Compact laser ultrasound system for endoscopic applications

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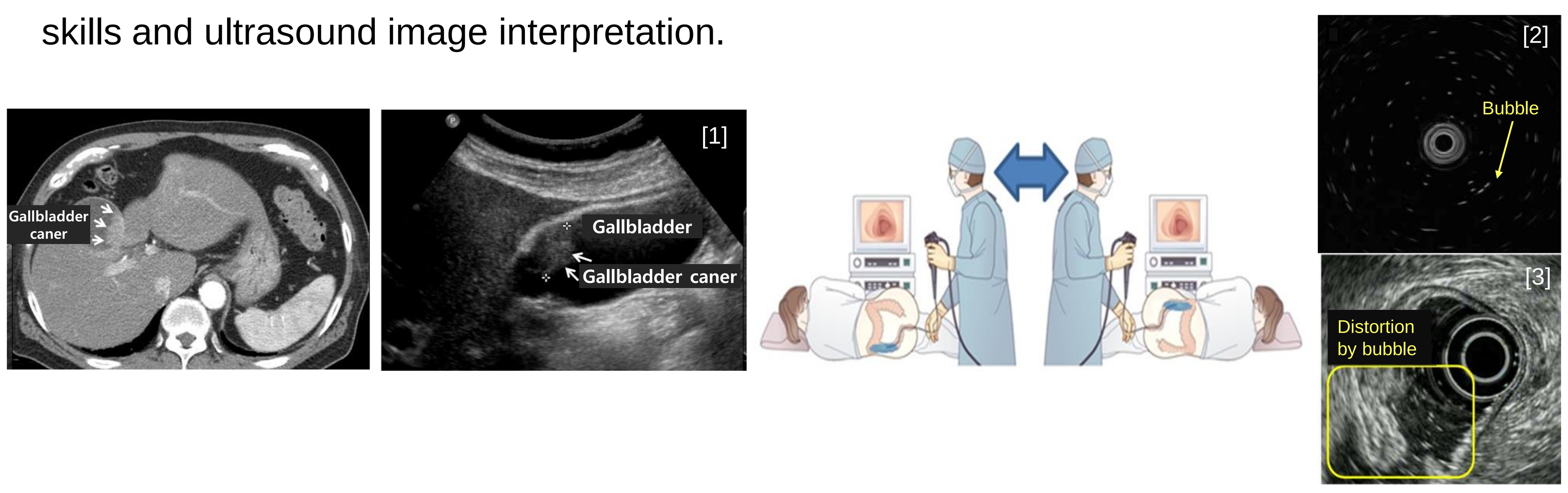
Introduction

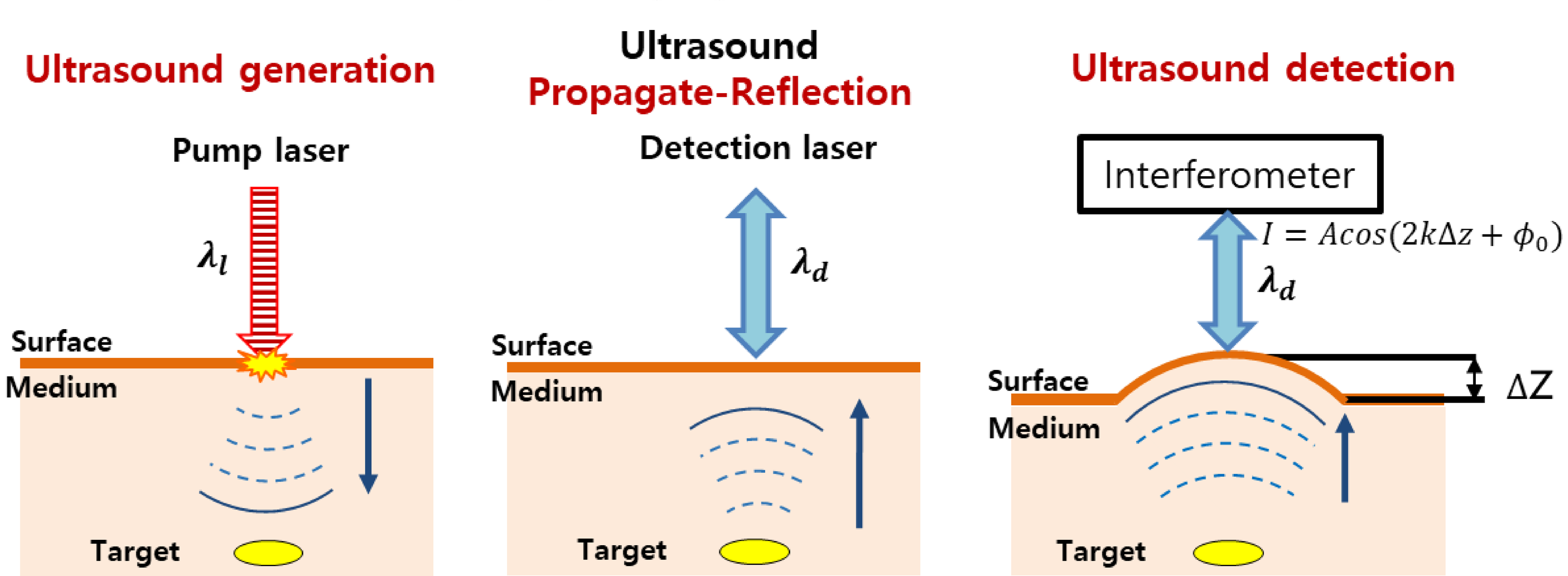
Ultrasound endoscopes share the commonality with regular endoscopes in their ability to measure deep organs. However, they differ in that ultrasound endoscopes utilize an ultrasound device attached to the endoscope instead of a camera. Illustrated in the image, these medical devices are employed to meticulously observe areas suspected of having a subepithelial tumor or early cancer, especially when scanned with a CT or MRI. A notable drawback is that it necessitates a skilled specialist proficient in both endoscopic operation skills and ultrasound image interpretation.



The measurement process of these endoscopes involves filling water inside the organ for accurate readings. However, this method has drawbacks, including the need for constant refilling due to water absorption and the requirement to reposition the patient for measurements on different sides. Additionally, the introduction of water may lead to the formation of bubbles, adversely affecting the image quality. To address these limitations, the objective is to develop measurement equipment that operates without the need for direct contact.

System Description

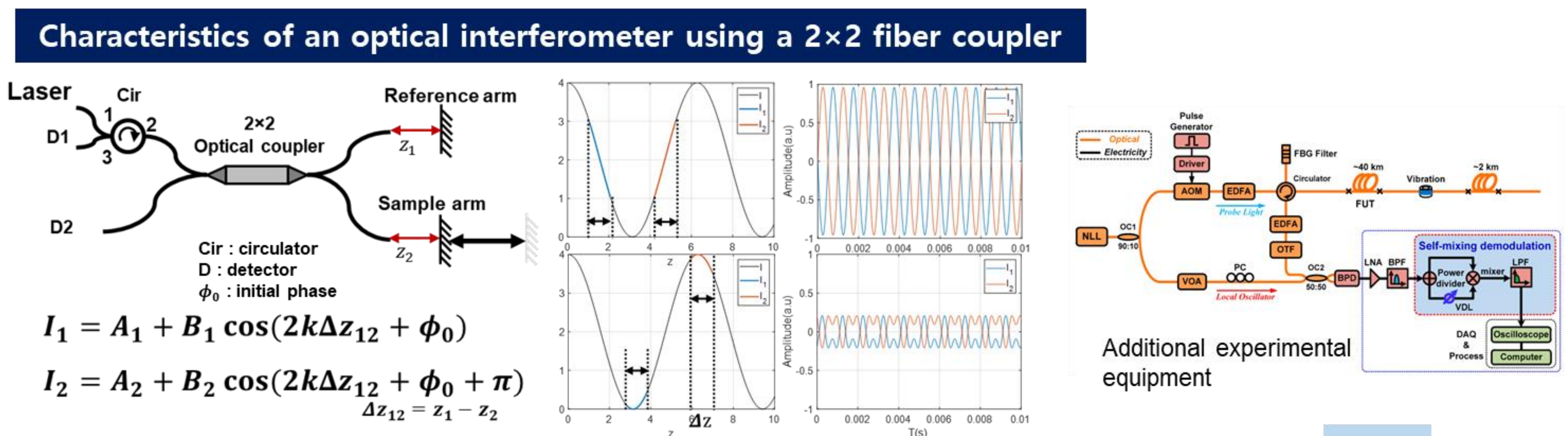
◆ Laser Ultrasound(LUS) Imaging



- → Irradiate the pump laser on the surface
- → Generate the several MHz ultrasound at the surface
- → Reflect the ultrasound at the target
- → Generate the displacement due to ultrasound pressure at the surface
- → Detect the displacement using the interferometer
- → Detectable to a few nm

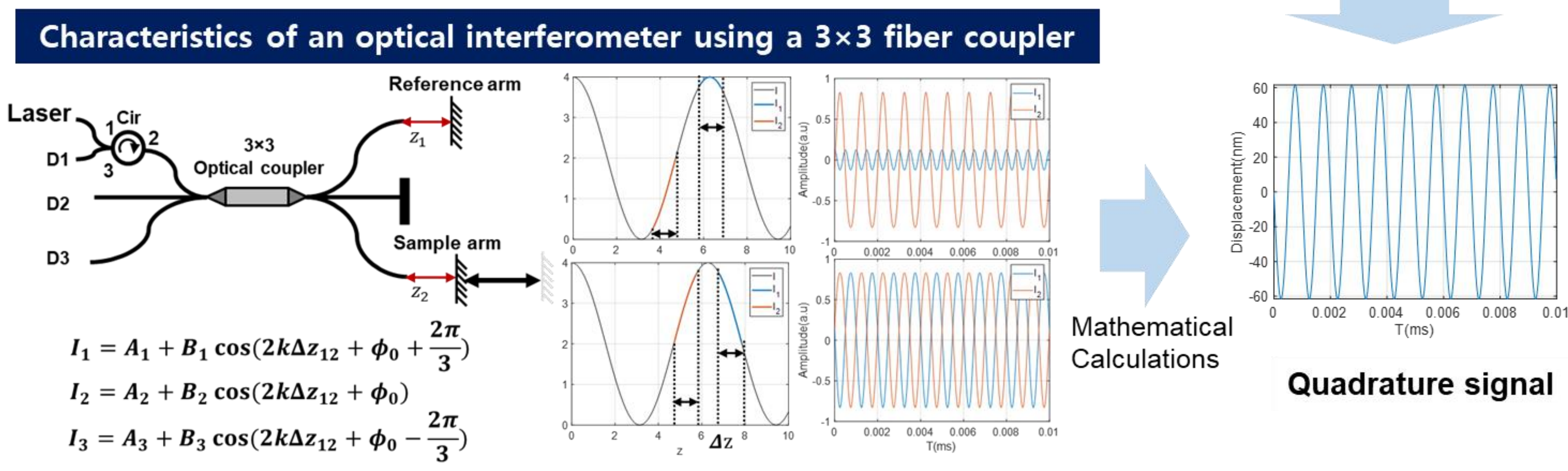
◆ Fabrication of an interferometer for laser ultrasound signal measurement

Characteristics of an optical interferometer using a 2×2 fiber coupler



$$I_1 = A_1 + B_1\cos(2k\Delta z_{12} + \phi_0)$$
$$I_2 = A_2 + B_2\cos(2k\Delta z_{12} + \phi_0 + \pi)$$
$$\Delta z_{12} = z_1 - z_2$$

Characteristics of an optical interferometer using a 3×3 fiber coupler

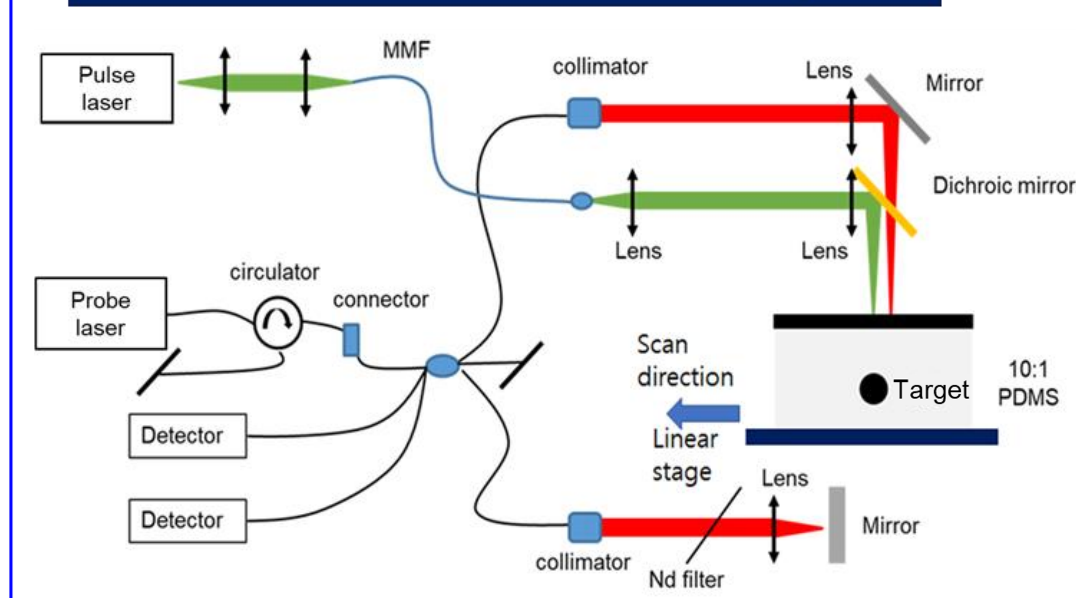


$$I_1 = A_1 + B_1\cos\left(2k\Delta z_{12} + \phi_0 + \frac{2\pi}{3}\right)$$
$$I_2 = A_2 + B_2\cos(2k\Delta z_{12} + \phi_0)$$
$$I_3 = A_3 + B_3\cos\left(2k\Delta z_{12} + \phi_0 - \frac{2\pi}{3}\right)$$
$$\Delta z_{12} = z_1 - z_2$$

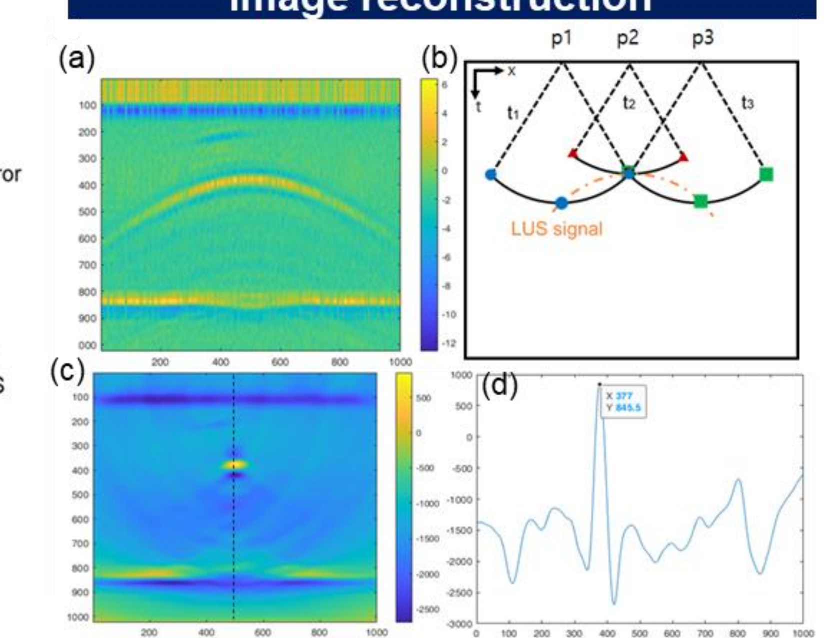
Results

◆ Laser ultrasound image of various samples

Schematic of the laser ultrasound system

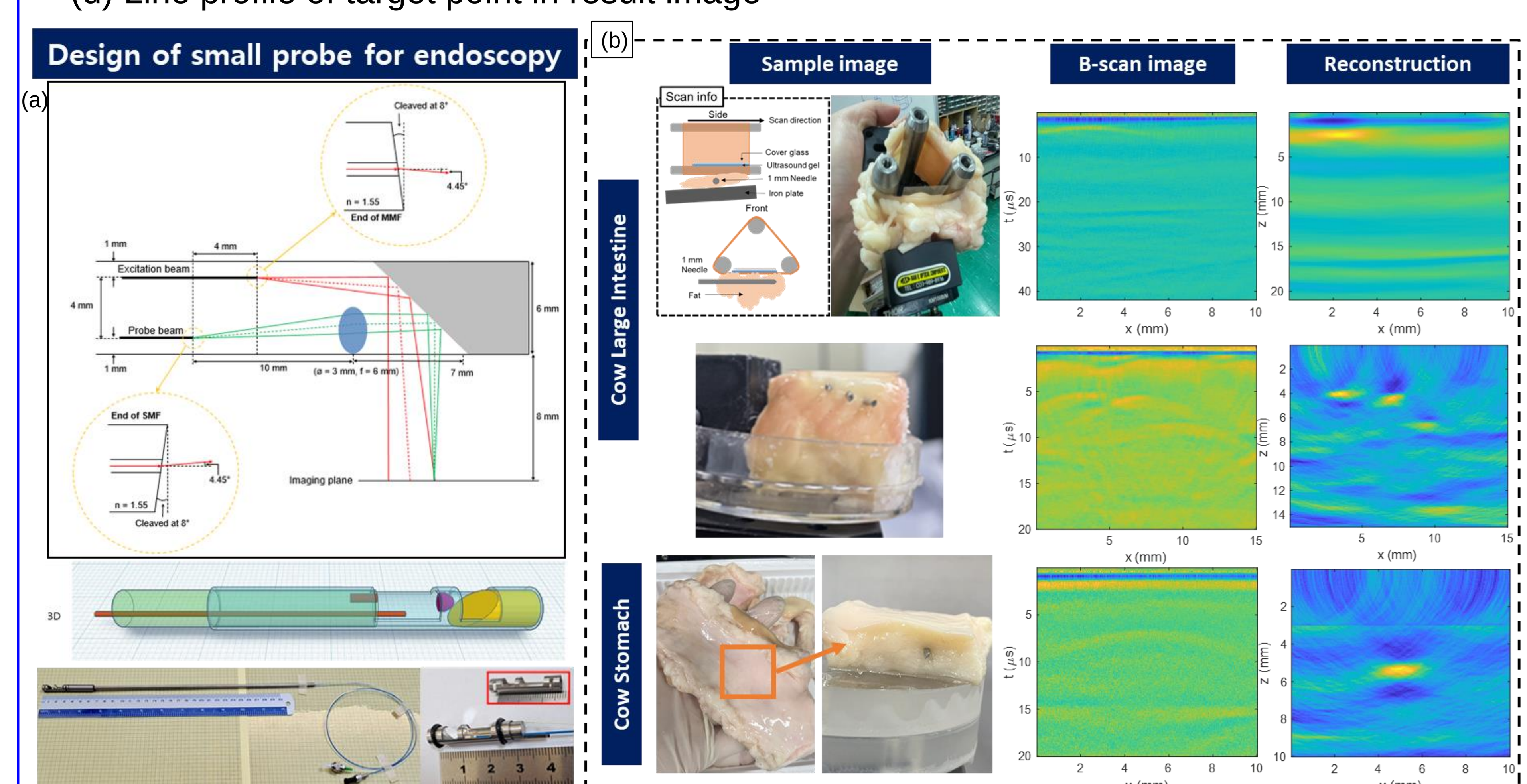


Schematic of laser ultrasound image reconstruction

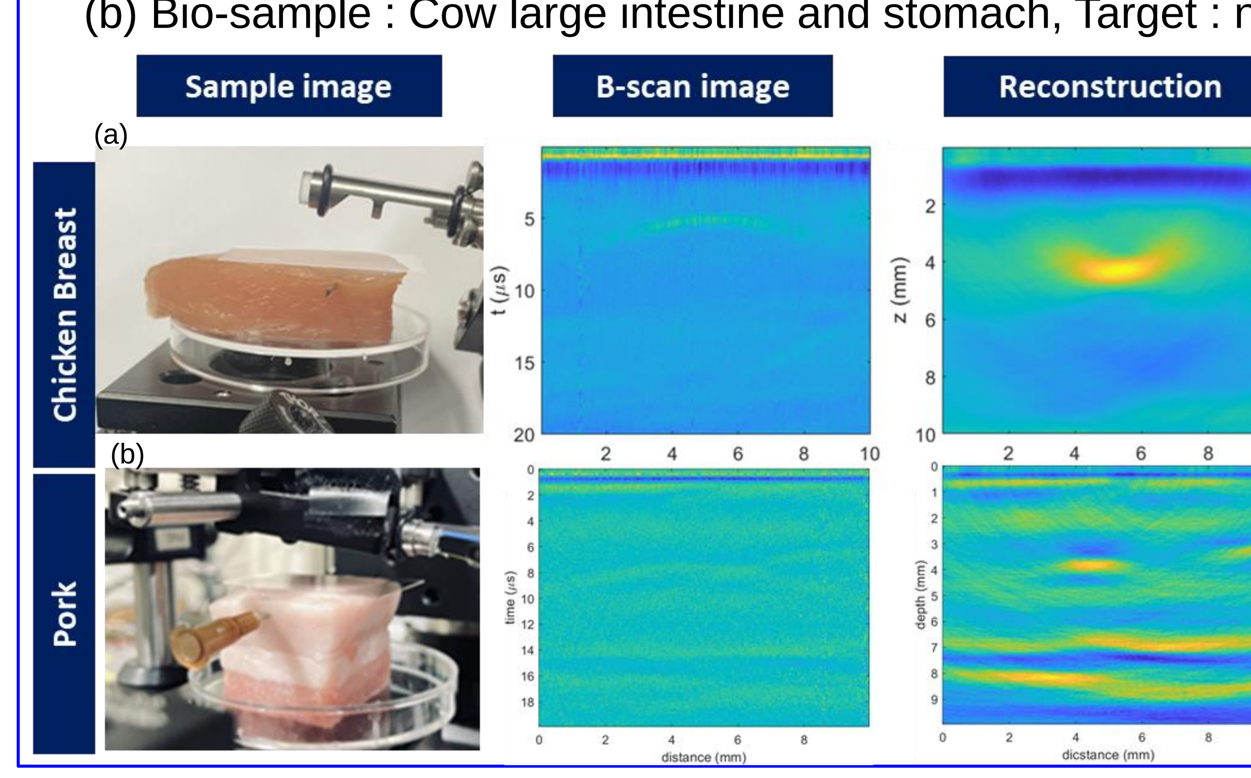


(a) B-scan image of PDMS sample
(b) Reconstruction method of laser ultrasound signal
(c) Result image of reconstruction of laser ultrasound signal
(d) Line profile of target point in result image

Design of small probe for endoscopy



(a) Design the probe outer diameter 7 mm, inner diameter 6 mm
(b) Bio-sample : Cow large intestine and stomach, Target : needle



(a) Bio-sample : Chicken breast, Target : needle

(b) Bio-sample : Pork belly, Target : needle

Conclusion

- A 3×3 optical fiber coupler was used to create a LUS system that stably acquires optical interference without additional equipment.
- B-scan and reconstruction images were successfully obtained for various ex-vivo samples and objects at a depth of up to 6 mm using the miniaturized probe.

Acknowledgement

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Reference

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