Fabrication and testing of the smallest "flute" on syringe needles

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ABSTRACT

Nowadays, lasers, as innovation tools, provide extraordinary opportunities in a wide range of material processing and manufacturing applications. Here, we present using an ultra-short laser to fabricate a flute in a university's lab on a syringe needle. By finely controlling the laser power and drilling time, holes can be drilled at one side but not penetrate the whole needle. With a set of holes arranged in a straight line, the needle acts as a "flute" when the gas flows into it. A microphone measures its acoustic frequency. Different tones were observed by changing the resonance length of the needle. Our work demonstrates the fabrication and testing of miniature flute on a syringe needle.

Keywords: laser processing, needle flute

1. INTRODUCTION

With the development of the laser technology, laser nowadays has been used universally not only in the lab to run experiments but also in the industry to process products. Laser processing refers to the use of laser beam projection to the surface of the material produced by the thermal effect to remove, melt material and change the surface properties of the object to complete the processing [1]. Comparing with the traditional manufacturing process, laser process is more time efficient and more precise even in the most delicate conditions. Including cutting, drilling, engraving and welding, laser process has been utilized on the products directly related to our lives [2]. In recent years, laser could even be used to do delicate processing on nano-scale materials [3].

Here, we built a millimeter scale “flute” by using a Ti: Sapphire laser to drill multiple holes on a metallic needle in our university’s research lab. The needle used in this experiment is made from a metallic hollow cylinder attached to a plastic holder. The processed needle was then flowed with nitrogen gas to produce multiple acoustic frequencies. The different frequencies were also observed by inserting a small screwdriver to change the resonance length of the needle.

2. PROCESSING

2.1 Experimental setup

The processing procedure includes drilling and monitoring parts as shown below in Figure 1. For the drilling process, the laser used to drill holes on the needle is Mai Tai Ti: Sapphire laser with wavelength 800 nm, pulse width 100 fs and average power 500 mW. The laser was first weakened by an attenuator and then focused on the needle to drill holes by a lens with a focal length of 3 inches. The needle has an out diameter of 1.81 mm, inner diameter of 1.65mm and thickness of 0.08mm. The needle was fixed on the controlling stage, which be moved back and forth, left and right, up and down. For the monitoring process, a flashlight was used to increase the brightness on needle’s curved surface since the light reflected from the drilling process is not bright enough to see clear image from the CCD camera. Another attenuator was used to weaken the laser power to protect the CCD camera. Two lenses with focal lengths of 5 inches and 2 inches were used to focus needle’s image on the CCD camera.

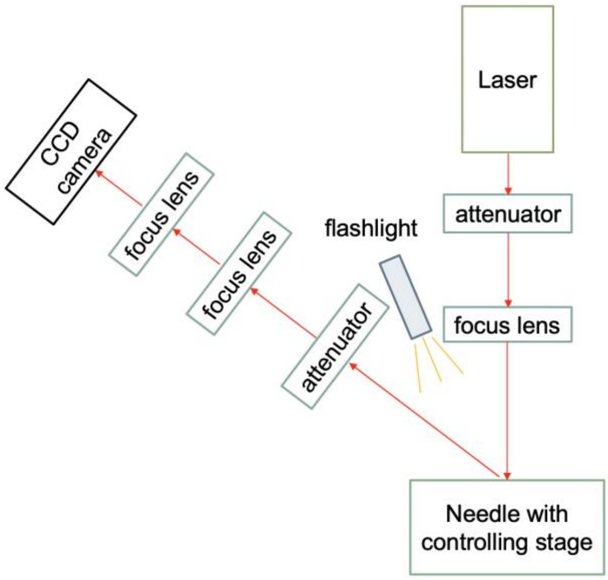

Figure 1. Experimental setup of the drilling (right) and monitoring (left) process.

The major problem in the drilling process is to find out the proper laser power and matched drilling time. The laser will penetrate both sides of the needle within a few seconds if the power is too strong but will produce burn marks on the surface and take a long time to drill hole if the power is too weak. To solve this problem, the laser power was first attenuated to a level that will not cause burn mark and take a relative long time to run through both sides of the needle and the penetrate time was measured. Then gradually decrease this drilling time until laser only puncture one side of the needle, the proper laser power and drilling time were therefore ascertained.

2.2 Drilling and monitoring process

When starting the drilling process, the needle was first adjusted to the position that the laser will hit the top part of it by the controlling stage. The needle's real time image from CCD camera was used to determine the drilling position as shown in Figure 2 (left). Since the needle is not perfectly straight in shape and we want each hole to have the same distance, red dashed lines and circle on the figure were drew to mark the positions of needle and hole after the first drill. The needle was then raised up and rotated to fit in the dashed lines, after that, laser under a very low energy was focused on the needle and a further adjustment of needle's position by the controlling stage will ensure the laser was focused within the circle. After that, the laser energy was increased and create plasma to drill the new hole as shown in Figure 2 (right). By using this method, a sequence of holes with same interval (2 mm) was drilled in a straight line on the needle. Figure 3 (left) is a snapshot of the processed needle under a microscope taken by a cellphone camera. The hole on the needle has a diameter of 150um as shown in Figure 3 (right) taken by an optical microscope.

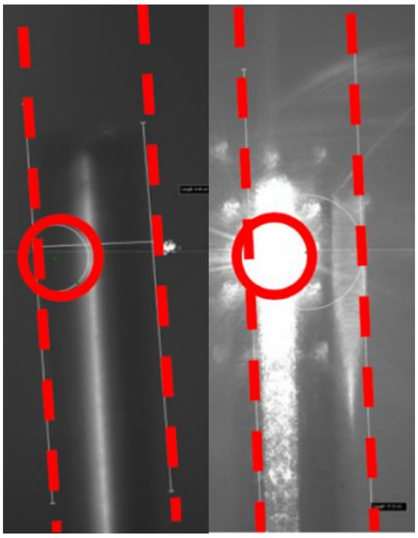

Figure 2. Images of the needle from CCD camera before (left) and during (right) the processing.

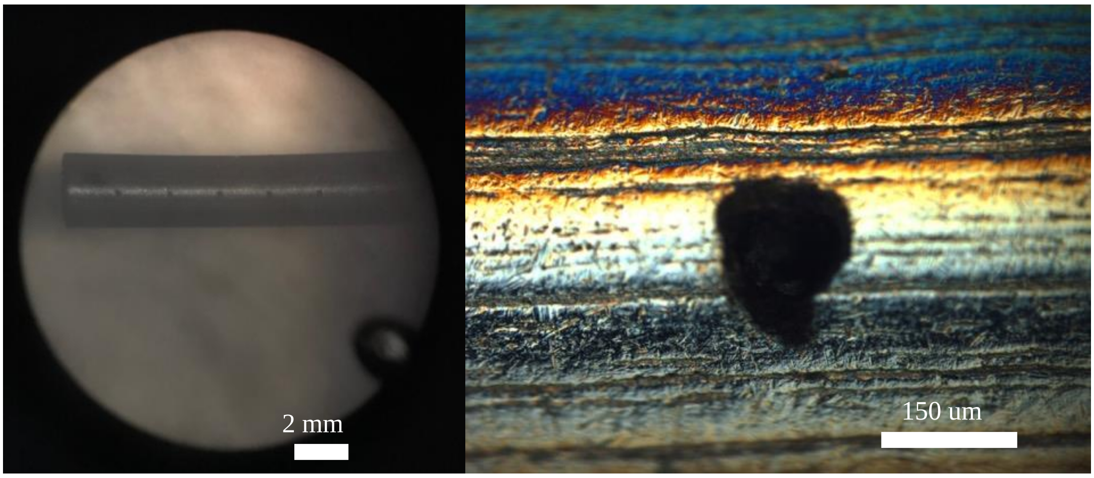

Figure 3. Needle after drilling a set of holes (left) and a closer look of one hole (right).

3. ACOUSTIC DETECTION

3.1 Whistle type

After drilling several holes on the metallic needle, it is time to test whether the processed needle can be used to generate acoustic frequencies. There are two types of sound generations can be applied on our needle: whistle and flute.

The whistle type does not require holes on the metallic part and could only be used to generate a single frequency. The structure was patterned from a bamboo slide whistle online [4] and shown as Figure 4 below, the whistle model needs a hole on the bottom plastic part as a sound production hole and the pinhead was been plugged. To produce sound, the gas (nitrogen in this experiment) enters a gradually narrow gap from the blowing hole at right, then it speeds up at and cut by the slope structure at the sound hole, causing high-speed airflow disorder, after that, the turbulent airflow enters the resonance chamber and resonates, the acoustic frequency was generated and detected at sound production hole. An oscilloscope connected with a microphone were used to detect the sound frequency as Figure 5. The environment frequency is 10.38kHz as shown on the oscilloscope and the whistle frequency is 3.38kHz.

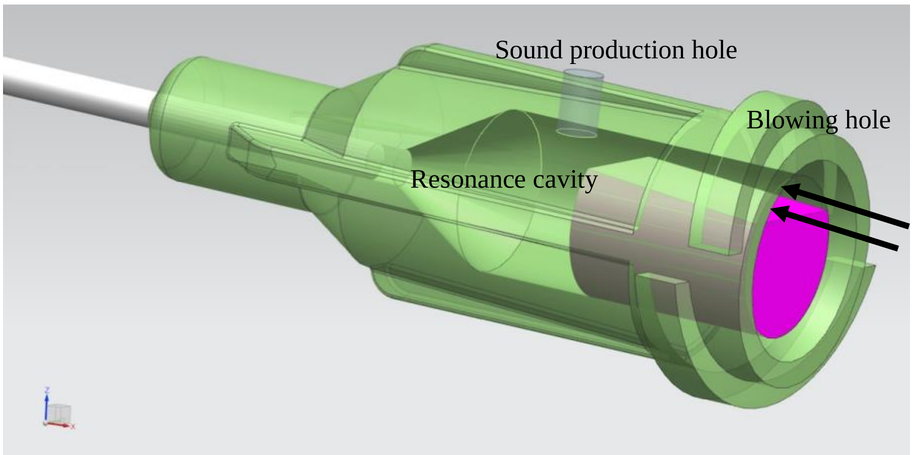

Figure 4. 3D model of the needle produce sound as whistle type. The gas flows in at the blowing hole and the sound comes out from the sound production hole.

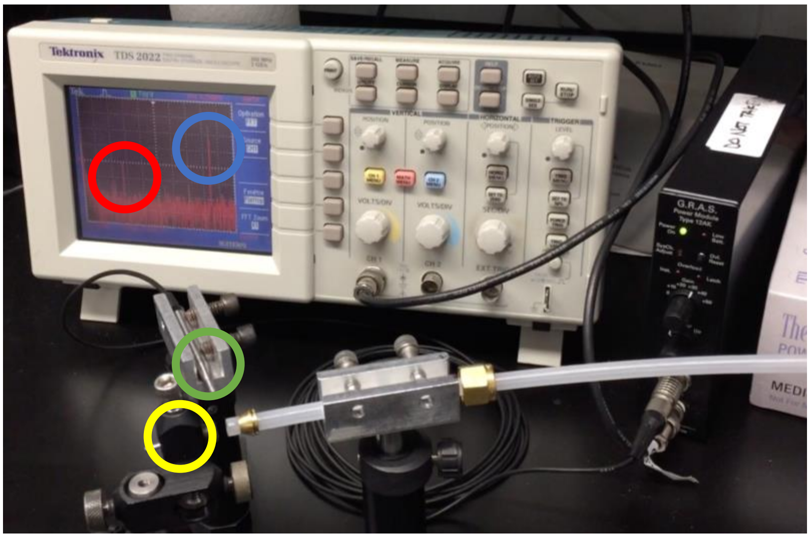

Figure 5. Sound detection for the whistle type, blue circle is the frequency from background (10.38kHz) and red circle is the frequency from the whistle type needle (3.38kHz). Microphone is marked with green circle and needle is marked with yellow circle; the nitrogen gas flows from the tube in the right.

3.2 Flute type

The flute type can be used to generate multiple frequency and the model is shown below as Figure 6. The flute types require a hole on the bottom plastic part as a blowing hole. The sound from flute was produced by blowing the gas and causing the gas enclosed in the tube to vibrate, with multiple holes opened or closed, the flute can produce different kinds of frequency [5]. In our model, frequency change was observed by manually moving a screwdriver inserted into the pinhead back and forth to block or open the holes. Two different acoustic frequencies (5.42kHz and 4.38kHz) were generated from the needle and recorded as Figure 7 and Figure 8 below. The environment frequency is also 10.38kHz as in the whistle type above.

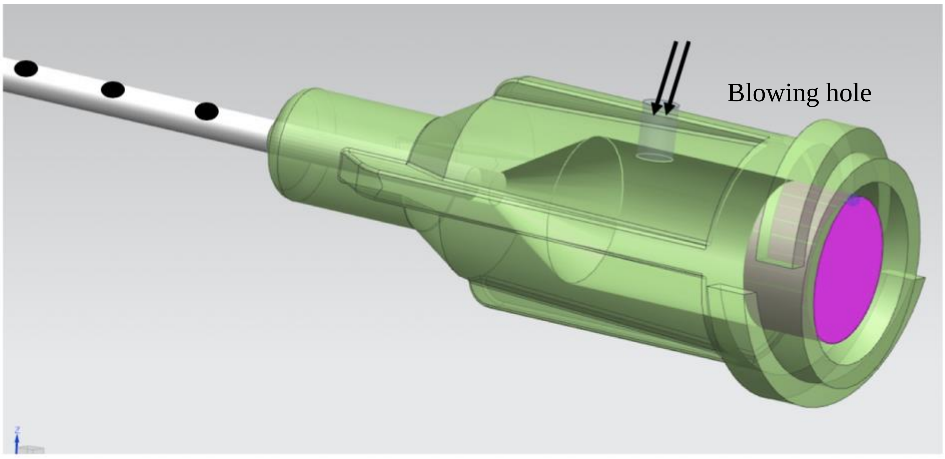

Figure 6. 3D model of the needle produce sound as flute type. The gas flows in at the blowing hole above and sound comes out from the holes on the metallic part.

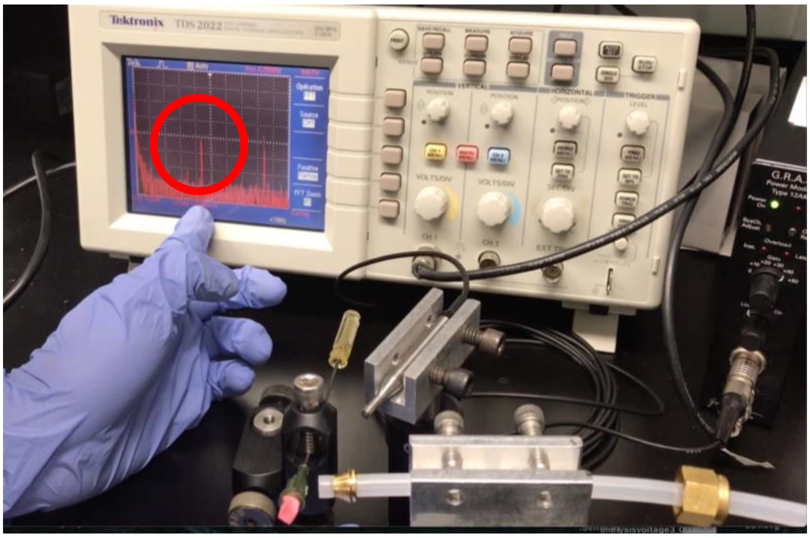

Figure 7. Sound detection for the flute type, red circle is the first frequency (5.42kHz) generated from needle.

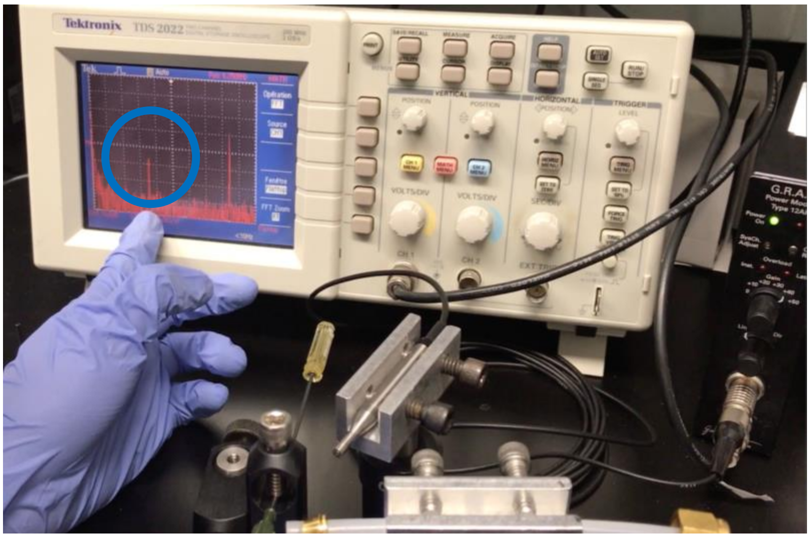

Figure 8. Sound detection for the flute type, blue circle is the second frequency (4.38kHz) generated from needle.

4. DISSCUSSION

In summary, by finely controlling the laser's power and drilling time, a miniature "flute" is made with set of holes on a thin metallic needle. The "flute" produces different detectable acoustic frequency by changing the resonance length manually. To use this needle-based flute to play songs, the holes drilled at the exact location for precious acoustic frequencies are required. From the perspective of music, if in the key of C major, the seven solfege are written as C (do), D (re), E (mi), F (fa), G (so), A (la), B (ti), together with octaves from 0 to 9, they can used to present a tone, this method is called scientific pitch notation[6]. The frequencies produced from both types are between the range of octave 7 and 8, 3.38KHz from whistle type is close to the tone of G-sharp at octave 7 (3.32KHz) ; 5.42KHz and 4.38KHz from "flute" type are close to the tone of F at octave 8 (5.58KHz) and C-sharp at octave 8 (4.43KHz). A further study of the mechanism of the micro-flute, the relationship of frequency with respect to hole size or hole distance and flow velocity need to be studied and considered; the frequencies of basic music notes (scale) on this “flute” and the combinations of different holes opened or closed should be identified in order to make tones from all octaves.

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