High-Frequency Ultrasonic Detector Using Photonic Crystal

MAY15-29 FINAL REPORT

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1. Abstract

The team developed an ultrasound detector using the photonic crystal (PC). The PC-based ultrasound sensor has potentials to offer a broad bandwidth and high sensitivity. The PC structure is comprised of a sub-wavelength dielectric grating, which selectively reflects light at a particular wavelength, known as the PC resonant wavelength. Acoustic wave can result in a shift of resonant wavelength due to the compression of the superstrate material. In our experiment, this shift was estimated by measuring the reflection from the PC substrate using a laser and a photodetector. For more challenge, the team developed an optical setup to generate high-frequency ultrasound with up to 2MHz frequency using a plasmonic substrate. The plasmonic substrate consists of a two-dimensional (2D) gold nanostructure, nipped between a glass coverslip and approximately 10um thick polydimethylsiloxane (PDMS) layer. The 2D gold nanostructure serves as light absorbing layer and DPMS layer can launch acoustic wave due to its thermos-elastic effect.

2. Introduction

The traditional piezoelectric sensor for detect ultrasonic acoustic sound is limited by their minimum detectable acoustic pressure and poor sensitivity at high frequencies. [1] In contrast, optical sensors for ultrasound signals provide good sensitivity over a board bandwidth. The proposal is to detect acoustic waves by exploiting the high sensitivity of photonic crystal materials to variations in the refractive index of the surroundings.

High frequency ultrasound has wide applications, such as precision-targeted therapy, medical imaging, health care (teeth cleaning), underwater distance measurement (sonar) and etc. As the ultrasound becomes widely used, find an effective detection method becomes even important.

Using optical sensor such as photonic crystal sensor can detect higher frequency range and get much wider bandwidth. According to this thesis, the team decides to build an optical setup based high frequency ultrasonic acoustic wave detector.

2.1 Detector

Our team developed an ultrasound detector using the photonic crystal (PC). The PC structure is comprised of a sub-wavelength dielectric grating, which selectively reflects light at a particular wavelength, known as the PC resonant wavelength. When the PC is illuminated with a broadband light source at a particular resonant wavelength or incident angle, interference occurs and nearly no light is transmitted, where we can see a peak shown in the reflection spectrum. [3] Acoustic wave can result in a shift of resonant wavelength due to the compression of the superstrate material. [6] And the shift in resonant wavelength would cause a change in reflection rate in any selected wavelength near the peak of the reflection spectrum. So we use a laser beam to illuminate the photonic crystal sensor. Wavelength of out laser beam is fix in 845nm and it has a very narrow bandwidth. If there is any reflection rate change in this particular wavelength, the power of reflected laser will change. In order to capture this change in light power, we decide to use photodetector. The photo detector can convert light intensity into voltage level.

To maximize the performance, which include enhancing its sensitivity, improve output level and decrease the noise, we keep improving our set up.

1. As the laser beam itself is 45 degree polarized, we add a polarizer before the laser goes into sensor. The laser itself is 45 degree polarize, so half of the light would horizontal with sensor grating (so called TM mode) and another half would mutually perpendicular with sensor grating (so called TE mode). The laser light in TM mode would give us the expected waveform. However, the laser in TE mode would just cause noise to the output. As a result, we use the polarizer to screening the TM-mode-light.
2. To achieve the maximum output change when a shift of reflection rate in resonant wavelength appear. We want the peak of reflection rate in resonant wavelength coincides with the peak of laser power in resonant wavelength. However, the resonant wavelength is quite fixed in 845nm and has very narrow bandwidth. So we decided to change the peak of sensor's resonant wavelength by etching.

2.2 Generator

High-frequency ultrasound has been widely used in various applications including precision-targeted therapy and medical imaging. Although the technology is mature to build piezoelectric array operating system for ultrasound generation with approximately 10MHz [1], it is difficult to produce frequency higher than 30MHz due to the limitation of piezoelectric connection [2]. Optoacoustic arrays can overcome the difficulties of piezoelectric devices, since there is no need to make piezoelectric connections.

The most common and efficient way for optical generation of ultrasound is the thermos-elastic effect. When a pulse laser beam is incident onto a thin film made of photo acoustic materials, the absorbed light is converted to heat by the carbon nanoparticle surface, leading to rapid localized temperature increase. This results in rapid thermal expansion of a local region, which leads to generation of ultrasound. [3,4]To obtain strong and high frequency acoustic pressure waves, one can increase the material absorption coefficient and/or increasing the incident laser power. However there is a limit on the absorption coefficient. Therefore, increasing the incident laser power becomes a popular way to obtain high frequency and pressure waves. However, the pulsed laser system with high power is usually bulky, expensive and dangerous to use. Thus, we develop a gold nanoparticle structure with PDMS on top of it. The absorbed light can be converted to thermal energy by the gold nanoparticle structure as well, and transferred over short time interval to PDMS layer resulting in thermal expansion, which launches a pulsed acoustic wave.

The light-absorbing layer is made of 2D array of gold nanoparticles on top of polymer substrate, followed by a thin PDMS layer. Gold nanoparticles associated with plasmonic structure have been extensively used for applications both in bio-imaging and photo-acoustic technology due their unique optical properties. [6] These properties are conferred by the interaction of light with electrons on the gold nanoparticle surface. At a specific wavelength of light, collective oscillation of surface electrons on the gold nanoparticle surface cause a phenomenon called surface plasmon resonance resulting in strong absorption of light. [6, 7] The particular wavelength, or frequency, of light where this occurs is strongly dependent on the thickness of gold nanoparticle on top of plasmonic substrate. [8, 9] Therefore, the gold nanoparticles serve as strong light absorber at a resonant wavelength. The PDMS layer is fabricated with desired thickness for function of thermal expansion, since the bandwidth of generated ultrasound is mainly limited by it. [3] The gold nanostructure placed in the water tank at the water surface. The laser source is a high-energy pulse laser with 532nm wavelength, which produces a 5ns laser pulse with energy of 25mJ.

3. Functional Components

3.1 Detector Part

Polarizer

Polarizer is an optical filter used to pass the specific polarization light and block waves of other polarization during the optical experiment process. It would help us to select the specific horizontal light wave from the laser diode to the beam splitter, and block other wave as the same time.

Laser diode modules (850nm)

A laser diode, or LD, is an electrically pumped semiconductor laser in which the active laser medium is formed by a p-n junction of a semiconductor diode similar to that found in a light-emitting diode. For the module we selected in our senior design project, we choose this laser diode with the output wavelength as 850nm. Its actual output during the real time experiment is about 845nm.

Non-polarizing cube beam splitter (R: T 50:50)

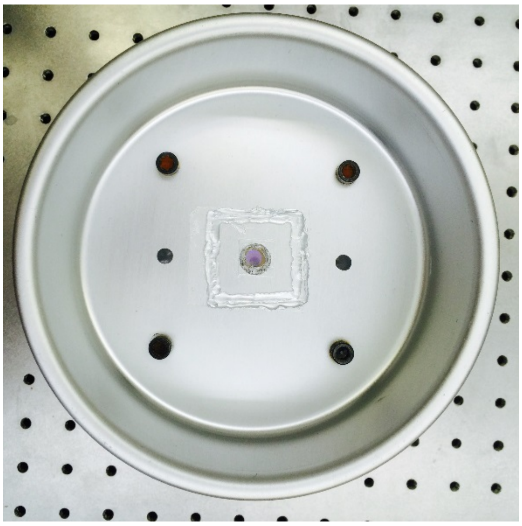
Beam splitter is an optical device that splits the beam of light into two beams. We use a 10mm cube beam splitter with the ration of refection rate to transmission rate as 50:50. Which means the 50% of the incoming light to be transmitted to the back side and 50% of light will be reflected to the upper side. This beam splitter is used to change the paths of our light wave from horizontal to vertical light.

Optical power meter

Power meter is a device used to measure the power of any optical signal. The term usually refers to a device for testing average power in fiber optic systems. By using the detector on the right side, we can focus the output light on the detect area for couple seconds, then the power meter can give us the power information results. We use this power meter in the detect part to make sure the reflection and transmission rate are among the right area. After this, we can then continue to measure the wave form.

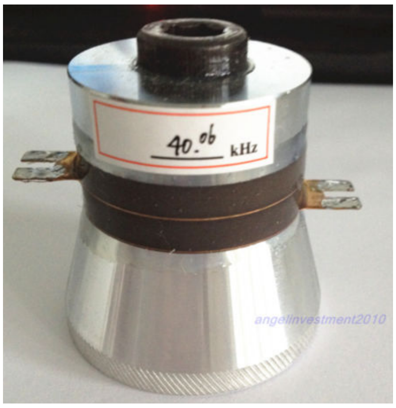
Sample holder (Water tank)

The sample holder an aluminum (Al) pan with an open hole on the center of it. It is used to hold the sensor on and the hole will let the laser light to pass through and reach the underside of the sensor, then let the reflected light pass back to the beam splitter. The holder has four holes which are used to connect the optical post assemblies.



Acoustic wave transducer

The acoustic wave transducer is a device that can generator ultrasound sinusoidal wave with frequency as 40 kHz. We use this ultrasound wave as the unknown input.



Photodetector

Photodetector is a kind for optical sensor, which can detect the light wave. It can be connected to an oscilloscope via BNC connectors and give out the information for the incoming light. We use photodetector to detect the light.

Oscilloscope

Oscilloscope is a basic electronic test device that allows observation of constantly varying signal voltages, usually as a two-dimensional plot of one or more signals as a function of time. Non-electrical signals (such as sound or vibration) can be converted to voltages and displayed. Oscilloscopes are used to observe the change of an electrical signal over time, such that voltage and time describe a shape which is continuously graphed against a calibrated scale. We use oscilloscope to show the waveform for the acoustic wave.

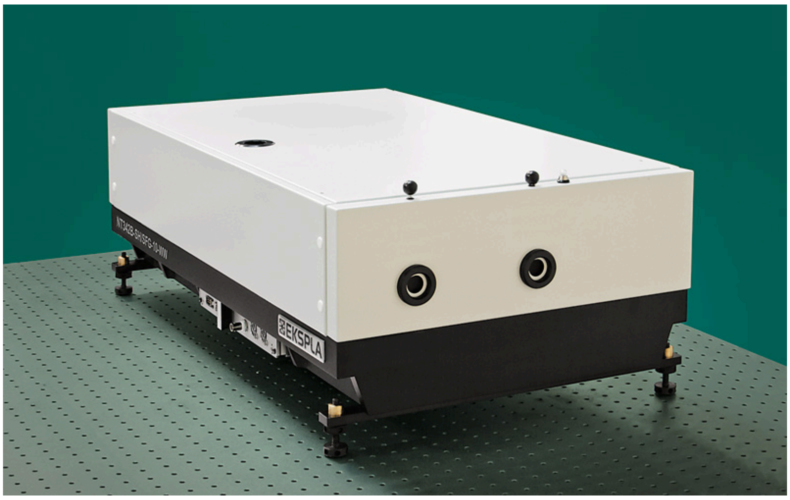
3.2 Generation Part

Rotation Stage

CR1

A unique rotation stage provides continuous high precision 360-degree rotation control. The precision rotary action is driven by a fine pitch screw and worm gear to provide fine positioning resolution. And a locking mechanism ensures that the stage is stable and will not move after the desired position is obtained. The continuous rotation stages are available in 120, 65, 40 and 25mm footprints. It has central apertures and may be mounted with an optical beam passing through its center.

High-energy pulse laser system



The NT340 series tunable wavelength nanosecond laser seamlessly integrates the nanosecond optical parametric oscillator and the Nd:YAG Q-switched nanosecond

laser – all in a compact housing.
The main system features are: hands-free wavelength tuning from UV to IR, high conversion efficiency, optional fiber-coupled output and separate output port for pump laser beam.

Narrow bandwidth models have a linewidth of less than 5 cm^{-1}, which is ideal for many spectroscopic applications.

The laser is designed for convenient use. It can be controlled from remote keypad or from a PC through an RS232 interface using LabView™ drivers that are supplied with the system. The remote keypad features a backlit display that is easy to read even through laser safety googles. The OPO pump energy monitoring system helps to control pump laser parameters. Replacement of laser flashlamps can be done without misalignment of the laser cavity and/or deterioration of laser performance.

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4. METHODS

4.1 Methods of acoustic wave detector

4.1.1 Fabrication of photonic crystal sensor

Photonic crystals are periodic optical nanostructures that affect the motion of photons in much the same way that ionic lattices affect electrons in solids. Photonic crystals occur in nature in the form of structural coloration and promise to be useful in different forms in a range of applications.

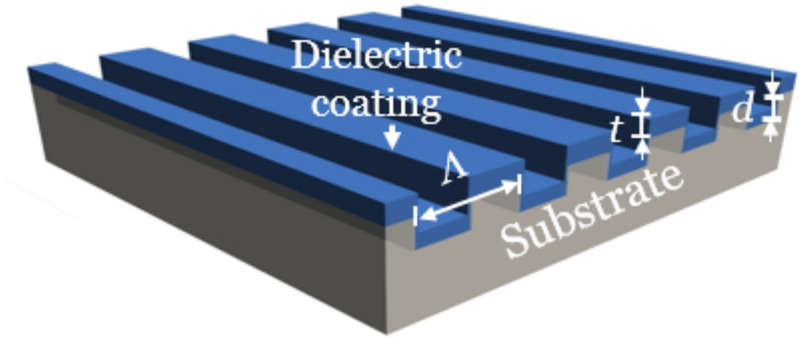


Figure 1 Structure of a photonic crystal

There are three important parameters in the photonic crystal, grating period, depth, and thickness. Any parameter change will affect the resonant wavelength, therefore, it is usually set thickness and depth at constant, and change the grating period to control the resonant wavelength. It suits for a formula called Bragg condition:

$$\lambda = \frac{2n_{eff}\Lambda}{m}$$

Which is the resonant wavelength. [8, 9]

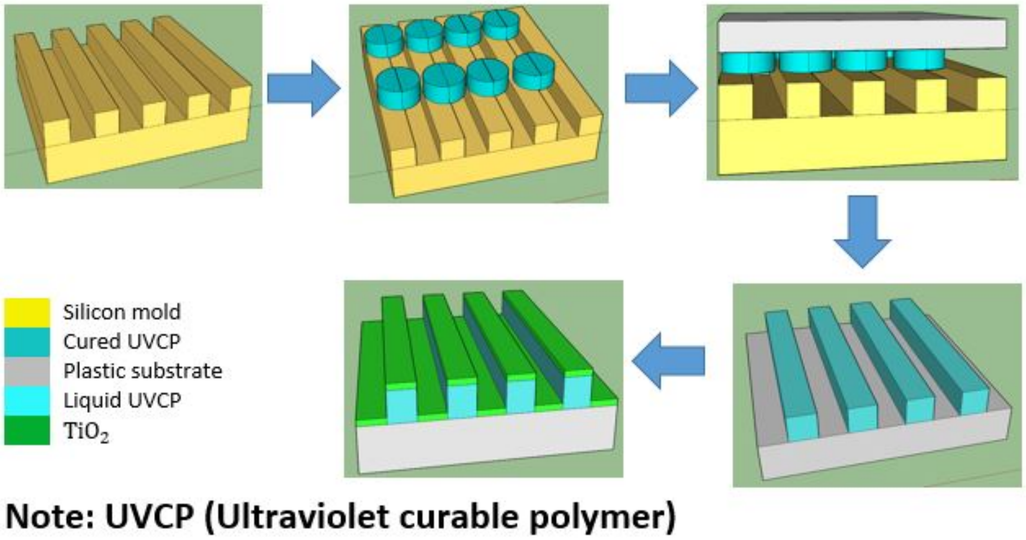


Figure 2 Procedure of fabrication of photonic crystal

First step: Start with a wafer mold that has periodic structures on top.

Second step: Put enough cured UVCP on top of the wafer mold.

Third step: Place plastic substrate on top of the wafer mold and squeeze the cured UVCP into the groove, and use UV light to shine on them.

Fourth step: After UV process, the UVCP is connected with the plastic substrate and the structure is inversed to the structure of wafer mold.

Final step: Place another layer of TiO2 on top of structure.

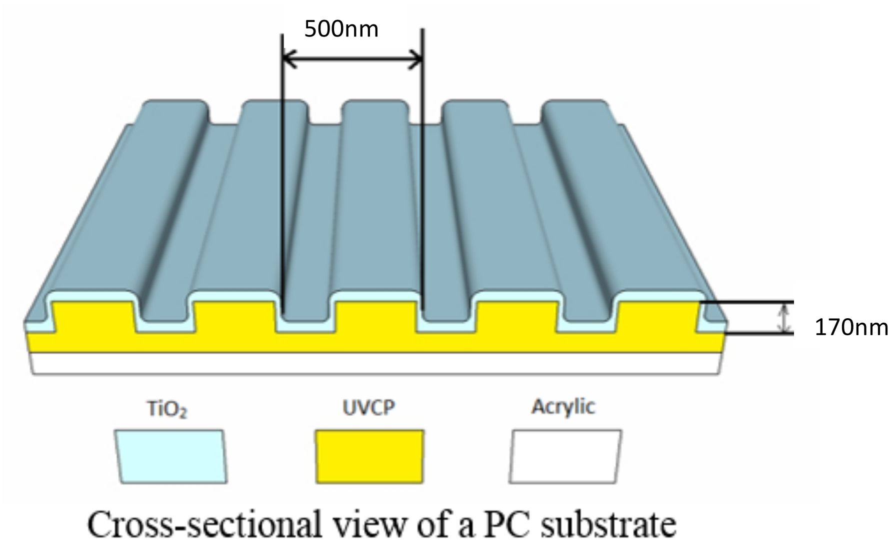
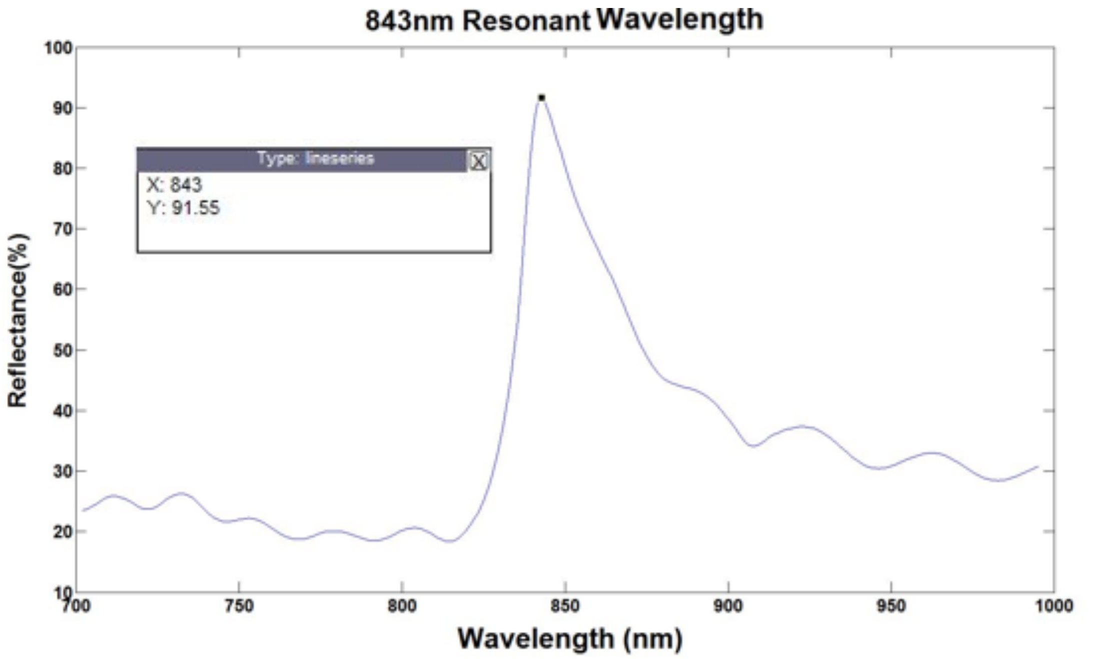


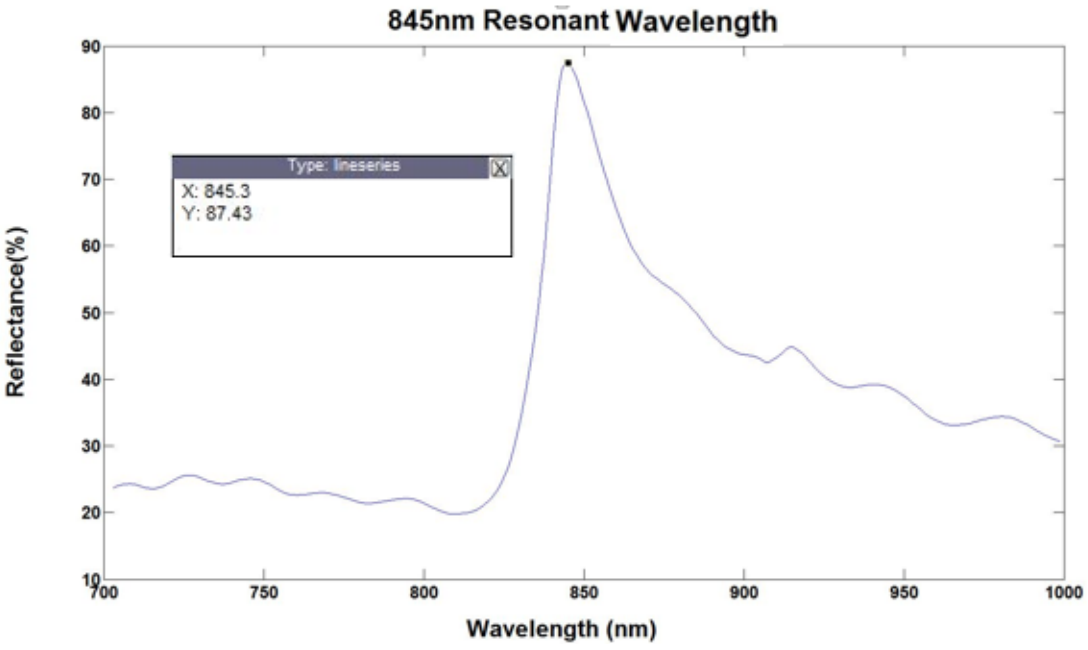
Figure 3 Front view of complete photonic crystal

4.1.2 Simulation of the photonic crystal resonances

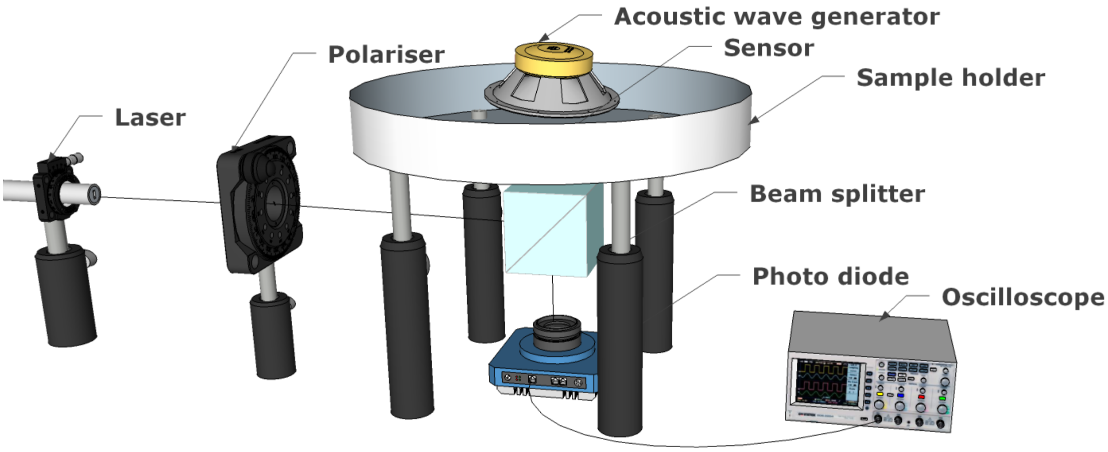
It is important to test and get some results of the sample photonic crystal before use it on the setup structure because we need to make sure it has the desire slope so that we can acquire the largest intensity in the results.

As you can see, we emit a wide-range wavelength light source. After polarizer, it becomes polarized light (this is to make the light more organized and stable). The sample photonic crystal was clipped by the sample holder, so that it is stationary and has the incident angle set to zero degree (Zero degree is important, if there is a angle when the incident light comes, the deep in the graph will shift to left proportional to the angle, which means the resonant wavelength is bigger). The resonant wavelength is blocked by the sample photonic crystal and the rest of the light transmit through. Thus, the result will be a deep in the transmission. The graphs are for reflectance.


843nm Resonant Wavelength
Type: lineseries
X: 843
Y: 91.55
Reflectance(%)
100
90
80
70
60
50
40
30
20
10
700
750
800
850
900
950
1000
Wavelength (nm)


845nm Resonant Wavelength
Type: lineseries
X: 845.3
Y: 87.43
Reflectance(%)
90
80
70
60
50
40
30
20
10
700
750
800
850
900
950
1000
Wavelength (nm)

4.1.3 Setup for the acoustic wave detection



For the acoustic wave detection part, we build an optical setup to organize the equipment and devices together.

The left most part is the laser diode. It is assembled on the bass board via optical assemblies. Then we adjust the assemblies to make sure that its output light wave will be straight.

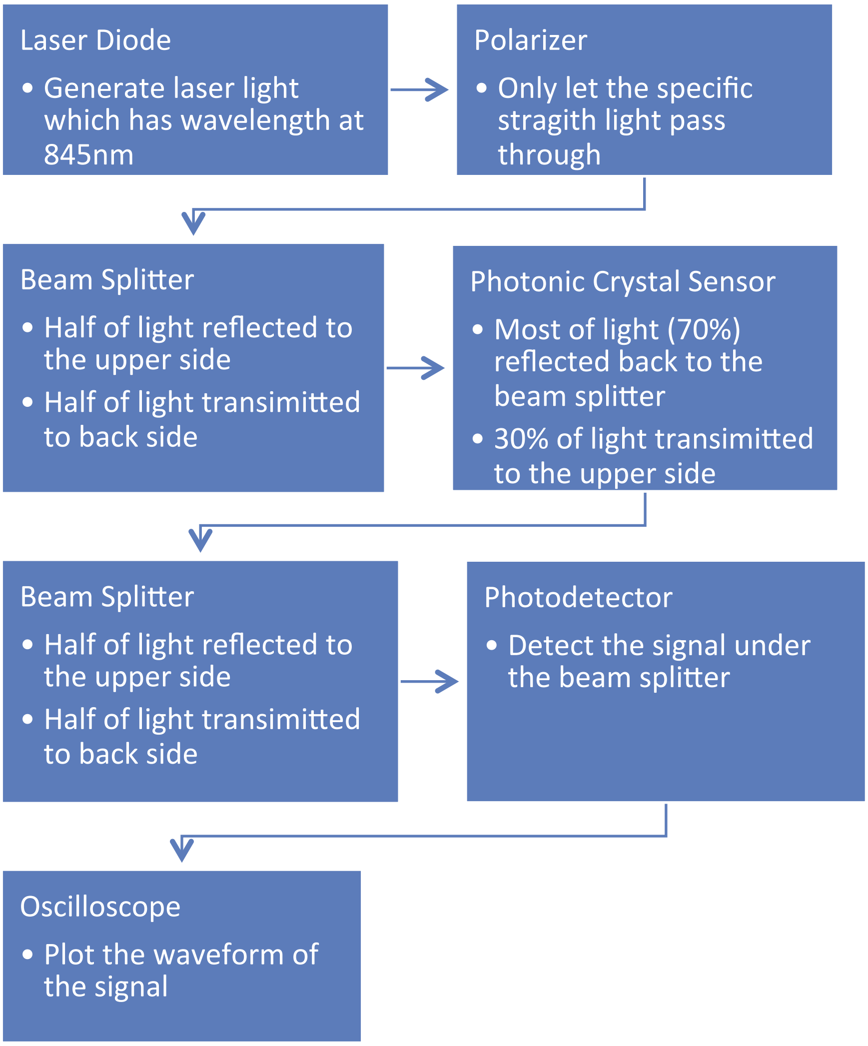
The next equipment is the polarizer. As we introduced before, polarizer can let the specific wave pass through and block other waves. Here we use it to let the 845nm wavelength straight light to pass through and block others.

An optical beam splitter has been held by the post. We adjust the position of the beam splitter to make sure that it locates at the same axis with the laser diode and polarizer. Then slightly adjust the height to make sure the incoming light after polarizer part can be exactly reached the beam splitter by the mid-center point. The light will be splitter to two beams, one of them will be transmitted to the back side of the splitter and the other beam will be reflected to the upper side.

Above the upper side of the beam splitter, there is an aluminate sample holder. There are four posts to support it and we use assemblies to install in on the plate. We want to make sure it never moves. The sample holder has an open hole at the center point.

We staple the photonic crystal sensor on to a glass slide and then attached the glass slide onto the hole. During this process, we need to make sure the round sensor sample is just above the hole.

4.1.4 Measurement procedure for the acoustic wave



As we turn on the power supply for the laser diode, an invisible laser light will be generated and it will go straight to the next part. Since the polarizer can let the specific wave of light pass through and block other waves, so all the light after the polarizer will be straight light which in the right wavelength range. Then it will continue to go into the next part which is beam splitter. The light will be splitter to two beams, one of them will be transmitted to the back side of the splitter and the other beam will be reflected to the upper side. As light comes in from the upper side of the beam splitter reaches the bottom side of the sensor, then the sensor will transmit part of the light and reflect most of them back to the beam splitter. Then the light will be splitter other two beams again. Half of them will be reflected to the laser side, and the other half of them will be transmitted to the bottom side.

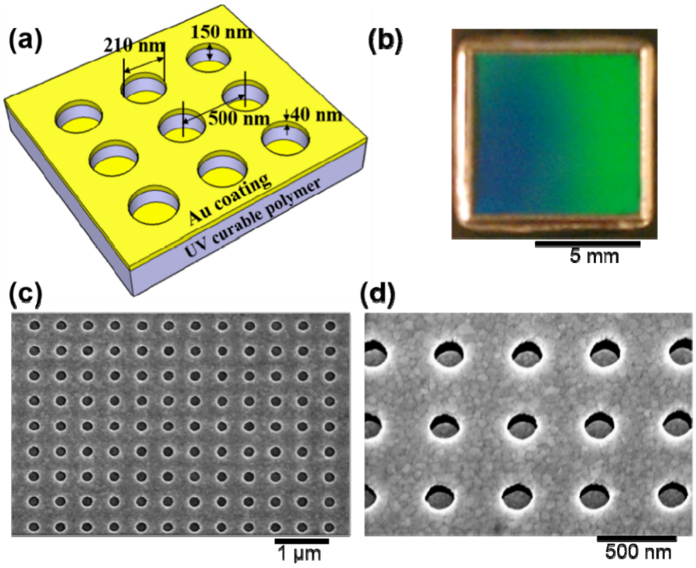
We put the acoustic wave transducer into the sample holder via a large post and put it right above the photonic crystal sensor. The acoustic wave transducer should be as close to the sensor as it can be. Then we add some water into the sample holder to make sure that the transducer and the sensor can be merged. The reason of this is not only to adjust the sensor's highest reflection wavelength to the right range, but also to protect the transmission of the acoustic from loss and disturbance. After this, we will turn on the power supply of the acoustic wave transducer. It starts to oscillate now. The oscillation will cause the resonance with the sensor (which briefly introduced in section 4.1).

We assembled a photo detector under the beam splitter, so the photo detector can detect the light which transmitted to the bottom side. The photo detector is connected to an oscilloscope via the BNC clue. Now we can observe the output results from the oscilloscope, to analysis the waveform of the acoustic wave.

4.2 Methods of ultrasound generation

4.2.1 Fabrication of plasmonic substrate

To prepare the plasmonic substrate, a 500nm thick polymer (J91) layer, with 2D arrangements of air holes spaced every 210nm, is fabricated on a polymer substrate by using nanoimprint lithograghy. A 50nm layer of gold is deposited on top of polymer structure using an electron beam evaporator.



(a) The three-dimensional view of the gold nanostructure. (b) The top-view of the coating on the surface of gold nanostructure. (c) & (d) The top-view of the nanostructure under microscope.

PDMS (Polydimethylsiloxane) is an elastic polymer that is used as a key part in the procedure of fabricating the fiber tip sensor. Due to its low elastic modulus, or high deformability, flow delivery will occur during the impact between PDMS and optoacoustic wave.

To prepare gold nanostructure, we place UV curable polymer (UVCP) onto the master mold and have it nipped with a glass coverslip. The UVCP is then poured onto the master mold where it creates a conformal coating. The mixed component is then exposure under the UV light for 300 seconds. After curing, the daughter mold (glass coverslip) is peeled off the master mold. Then the coverslip with coating is spanned with PDMS for 15minutes at 6500rpm in order to create a 10um PDMS layer. [9]

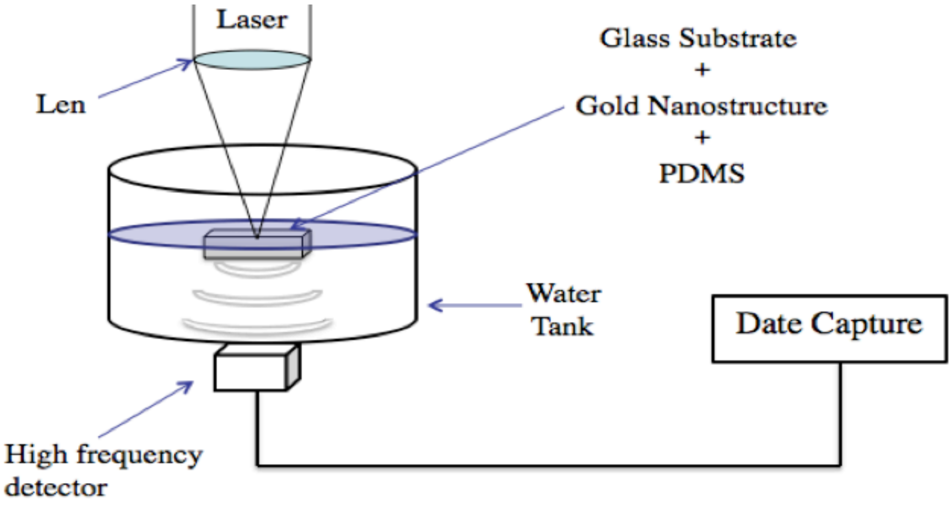
4.2.2 Simulation of the plasmonic resonances

Optical reflection measurements are done using spectrometer with transmitted light coupled into an Ocean Optics fiber. Because the absorption of the plasmonic substrate depends on the incident laser wavelength and the angle of incidence of the laser beam on the surface of plasmonic substrate, we expect the light absorption to change with the incident angle of laser beam. With the laser system at 532nm, we are able to change to incident angle of laser beam and measured the light absorption of plasmonic substrate at different angles.

The absorption of light of plasmonic substrate measurements are done using powermeter with laser beam coupled into an Ocean Optics fiber. With the adjustments of incident angle of laser beam on the surface of plasmonic substrate, we are able to find at which angle the maximum absorption of light occurred and the amplitude of power at different angles.

4.2.3 Setup for the ultrasound generation

The experimental setup for high frequency generation of ultrasound is shown as follows.



The fabricated plasmonic substrate device will be characterized, which will be used to demonstrate the effort of high frequency ultrasound generation using pulse laser. A transparent water chamber is perforated into two holes. The plasmonic substrate is mounted on the one side of surface of chamber and illuminated with an exteranal pulsed laser system. Nanosecond laser pulse (5ns pulse width) is produced through intensity-modulation laser diode, which can induce high frequency (about 10MHz) ultrasound in the water through laser induced thermoelastic expansion of the PDMS layer on top of plasmonic substrate. The laser generated ultrasound signal will be evaluated with a built-in piezoelectric transducer in the water chamber, which will be used to measure the pressure level of induced ultrasound. In order to evaluate the ultrasound generation using plasmonic substrate, the substrate is operated with different angles to induce ultrasound signal, which will be used to compare with each other to determine the factor of laser-ultrasound generation via plasmonic substrate. Therefore, a rotation stage mounted at bottom of water chamber, which is easy to determine the angle adjustments and the prediction of the factor of laser-ultrasound generation via plasmonic substrate.

4.2.4 Measurement procedure for the ultrasound generation

At a particular resonant wavelength or incident angle, the incident white light can be coupled into gold nanostructure. The resonant transmission peak is accompanied by dispersion, which can lead to a reduction in the group velocity of the transmitted light. This characteristic of gold nanostructure can be used as light trapping and enhancement in the process of ultrasound generation.

An optoacoustic structure, which consists of a 2D gold nanoparticle array nipped between glass substrate and 10um PDMS layer. When a pulsed laser beam is focused onto the gold nanostructure layer through the glass substrate at the resonant wavelength, a large fraction of incident energy is absorbed. The light energy is converted to thermal energy with a localized volume and transferred over a very short time interval from the light-absorbing layer to PDMS, resulting thermal expansion that launches an acoustic pulse. The acoustic pulse is then captured by photodetector and resolved by oscilloscope.

5. TESTING & RESULTS

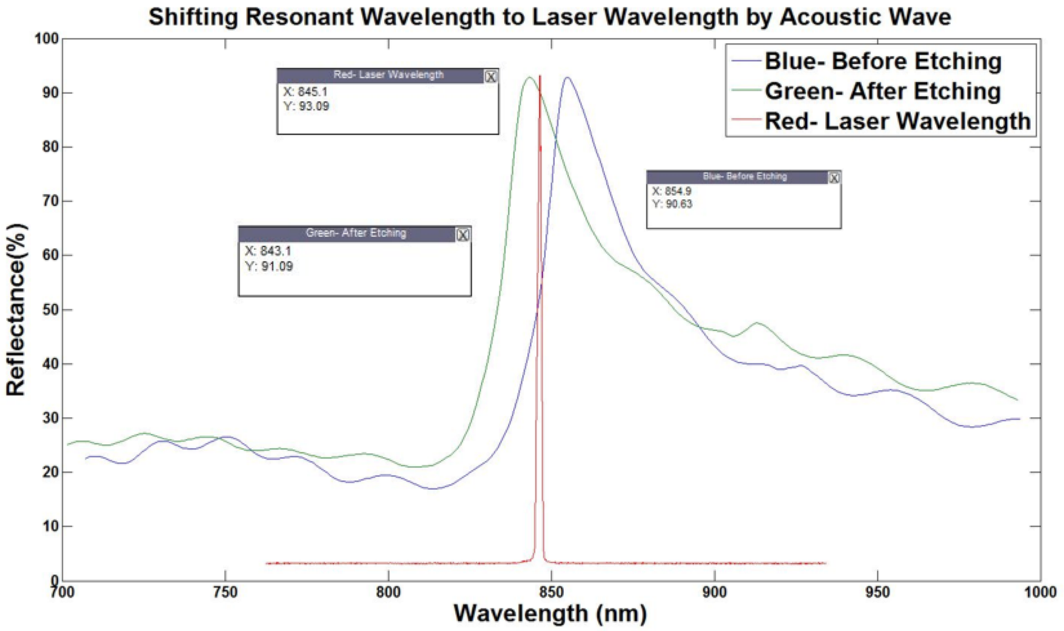
5.1 Testing & results of acoustic wave detection

5.1.1 Characterization of the photonic crystal structure

Since each photonic has tiny difference in resonant wavelength (like 0.1nm), which is negligible. We therefore treat the whole piece of photonic crystal as a single large photonic crystal. However, the average resonant wavelength of photonic crystal is around 830 nm and 855.5nm in water. The experiment needs water as medium for the change of refractive index. The laser we use, is 845 nm that is 9.5 nm off. Because the thickness of the TiO2 has some effect on resonant wavelength (the thicker, the higher resonant). Thus, we need to etch some thickness off from the photonic crystal so that the resonant wavelength decreases and match to desire wavelength. We use HF acid to etch, and the time we use has a relationship to resonant wavelength of photonic crystal in water:

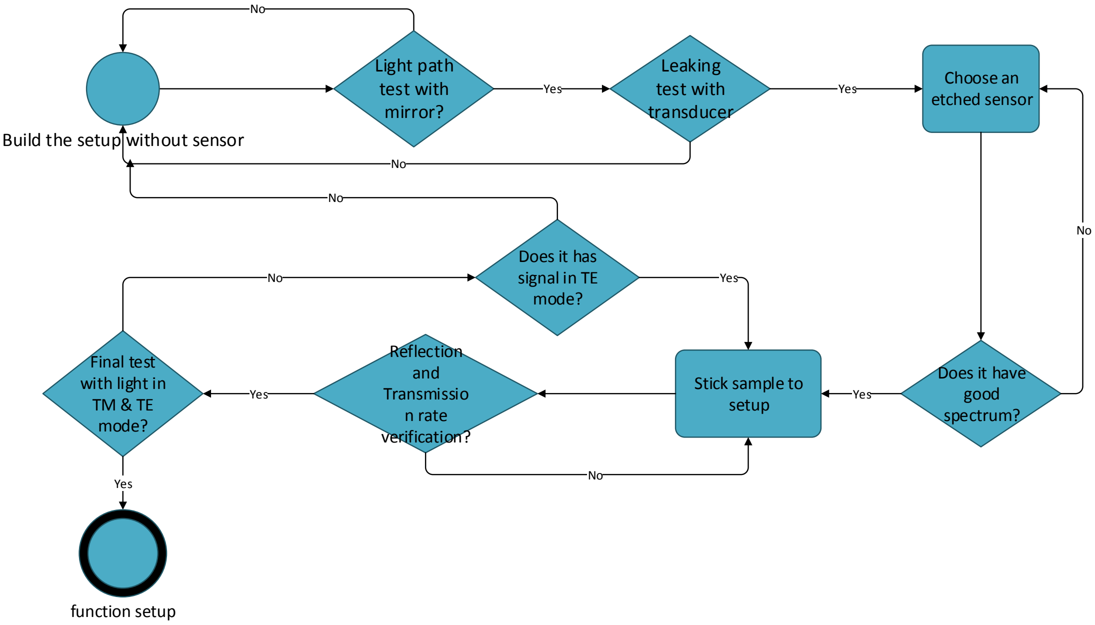
time vs wavelength	**wavelength**
2minutes	850 nm
3minutes	848 nm
3minutes and 30 seconds	845 nm
3minutes and 35 seconds	844 nm
3minutes and 40 seconds	843 nm
3minutes and 50 seconds	842 nm
4minutes	840 nm
5minutes	836 nm

Actually, we did not use the exactly 845 nm sample. This is because the at the peak, the slope around peak is flat which affect our result. At 843 nm, the sample we achieved has the best result.



5.1.2 Preliminary test of acoustic wave using the photonic crystal

In order to have an effective design, testing is a key point that should be processed very carefully. When we are dealing with the setup, we found that even a very small change to the incidence angle would cause a sharply decrease in our sensitivity of the whole setup. Besides, our group members used to always go back for verifying and modifying to target errors. All these evidence shows having a clear plan for testing is very important. So, we make a testing procedure for group member to do the test step by step. Doing the setup in this way not only shows our setup works functionally, but also avoid targeting the possible error and mistake that would influence our final result. Finally, normative testing procedure gives member a quite clear idea about testing progress.



This block diagram has helped us in building our setup. Especially in trouble shooting. Having the ability to break down the system into blocks and isolate the errors has proven to be very difficult but effective. In addition, the TE & TM mode test is really help test. It separate the problem caused by the setup itself and the sample error. Usually, there will be a mismatch caused by the sample we use since we cannot control the exact etching time for every single sample in the whole piece. Also the wet etching is not uniform, so there can be a variation between them. Besides, when the transducer is working, setup will be more or less influence by the vibration it causes. So, we usually have no idea about where is the failure come from. However, with TE & TM mode testing, we can confidently point it and modify it.

5.1.3 Numerical simulation results

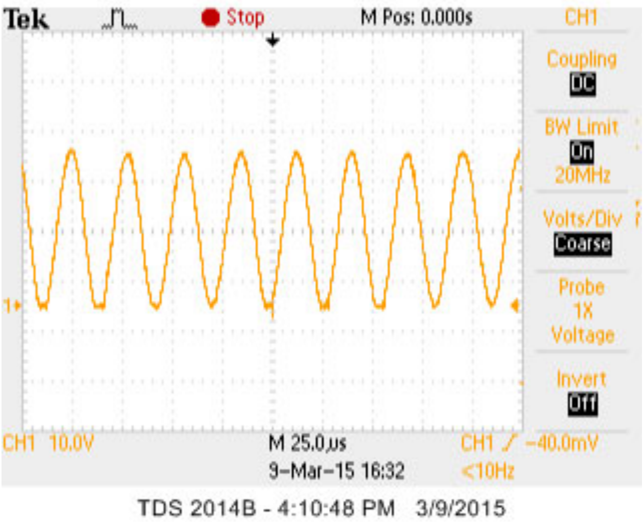
In order to test our system once we completed it, we use a 40K transducer to test it. Both frequency and output magnitude are fixed for this 40K transducer. This means we cannot change the frequency or output magnitude to test the performance higher or get the lowest possible input magnitude of our setup. However, it also means that the output is reliable, it need have no variation to the output.

The main instruments used for the test setup can be seen in the table below.

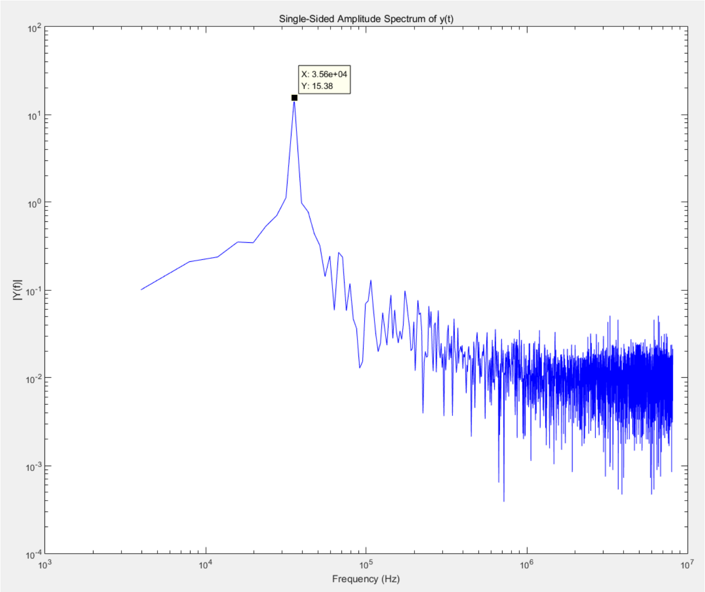
Instrument	Model	Usage
Power meter	Thorlab PE320E	Power measurement
Oscilloscope	Tektronix MSO2014B	Capture the output voltage

Test 1

For first test, I use the high frequency testing equipment to get the waveform of our transducer as a reference to the fallowing testing result since we will use this transducer to test out setup.



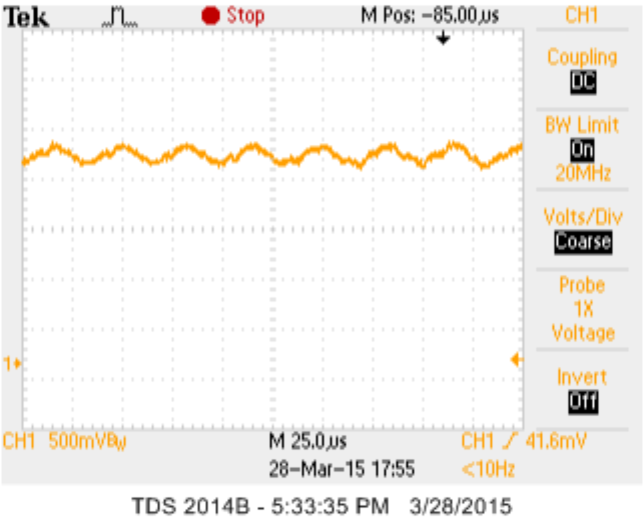
According to the waveform as well as the data we captured from the Oscilloscope, I plot out the Fast Fourier Transform (FFT) result by MATLAB. By the FFT result, we can identify its performance at frequency domain quite easy.



From the frequency spectrum we can find out the frequency of the transducer is 35.6KHz.

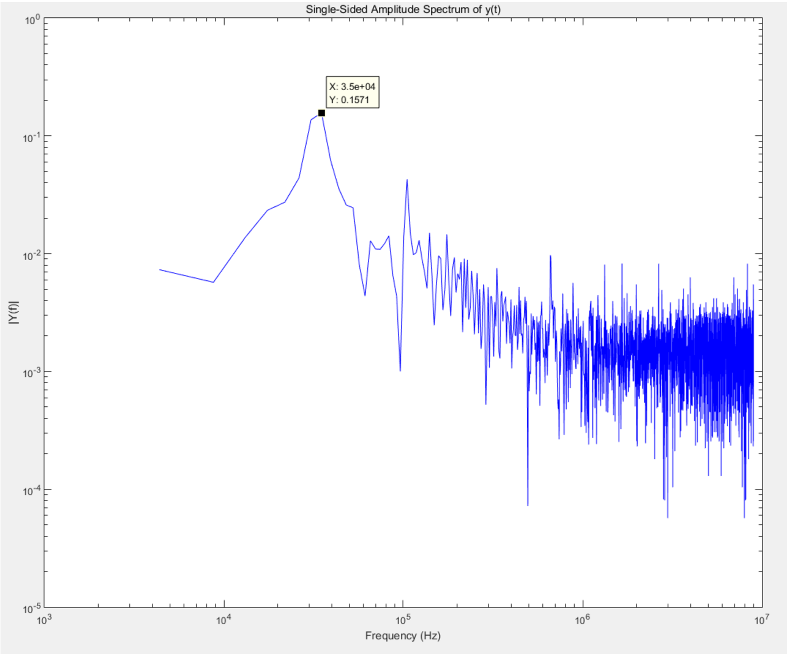
Test 2

The next test was to see if we could capture the waveform of the transducer by out setup. To get the best performance we get use the polarized light from polarizer. In this test the light is in TM mode respected to photonic crystal.



M Pos: -85.00µs
CH1
Coupling DC
BW Limit On 20MHz
Volts/Div Coarse
Probe 1X Voltage
Invert Off
CH1 500mV
M 25.0µs
CH1 ∕ 41.6mV
28-Mar-15 17:55
<10Hz
TDS 2014B - 5:33:35 PM 3/28/2015

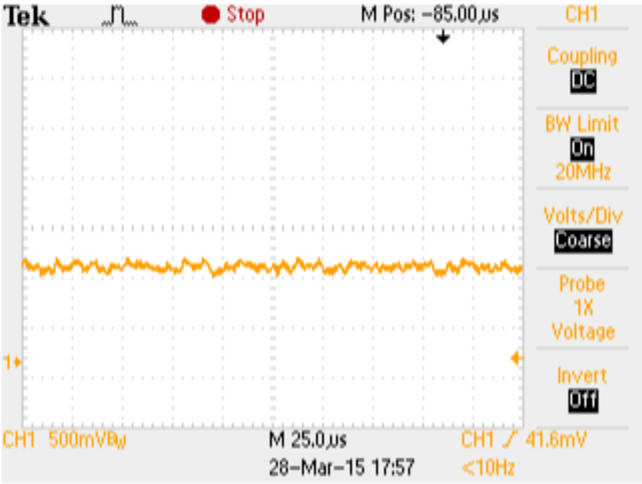
I also plot out the Fast Fourier Transform (FFT) result by MATLAB. By the FFT result, we can compare the waveform we get with its transducer's performance quite easy.



From the frequency spectrum shows that our result (35 KHz) is very close to the frequency of transducer which is 35.6 KHz.

Test 3

To make sure that the result is coming from the reflection rate change due to the vibration of water. We repeat the Test 2 which TE mode respected to photonic crystal. This test should give us no output waveform. And here is output result:



M Pos: -85.00µs

CH1

Coupling DC

BW Limit On 20MHz

Volts/Div Coarse

Probe 1X Voltage

Invert Off

CH1 500mV Bw

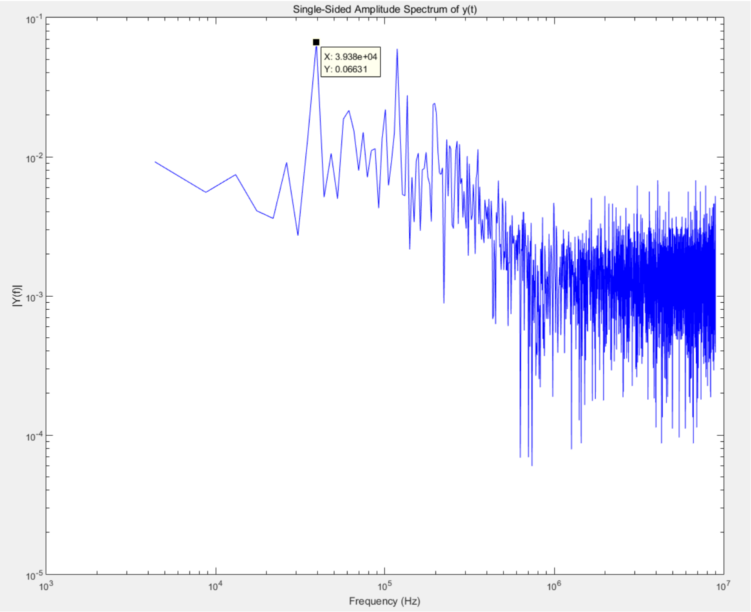
M 25.0µs

CH1 ⁄ 41.6mV

28-Mar-15 17:57

<10Hz

TDS 2014B - 5:36:04 PM 3/28/2015

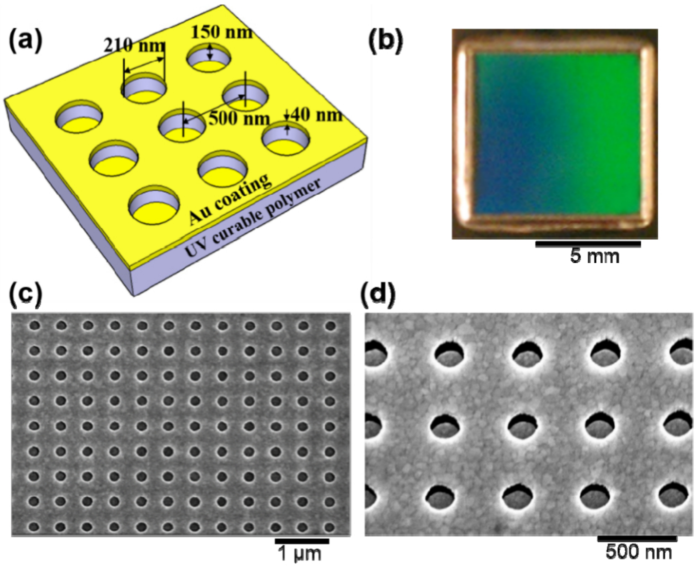


From the FFT result we can figure out that the vibration caused by transducer will have some influence in output at the same frequency. It's mainly because the vibration would transmit to the sample holder so that photonic crystal itself would have a slight displacement at the same frequency of our input waveform. However, the magnitude of this sample holder vibration based result is 10 times smaller than the result we want.

5.2 Testing and results of ultrasound generation

5.2.1 Fabrication of the plasmonic substrate

As we demonstrated above, the gold nanostructure is comprised with a 500nm thick polymer (J91) layer, with 2D arrangements of air holes spaced every 210nm, is fabricated on a glass coverslip by using nanoimprint lithograghy. A 50nm layer of gold is deposited on top of polymer structure using an electron beam evaporator.



(a) The three-dimensional view of the gold nanostructure. (b) The top-view of the coating on the surface of gold nanostructure.   (c) & (d) The top-view of the nanostructure under microscope.

5.2.2 Characterization of the plasmonic substrate

Optical reflection measurements are done using spectrometer with transmitted light coupled into an Ocean Optics fiber. In the Fig.1, reflection through the nanostructure varies with wavelength.

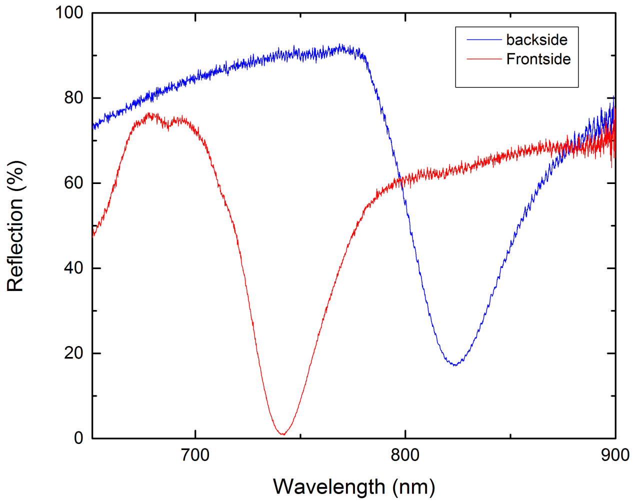


Fig.1 Optical reflection vs. wavelength

The reflection of the reflected light from frontside and backside of the plasmonic substrate are measured. Maximum reflection (minimum transmission) occurs at 745nm on frontside and at 825nm on backside. There is a factor of 4.5 greater transmission at 780nm compared to 825nm on backside. Likewise, there is a factor of 7 greater transmission at 670nm compared to 745nm.

Because the absorption of the plasmonic substrate depends on the incident laser wavelength or incident angle and the amplitude of the output acoustic wave should be a linear function of the absorbed energy, we expect the wavelength of the pulse laser system is identical with the resonant wavelength of plasmonic substrate. With our pulse laser system, we are able to generate a 5ns laser pulse with energy of 25mJ at 1064nm. Since the wavelength of pulse laser system and the resonant wavelength of the sensor cannot be changed, the incident angle of laser beam seems to be the only option that can make both wavelength to be identical.

Fig.2 shows the detected reflection of the reflected light from the frontside of the plasmonic substrate, for optical excitation at 745nm. In comparison, the detected reflection from the frontside of the sensor at 15 degree is shown as well. The reflection deep makes a shift to 866nm as we expect, since 866nm is closer to the wavelength of the pulse laser system. Further measurements of reflection spectrum above 900nm cannot be made due to the limitation of detecting range of spectrometer. That brings us a significant trouble in the procedure of making the resonant wavelength of plasmonic substrate and wavelength of laser beam are identical.

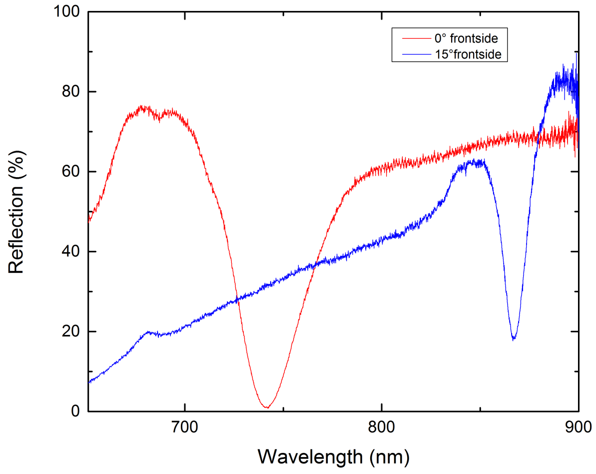
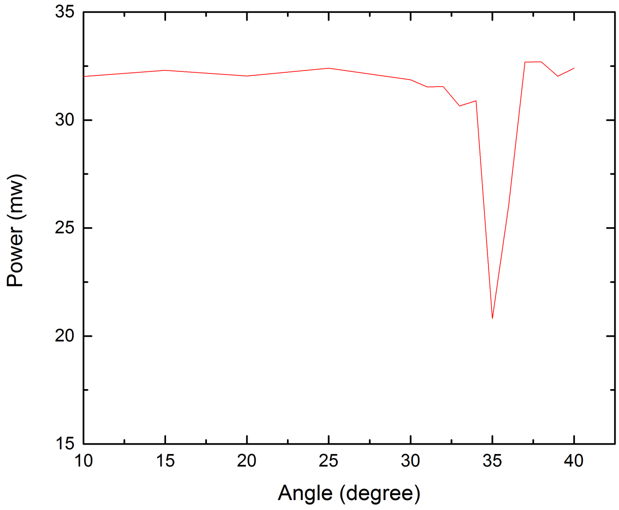


Fig.2 Optical reflection vs. wavelength

As we've discuss before, the amplitude of the output acoustic wave should be a linear function of the absorbed energy, the power of absorbed light is necessary. The laser beam at 532nm is focused on to the plasmonic substrate and the measurement of the power of reflected light is shown in Fig.3.



According to Fig.3, the maximum reflection occurs at 35 degree between the laser beam and the plasmonic substrate, and approximately 35% laser energy can be absorbed by the substrate. Although the plasmonic substrate is not able to absorb 100% of the laser energy, we believe that the light absorption from the plasmonic substrate is still capable of producing thermal energy based on out high power pulse laser system. The heat transition time from the gold nanoparticles to PDMS is about 100 fs, which is much shorter than the pulse duration. Fast heat transfer like this will generate ultrasound with higher frequency components.

5.2.3 Preliminary test of generation using plasmonic

The procedure of ultrasound generation is attempted via the optical setup that we've developed. It seems that the laser pulse generated by the laser system cannot be capture by the oscilloscope due to the limitation of response time. More testaments may be taken in the future.

6. Discussion

6.1 Timeline

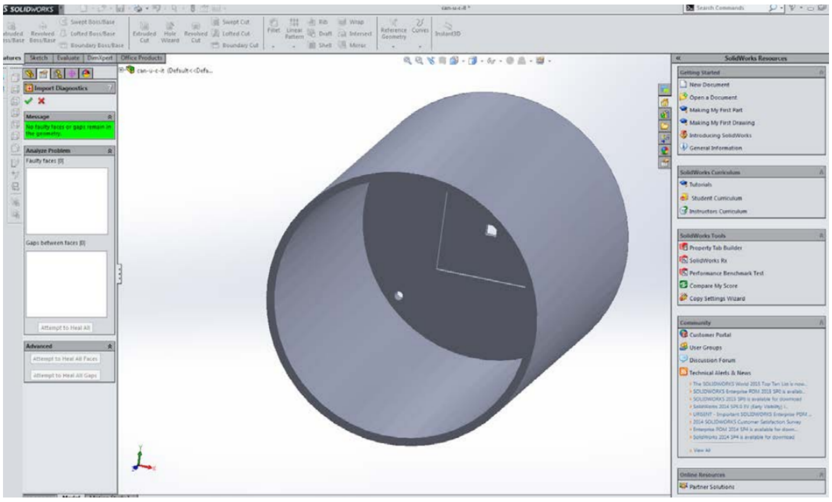
Fall2014 Week1	• Get started with the senior design project • Get familiar with the key idea
Week4	• First Version of sample holder has been made via 3D print • Test the wavelenght for PDMS & J-91
Week7	• Get power supply for acoustic wave transducer • Setup for acoustic wave transducer • Attach sensor sample onto the sample holder
Week11	• Laser diode has been installed • Setup for detector almost complete
Spring 2015 Week1	• First test for detection setup • New idea for generation part
Week3	• Etch sample to adjust the most useful wavelength • New idea for sample holder
Week5	• First version of data for acoustic wave generator • Anaylsis the input and output waveform
Week 7	• Testing the detector parts • Get nice results for this part
Week 10	• Get start with the final documentation materials • Get start with the final presentation preparing
Week 14	• Finished poster design • Get ready for final presentation & demo!

6.2 Design Story & Brain Storm

6.2.1 3D Printed Sample Holder

The sample holder (water tank) is designed to hold the photonic crystal sensor. At the first beginning, our team thought that this might be an easy part for our project. We first used Solidworks and designed a 3D sample holder. Then we sent this file to Design college and used 3D printer to get the prototype for the water tank. The reason why we use 3D printer to printer the water is we think we would use some fancy technology used in the project. The distance between each hold at bottom is 3 inches, the height of water tank is 5 inches and the diameter of bottom is 6 inches. There is a 3D printer inside the Design College. The time the printer need to work is 12 hours, also the printer can work overnight.

The principle of 3D printer is injecting cell on different layer. First, the probe eject some plastic cell on the first layer. Second, the probe inject the cell on the second layer to make the basic structure. Third, the probe eject on the third layer to make the final structure. There is some time between each layer to cool the layer down. When the probe just eject the plastic cell onto the layer, the temperature of layer is very high and it is very easy to make a shape. When the layer cools down, the shape is solid, thus the probe can keep on ejecting to make the other layer.


No faulty faces or gaps remain in the geometry.

Faulty faces (0)

Gaps between faces (0)

Advantage of 3D printer:

The 3D printer take convenient to the operation. In the project, if we need something with specific shape and 3D printer can print any stuff for us. The benefit is we don't need to buy things online, we can make any idea become realistic with 3d printer technology.

Disadvantage of 3D printer:

The 3D printer is not well developed and the price is relatively expensive. The water contain I printed is $90. However, the same size on amazon is just $6. Second, the material used in 3d printer is not very well, it is plastic, which means the material is easy to break. Also, because of different layer. There is tiny space between each layer. When we use water tank to hold water, there is some drop comes out through the tiny space.

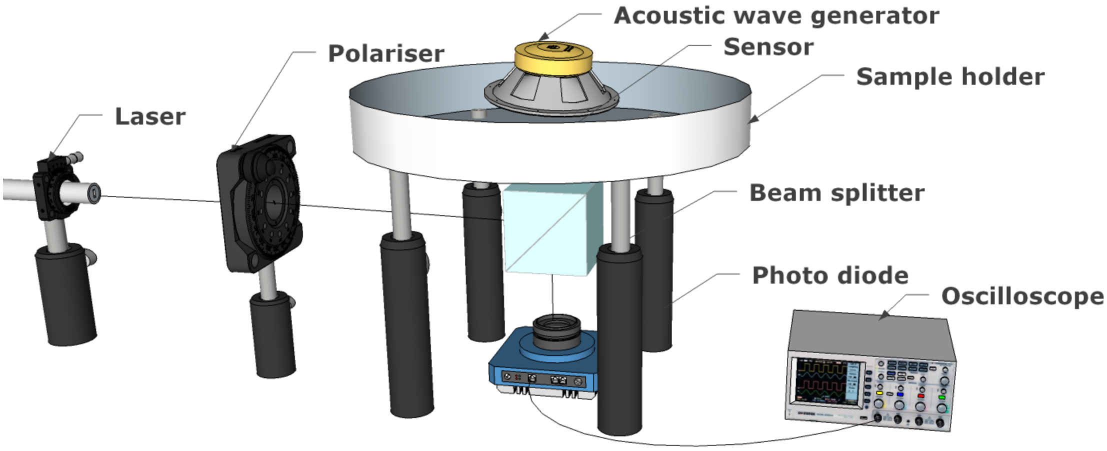
6.3 Challenges & Discard ideas

6.3.1 Al Sample Holder

The time of 3D printed sample holder was at the very beginning of the first semester. But till the second semester, when we got to the testing process. We tried to add water in it to cover the photonic crystal sensor. The water sinks. It takes us couple days to get out of this trouble. The 3D print center used is really not good to work with water. Also, after four to five months, the materials get aging and it's not tight enough anymore. We had to choose another kind of materials. We change the plan and choose to use an Al water tank. The Al one works pretty well and it is much robust than the 3D-printed one.

6.3.2 Alignment and Optical setup for detector

The alignment for the optical setup is always a big problem. It is the most important step for our whole project. As mentioned before (sect 4.3.1), we need to build an optical setup to achieve the function of an ultrasound detector.



Our team wants to make sure that the centers of the laser diode, polarizer and beam splitter are on the same horizontal line. So that we can make sure the laser beam can directly reach the center of the sensor which lays on the center of the sample holder. Furthermore, we can make sure the reflection lights detected by the photo detector is reached at the center point. We are trying to eliminate the loss of light and power.

But the alignment is very hard to adjust, since all the components can move in three directions. We tried a lot to keep them in the best detection way. It takes lots of time and really need patient.

7. Conclusion

In conclusion, our team developed an ultrasound detector using the photonic crystal based on the characterization of the PC structure. This PC structure is comprised of a sub-wavelength dielectric grating, which selectively reflects light at a particular wavelength, known as the PC resonant wavelength. When the PC is illuminated with a broadband light source at a particular resonant wavelength or incident angle, interference occurs and nearly no light is transmitted, where we can see a peak shown in the reflection spectrum. Acoustic wave can result in a shift of resonant wavelength due to the compression of the superstrate material. And the shift in resonant wavelength would cause a change in reflection rate in any selected wavelength near the peak of the reflection spectrum. So we use a laser beam to illuminate the photonic crystal sensor. Wavelength of out laser beam is fix in 845nm and it has a very narrow bandwidth. If there is any reflection rate change in this particular wavelength, the power of reflected laser will change. In order to capture this change in light power, we decide to use photodetector. The photo detector can convert light intensity into voltage level.

After finishing implement the high-frequency ultrasonic detector by an optical setup, our team use a 40 kHz acoustic wave transducer to test the detector. We already have the waveform for this 40 kHz wave as the reference data, then we obtain our test results by using our optical setup based ultrasonic detector. The results shows that these two waveform are matched which have same period and same characteristic. Which means our high-frequency ultrasonic detector works well.

8. Reference

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