The 2016 Biomedical Engineering International Conference (BMEiCON-2016)

Investigation on feasibility of using surface plasmons resonance (SPR) sensor for ultrasonic detection

A novel optical detection of ultrasonic waves

Manas Sangworasil
Faculty of Biomedical Engineering
Rangsit University
Pathum Thani, Thailand

Phitsini Suvarnaphaet
Department of Physics, Faculty of Science
Mahidol University
Bangkok, Thailand

Suejit Pechprasarn[1,2], Supannee Learkthanakhachon[2] and Kodchakorn Ittipornnuson[1]
[1]Faculty of Biomedical Engineering
Rangsit University
Pathum Thani, Thailand
[2]Department of Electronic and Information Engineering
the Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong SAR, China

Naphat Albutt*
Division of Industrial Materials Science
Faculty of Science and Technology
Rajamangala University of Technology Phra Nakhon
Bangkok, Thailand
*Email: naphat.cha@rmutp.ac.th

***Abstract*—Scientists and engineers have dreamed of a high resolution ultrasonic microscopic imaging, where the resolution of the ultrasound is required to be as high as optical resolution. In order to achieve this, of course, a very high frequency ultrasonic source in GHz regime is required as well as a highly sensitive ultrasonic camera in the same operating frequency range. In this talk, we will show some experimental results and discuss a feasibility and key issues of employing a standard Kretschmann based surface plasmons resonance (SPR) sensor system to perform high frequency ultrasonic imaging. At the end of the talk, we will discuss some ways to get around the issues.**

***Index Terms*—High Frequency Ultrasonic Detection, Surface Plasmons Resonance, SPR, Optical detection**

I. Introduction

Ultrasonic imaging has been one of the gold standard in biomedical imaging tools for clinical use [1]. For human tissues and organs, ultrasonic frequencies around 1-5 MHz range are sufficient to image human body [2]. However, there is another field which requires a much higher ultrasonic frequency, which is acoustic microscopy [3]. Main reasons to employ an acoustic microscope rather than an optical microscope are that firstly the acoustic and optical microscopes measure different quantities of the sample. For the optical wave, it is use to reflect and transmit light from/through the sample. This is essentially related to refractive indices of the sample. For the acoustic wave, the way that this wave interacts with the sample does not depend on the refractive indices, but rather depends on its mechanical properties, such as, stress, strain and acoustic impedance of the sample. In other words, the acoustic microscope provides a microscopic image that is related to mechanical properties of the sample. This may enable us to understand more about cells and drug delivery, e.g. how cells move and how the receptor channels open for up taking drugs.

The key challenges in acoustic microscopy are that there is a trade-off between image resolution and sample penetration depth; especially for biomedical samples where water is the main substance here. At the frequency up to 1.5GHz the attenuation in water of the acoustic wave becomes problematic [4]. In order to get around this, a very strong ultrasonic generator and/or a very sensitive ultrasonic detector are required.

For high frequency acoustic microscopy, a very high bandwidth camera is required to detect a GHz frequency and scan multiple spots to form an image.

II. Surface Plasmons Resonance (SPR) Sensor

Surface Plasmons Resonance (SPR) is a guided electromagnetic wave propagating along a uniform surface of noble metals, such as, gold (Au), silver (Ag) and copper (Cu). The SPR wave is sensitive to refractive index change in its surrounding medium as shown in Fig. 1. Fig. 1a shows the conceptual diagram for SPR experiment using 50 nm gold deposited on a glass prism (BK7) with excitation wavelength 690 nm; where the sample was water (n=1.330) left hand side Fig. and ethanol alcohol (n=1.359) [5] right hand side Fig. The reflection spectrum shows a dark band dip, which is a strong evidence of the SPR effect, so called, SPR dip. The angle, where the SPR dip occurs, is called plasmonic angle or θ_p. We can see from Fig. 1b that the Fresnel equations simulation

978-1-5090-3940-1/16/$31.00 ©2016 IEEE

shows that the plasmonic angle for water and ethanol alcohol were $\sin\theta_p$=0.934 and $\sin\theta_p$=0.956 respectively. This illustrates how the SPR system work as a label-free sensor sensing any local refractive index change within 250nm height above the gold sensor surface due to the penetration depth of the SPR field.

There are some requirements that are needed to be satisfied in order to excite the SPR.

(1) Negative real part of a complex permittivity; which metals like gold, silver or copper serve the purpose here.
(2) Proper thickness of metal, i.e. 50 nm for gold and silver. For this study, a sputter coating technique was used to sputter 50nm on glass substrate with 3 nm of Cr layer as an adhesion layer.
(3) High refractive index coupling material since the SPR cannot be excited through air. In this study, we used SF11 prism (n= 1.7726) [Schott glass]
(4) P-polarization (TM polarization) of the incident wave
(5) Total internal reflection excitation. The SPR only occurs beyond the critical angle.

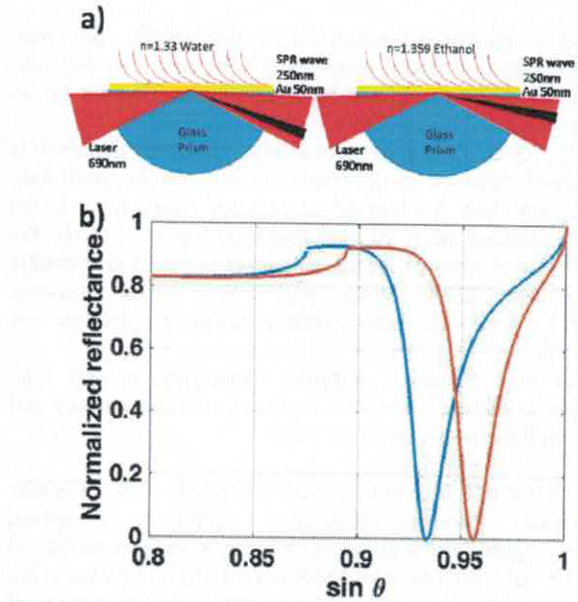

Fig. 1. shows (a) conceptual diagram of Kretschmann based SPR sensor when the samples are water (left hand side) and ethanol (right hand side) and (b) simulated results for the SPR dips corresponding to the system configuration in Fig. 1a. The blue curve is for the water case n=1.330 and the red curve is for the ethanol case n=1.359.

Kretschmann based Surface Plasmons Resonance (SPR) configuration is one of approaches that satisfies all the requirements [6]. The Kretschmann SPR sensor has been widely employed in biomedical proteomic studies, such as, protein binding and immunoassay [7].

In this study, an SPR sensor system has been aligned as shown in Fig. 2 and employed in order to investigate the feasibility of detecting an acoustic wave from an ultrasonic transducer with 2.5Bar magnitude and frequency of 5MHz. The ultrasonic transducer was positioned above the gold sensor in water environment. The water layer also served as an acoustic medium. The system consists of a 690nm laser with a fiber coupling to a doublet f=60 lens producing a well collimated beam. The beam was then passed through an aperture and a linear polarizer to clean up the beam quality and maintain a linear polarization of the laser beam. The beam was then passed a rotatable half waveplate to ensure that the incident wave on the sample was p-polarized. The beam then reflected on a mirror for directing the beam off-axis before passing through a cylindrical lens and focused down on a 50 nm gold sensor through a SF11 prism.

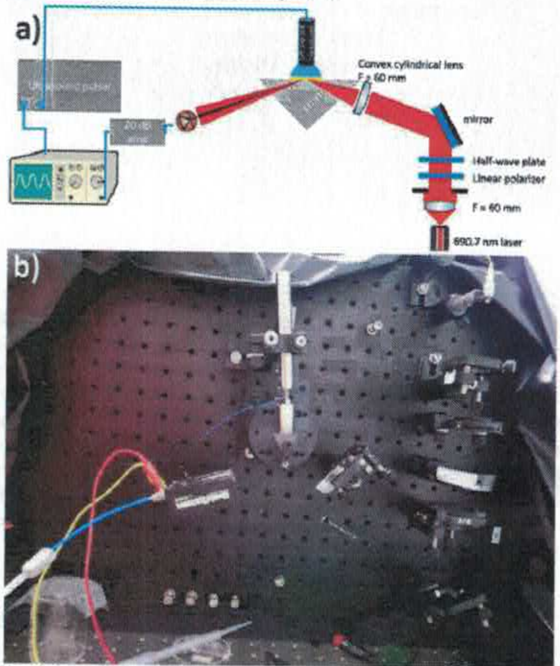

Fig. 2 shows (a) a conceptual diagram of SPR system setup for acoustic detection (b) a photo of the experimental setup.

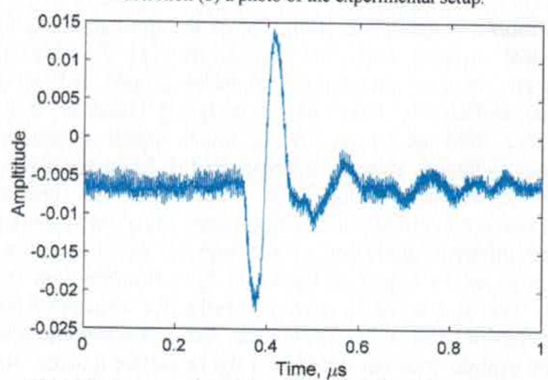

Fig. 3 shows an experimental result obtained from the system in Fig. 2.

The ultrasonic wave is a mechanical wave, which compresses and decompresses the water medium making the local refractive index on the gold sensor varies following the ultrasonic wave pulse pattern. This enables us to measure the ultrasonic wave through this local refractive index change. We have performed a series of theoretical analysis [8] and found that the refractive index of the water change due to 1 Pa pressure, d_n/d_p, is 1.4 x 10^{-10}RIU/ Pa or 1.5x10^{-5} RIU at atmospheric pressure. Therefore with the pressure of 2.5 bar, it is expected that the SPR system can detect the ultrasonic wave. Fig. 3 shows an experimental result obtained from an accumulated read out signal for 50 times on the oscilloscope of the system in Fig. 2. We can see that the system can be employed to detect the ultrasonic waves. We have checked the data that it agrees very well with the pulse duration generated by the ultrasonic pulser. Although the system still needs some improvements especially in term of signal to noise, it does demonstrate the feasibility of using the SPR to detect the ultrasonic wave. One key advantage of the system is that it does not require to detect any echo of the ultrasonic wave and this will open a novel way to perform ultrasonic imaging.

III. DISCUSSION

We have demonstrated that the SPR system can be employed to detect the ultrasonic wave. Some improvements still, however, are needed to be investigated in order to improve the sensitivity of the SPR system. There is a number of research work done on enhancing the sensitivity of the SPR system, such as, measuring the phase of the SPR [9], grating structures [10] and nanoparticles [11].

The other issue that needs to be discussed is that how the system can scan very quickly to serve as a camera rather than a single point detector. In this case, it does require a very high bandwidth system in GHz range. This is very demanding even for the current state of the art electronic technology. Here we would like to investigate in the future study whether we could adapt time-stretching microscope [12] technique to perform the high speed scanning. The time-stretching microscope performs a very high speed imaging by encoding the spatial information in the wavelength dimension.

IV. CONCLUSION

In this talk, we have discussed some key issues in acoustic microscopy, which are (1) the trade-off between penetration depth and resolution and (2) the technique requires very high bandwidth ultrasound sensitive camera. We have demonstrated the feasibility of employing the standard Kretschamnn type SPR system to detect the ultrasonic wave. At the end of the talk, we have discussed some techniques to improve the sensitivity of the SPR system and a possible way to perform a high speed scanning by employing a time-stretching microscopy technique.

ACKNOWLEDGMENT

The authors would like to thank and acknowledge the research funding from Research Institute of Rangsit University (RiR) Grant no. 88/2558 and the Hong Kong Polytechnic University. We would like to acknowledge Ms Queenie Shea, Biomedical Engineering, the Hong Kong Polytechnic University for their support on characterizing the ultrasonic transducer used in this project and the authors would also like to thank the division of Industrial Materials Science, Faculty of Science and Technology, Rajamangala University of Technology Phra Nakhon (RMUTP).

REFERENCES

[1] D'Hooge, J., Heimdal, A., Jamal, F., Kukulski, T., Bijnens, B., Rademakers, F., Hatle, L., Suetens, P., and Sutherland, G.R.: 'Regional Strain and Strain Rate Measurements by Cardiac Ultrasound: Principles, Implementation and Limitations', European Journal of Echocardiography, 2000, 1, (3), pp. 154-170.

[2] Lin, L.: 'Practical Clinical Ultrasonic Diagnosis' (World Scientific, 1997.

[3] Maslov, K., Zhang, H.F., Hu, S., and Wang, L.V.: 'Optical-resolution photoacoustic microscopy for in vivo imaging of single capillaries', Opt. Lett., 2008, 33, (9), pp. 929-931.

[4] Maev, R.G.: 'Acoustic Microscopy: Fundamentals and Applications' (Wiley, 2008.)

[5] Kedenburg, S., Vieweg, M., Gissibl, T., and Giessen, H.: 'Linear refractive index and absorption measurements of nonlinear optical liquids in the visible and near-infrared spectral region', Optical Materials Express, 2012, 2, (11), pp.1588-1611.

[6] Kretschmann, E.: 'The determination of the optical constants of metals by excitation of surface plasmons', Zeitschrift für Physik, 1971, 241, (4), pp. 313-324.

[7] Roh, S., Chung, T., and Lee, B.: 'Overview of the characteristics of micro- and nano-structured surface plasmon resonance sensors', Sensors, 2011, 11, (2), pp. 1565-1588.

[8] Wall, J., and Colley, T.: 'Preventing pressure ulcers among wheelchair user: Preliminary comments on the development of a self-administered risk assessment tool', World Wide Wounds, 2004.

[9] Huang, H.C., Yeh, C.H., Chen, C.M., Lin, Y.S., and Chung, K.C.: 'Sliding and pressure evaluation on conventional and V-shaped seats of reclining wheelchairs for stroke patients with flaccid hemiplegia: A crossover trial', Journal of NeuroEngineering and Rehabilitation, 2011, 8, (1).

[10] Arthanat, S., and Strobel, W.: 'Wheelchair ergonomics: Implications for vocational participation', Journal of Vocational Rehabilitation, 2006, 24, (2), pp. 97-109.

[11] Samuelsson, K., Björk, M., Erdugan, A.M., Hansson, A.K., and Rustner, B.: 'The effect of shaped wheelchair cushion and lumbar supports on under-seat pressure, comfort, and pelvic rotation', Disability and Rehabilitation: Assistive Technology, 2009, 4, (5), pp. 329-336.

[12] Wang, F., and Zhang, J.G.: 'Mechanical design for a power wheelchair with self-actuated seating functions based on ergonomics', in Editor (Ed.)^(Eds.): 'Book Mechanical design for a power wheelchair with self-actuated seating functions based on ergonomics' (2013, edn.), pp. 799-802.