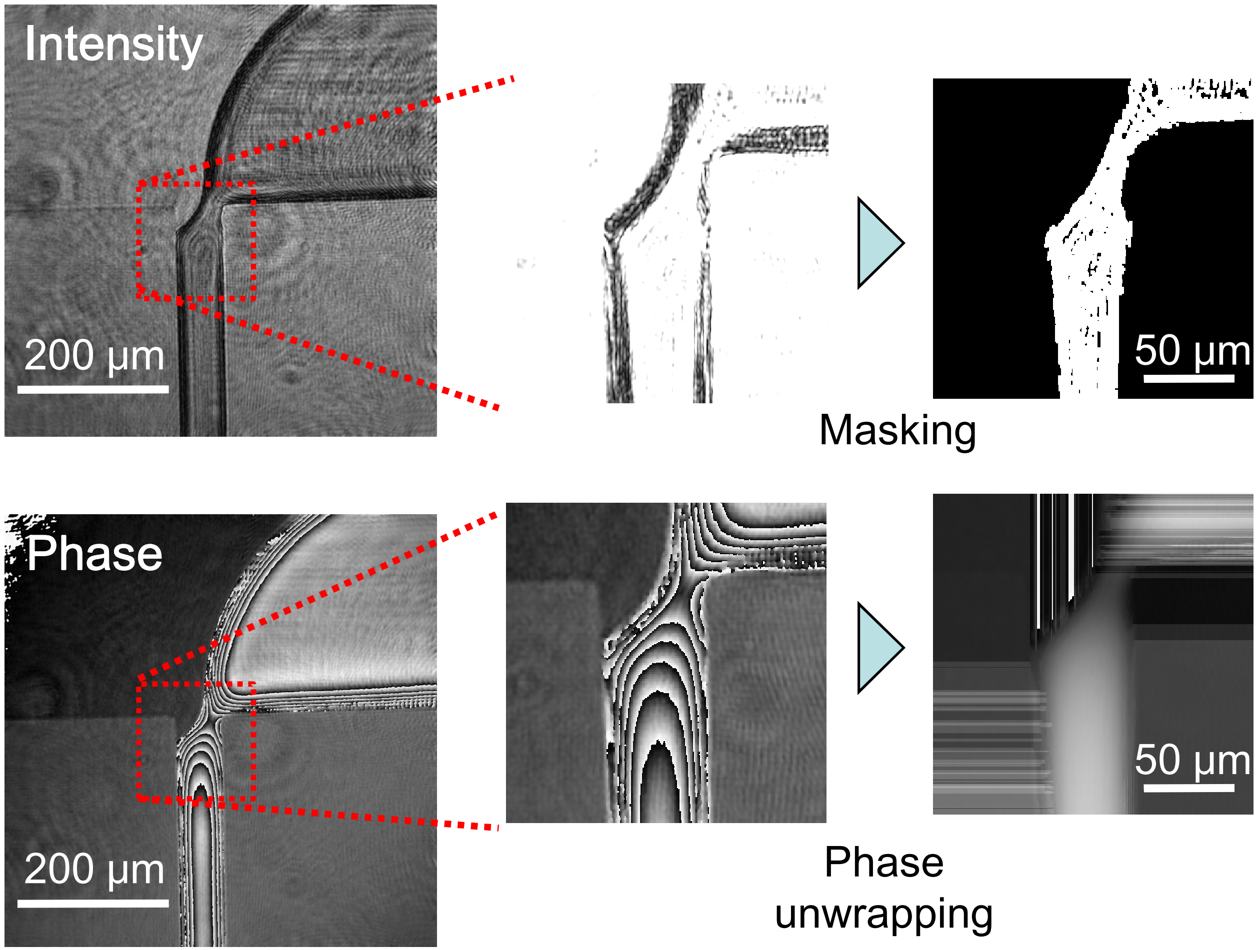
Intensity   Phase



➤The movie is obtained by our original software

Extraction process of 3D shape

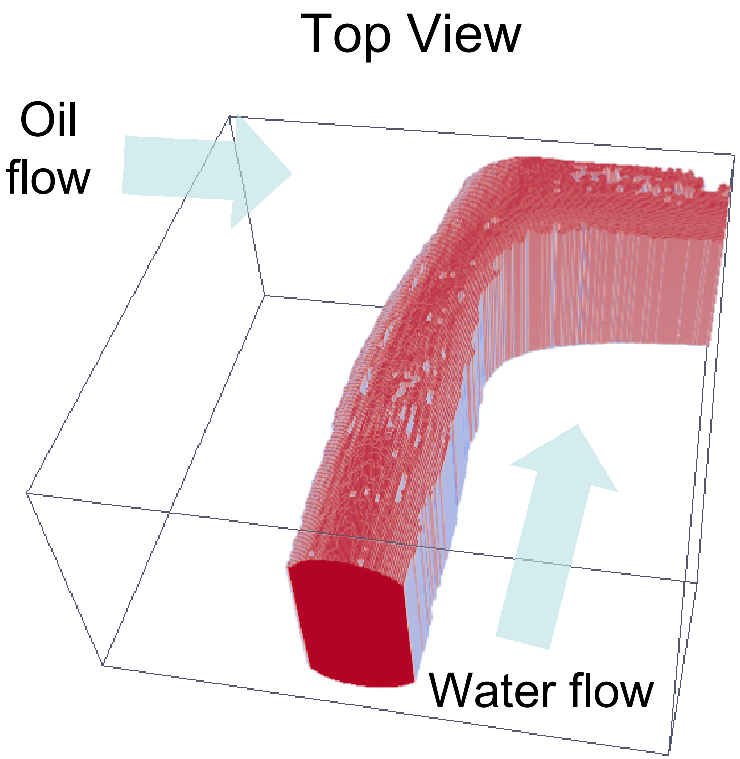
Reconstructed images

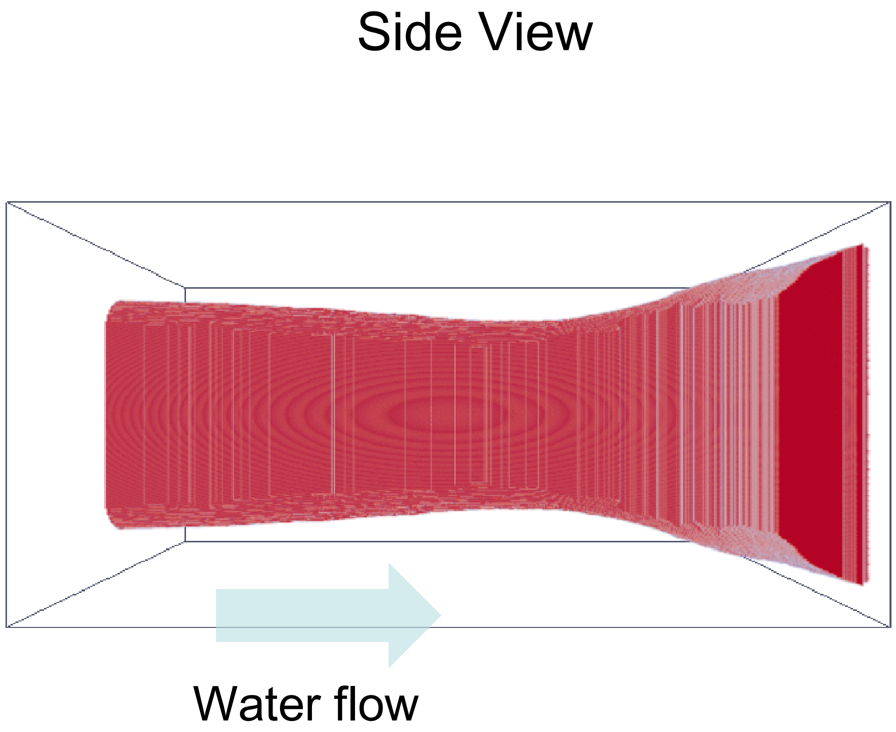


3D shape

Convert phase to height by the use of the refractive index difference of the each fluids

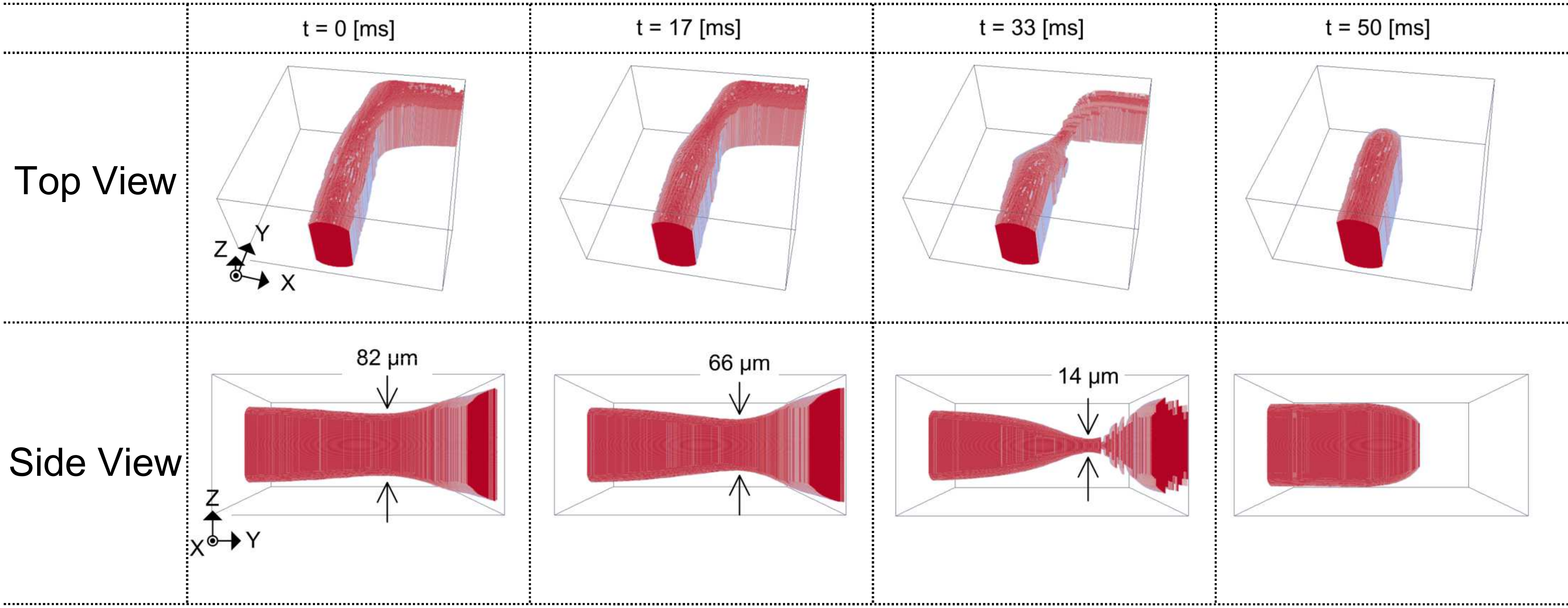
3D visualization





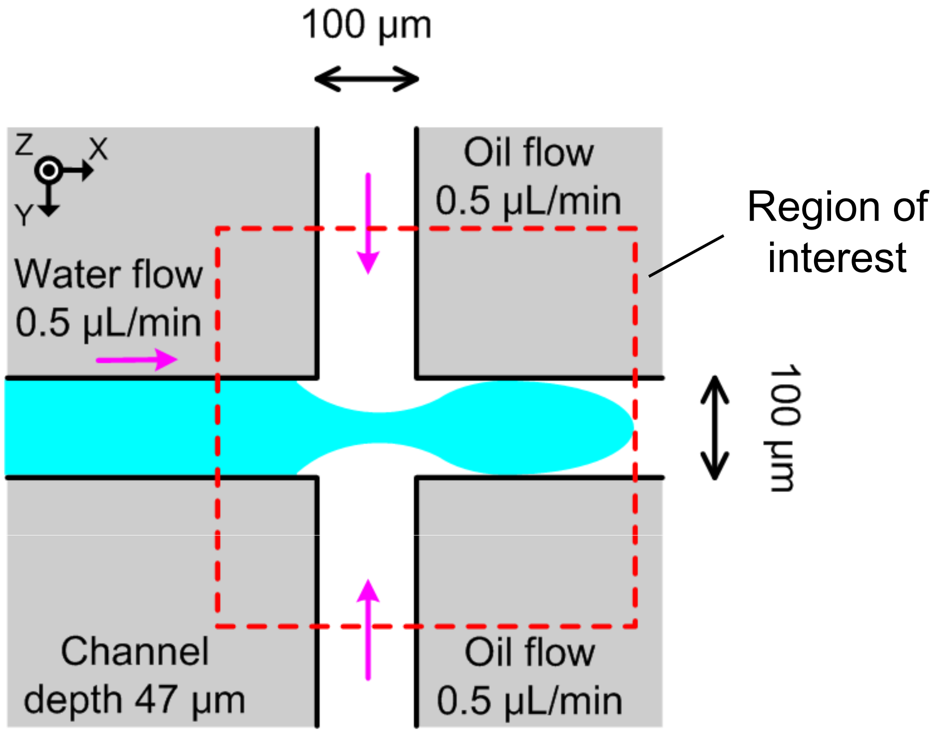
Reconstructed volume (xyz)	: 176 μm×176 μm×100 μm
Visualized sample	: Sequential 4 frames at the moment of droplet formation
Time interval	: 16.7 ms (60 fps)

3D visualization



➢ We have succeeded in real-time quantitative measurement of 3D shape of a droplet

Demonstration with a high-speed camera



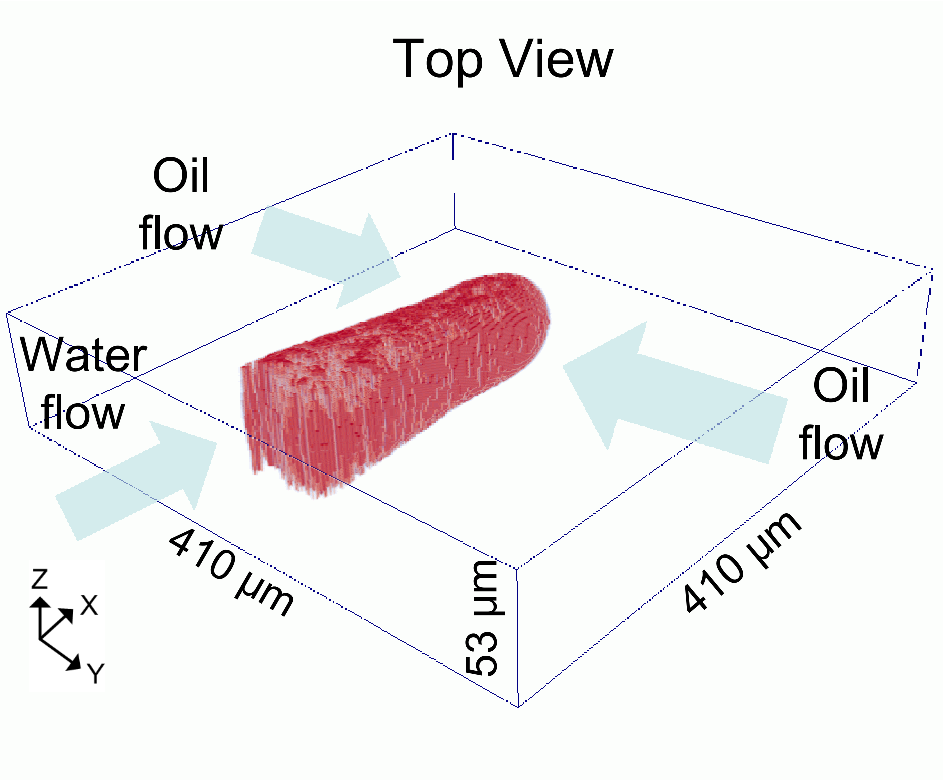
Channel:
Cross-shaped microchannel for droplet formation made from PDMS, hydrophobic nature

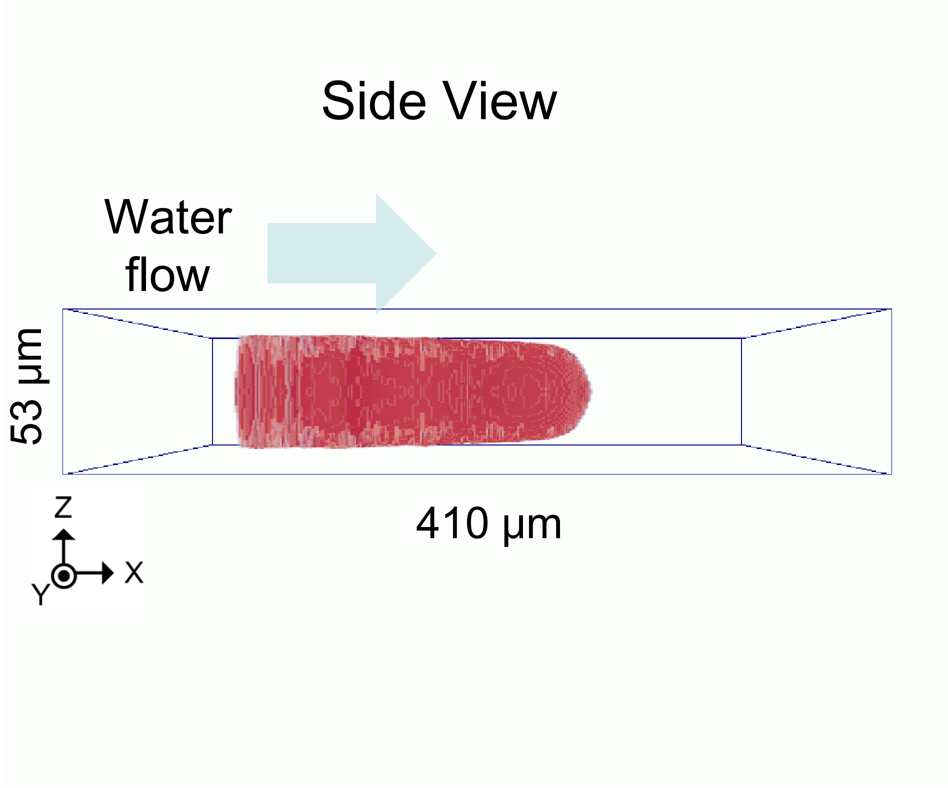
Working fluid:
water(droplet), silicone oil

②Measurement condition

Magnification	20 X
Measurement area	XY:410×410 µm Z: 1078 µm
Resolution	XY:0.8 µm Z: 0.062 µm
Frame rate	1000 fps
Exposure time	0.05 ms
Light source	HeNe laser 633 nm
Illumination	Transmission

3D visualization





- ➢We have also successfully measured the dynamic change of droplet shape in 3D and in real time at 1 ms time intervals

Conclusions

- 1. We have developed the real-time measurement technique of 3D shape microscopic droplet using the DHM

&

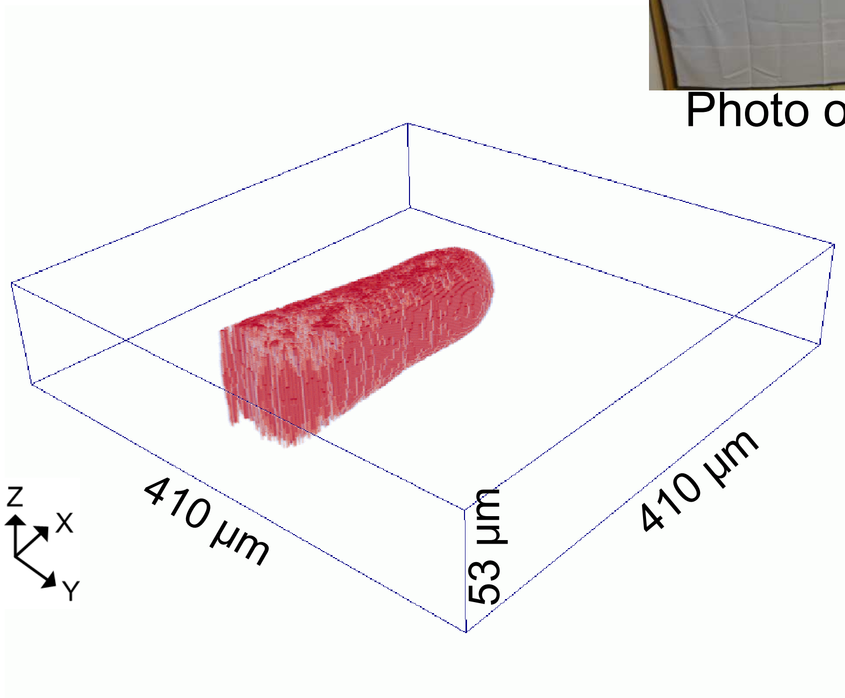
- 2. We have demonstrated the effectiveness of the DHM for 3D dynamical microscopic phenomena

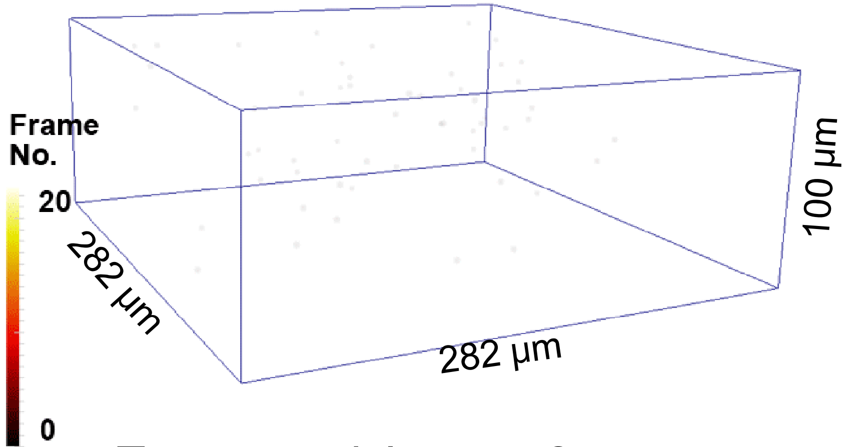
【Future tasks】

1．Applications to various microscopic objects
⇒bubble, red blood cell, etc…
2．Product commercialization

Please visit our booth exhibition !　　Booth No. 15-16

Photo of booth exhibition





Tracer particles　:φ2 μm
Sequential 20 frames

Droplet shape measurement

DHM-PTV
(3D flow measurement)