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<http://acousticalsociety.org/>**ICA 2013 Montreal****Montreal, Canada****2 - 7 June 2013****Engineering Acoustics****Session 4pEAb: Fields and Devices****4pEAb11. Sound generation using photoacoustic effect**

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It is highly important to generate a point sound source in mid air for several applications such as virtual reality and precise acoustic measurement since most of acoustic theories are based on a point sound source. One possible solution for generating a point sound source in mid air is the photoacoustic effect that generates sounds from the alternate-current components of air expansion due to the heat generated by light absorption of a material when light modulated with acoustic signal is radiated to a material. To apply this method to molecule of gases in mid air, it is possible to generate a point sound source in mid air. Thus, for the first step to realize this possibility, this paper attempt to confirm that it is possible to generate audible sounds using the photoacoustic effect. In particular, this paper describes the sound generation using a charcoal that has high absorptive power and a halogen lamp that can produce high intensity infrared light, which is easier, absorbed by gas molecules than visible light.

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## INTRODUCTION

It is highly important to generate point sound sources in mid air for several applications such as virtual reality and precise acoustic measurement since most of acoustic theories are based on point sound sources. One possible solution for generating point sound sources in mid air is the photoacoustic effect: energy transduction from light energy to sound energy. The photoacoustic effect generates sounds from the alternate-current components of air expansion due to the heat generated by light absorption of a material when light modulated with acoustic signal is radiated to a material. Our research focuses on the sound generation by the photoacoustic effect using infrared light source since molecules of greenhouse gases absorb infrared light. Since greenhouse gases exist in mid air, it has possibility to generate point sound sources in mid air by applying the photoacoustic effect to the molecules of greenhouse gases in mid air.

In this paper, in order to confirm the possibility of sound generation using the photoacoustic effect, experiments of the sound generation with the photoacoustic effect by radiating the light, produced by a halogen lamp, to charcoals that have high absorptive power are described. First, we confirm that halogen lamp can be modulated with an acoustic signal. Next, we discussed about the generation of sinusoidal waves and the musical sound.

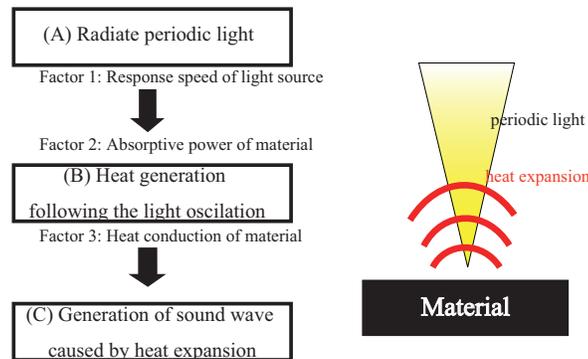
## THE PHOTOACOUSTIC EFFECT

The photoacoustic effect was discovered by Alexander Graham Bell in late 1880 when he was experimenting with long-distance transmission of sound waves. Fifty years later, the photoacoustic effect was re-examined as a well-established technique for gas analysis: so called the photoacoustic spectroscopy (PAS)<sup>1</sup>.

Following the recent development of a laser technology such as femtosecond pulsed lasers and a sound reproduction technology using pulse signals such as a high-speed 1-bit processing<sup>2</sup>, the photoacoustic effect is re-examined as a technique for a sound source generation<sup>3</sup>.

### Principle of the Photoacoustic Effect

Sound generation using the photoacoustic effect has two main steps, heat generation by incident modulated light and sound generation by subsequent thermal expansion. Figure 1 shows the principle model of the photoacoustic effect. In the first step, periodic heat is generated on the surface of a material by absorbing light that is modulated with acoustic signal. In order to increase the amount of periodic heat, three main factors are related, which are intensity of radiated light, response speed of light source and absorptive power of material. Therefore to increase the amount of generated heat, high intensity, high response speed and high absorptive power are required. In the second step, sound wave is generated by heat expansion caused by heat conduction from material to the air. Thus, in order to generate louder sound, it is required that material has high thermal conductivity. Based on these things, the high power and high response speed light source and the high absorptive power and high heat conductivity material are required to increase the loudness of the generated sound.



**FIGURE 1.** Principle model of the photoacoustic effect. The left side is the flowchart of the photoacoustic effect. In this figure, main factors related to loudness of generated sound are enumerated. The right side is the model of the photoacoustic effect.

## SOUND GENERATION USING HALOGEN LAMP AND CHACOAL

On the photoacoustic effect, it is important to generate heat effectively since the photoacoustic effect is the combined effect of heat generation by absorbing modulated light and sound generation by subsequent thermal expansion. Thus, in this section, in order to confirm the possibility of sound generation using the photoacoustic effect, the experiment of the photoacoustic effect using a halogen lamp that contain a wideband spectrum of light from visible light to deep infrared and a charcoal that has high absorptive power is described.

### Response Speed of Halogen Lamp

Although a halogen lamp can produce high intensity infrared light, its response speed is slow since it is a filament light source that generates light energy from heat energy. Therefore it is required to confirm that a halogen lamp can be modulated with an acoustic signal. In order to confirm it, a 150W halogen lamp was modulated using a modulation circuit represented in Fig.2 and observed the signal received by a receive unit represented in Fig.3. Figure 4 shows the frequency characteristic of the two observed signals when the time-stretched pulse (TSP) signal is input into the modulation circuit and no signal is input it. Because of the difference between the voltage level of TSP signal and no signal, it is confirmed that a halogen lamp can be modulated with wide-range frequency band although the characteristic of low-pass filter was observed.

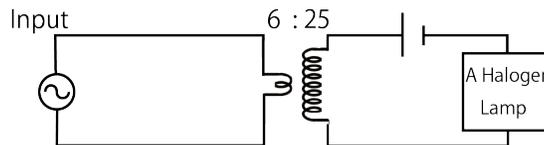


FIGURE 2. Modulation circuit. The wattage of the halogen lamp is 150W.

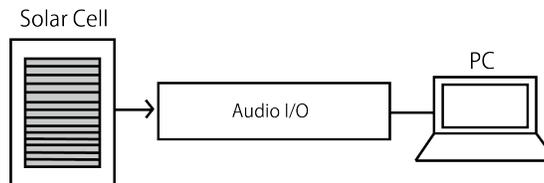


FIGURE 3. Receiving unit.

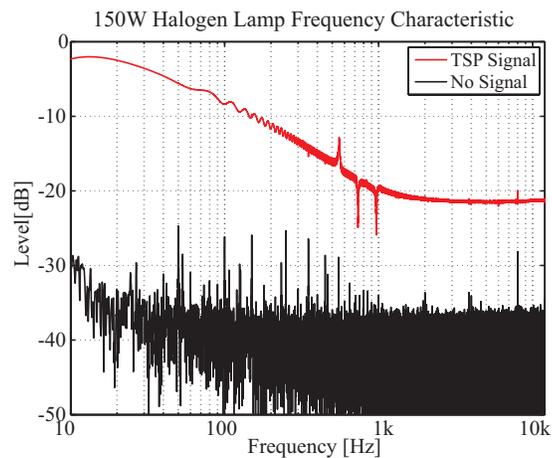


FIGURE 4. Frequency characteristic of the 150W halogen lamp. The red line is the frequency characteristic of the received signal when the input signal is the TSP signal. The black line is that of the received signal when the input signal is no signal. The frequency characteristic of TSP signal decreases about 16dB from 10Hz to 1kHz. The difference of voltage level of these signals is about 15dB at 10kHz.

## Sound Generation Using Charcoal

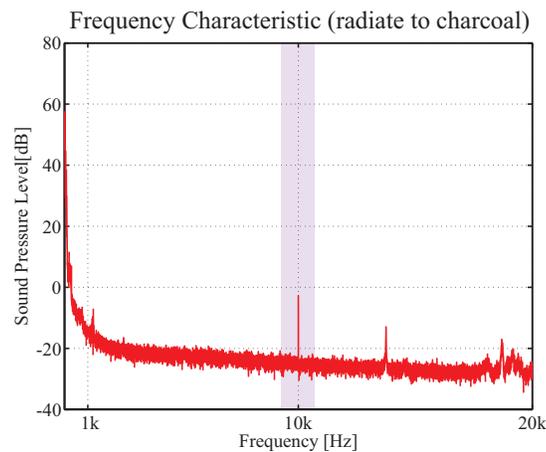
The experiments to generate a pure tone and a musical sound is performed. In order to generate louder sound, the light of 150W halogen lamp is focused on a charcoal, which has high absorptive power since a charcoal is black and spongy. In this experiment, the elliptical mirror is used to concentrate the light on a charcoal. Figure 5 shows the scene of this experiment.



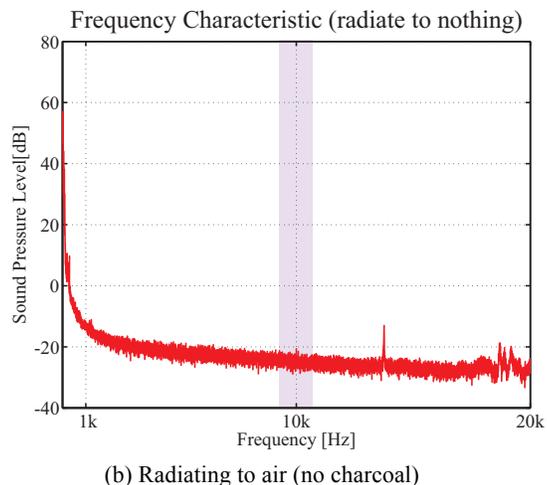
**FIGURE 5.** Experiment Scene. The light produced by a halogen lamp is concentrated on the surface of the charcoal by the elliptical mirror. A sound-level meter is put close to the charcoal.

### *The Generation of Sinusoidal Wave*

In order to confirm the generation of audible sound, the experiment to generate sinusoidal wave is carried out, where sinusoidal wave of 10kHz is used as the signal input into the modulation circuit in Fig.1 and the sound pressure level in vicinity of the charcoal is measured. Figure 6 shows that the frequency characteristics of sinusoidal sound of 10kHz is reproduced at the charcoal.



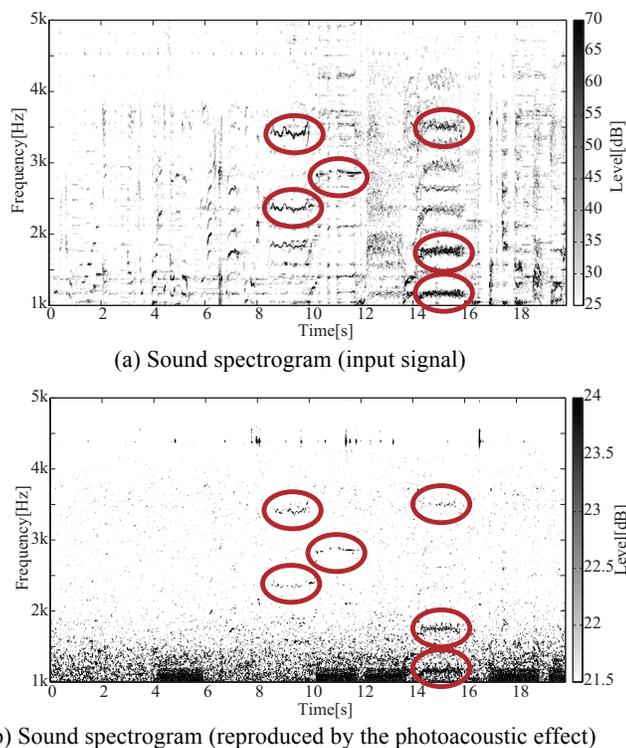
(a) Radiating to charcoal



**FIGURE 6.** Frequency characteristics of sound in vicinity of the focal point. The input signal is sinusoidal wave of 10kHz. (a) The frequency characteristic when the light is focused on the surface of the charcoal. (b) The frequency characteristic when the charcoal is removed and the light is focused in mid air. Since the peak at 10kHz is shown in (a), the sinusoidal of 10kHz wave is reproduced at the charcoal.

### *The Generation of Musical Sound*

The experiment to reproduce musical sounds was carried out, where the musical sound was used as the input of the circuit in Fig.2 and sound in the vicinity of the charcoal was measured. Figure 7 shows sound spectrogram of them. Both sound spectrograms have the similar characteristics. This result proves that the photoacoustic effect can reproduce a musical sound.



**FIGURE 7.** Spectrograms of the input signal and the measured signal in the vicinity of charcoal. (a) The spectrogram of input signal. (b) The spectrogram of measured signal. The input signal is “Matsuken Samba 2” sung by Ken Matsudaira who is a Japanese actor. To compare the marked points in Fig.7 (red circle), it is confirmed that both signals have the same frequency

components at the same time. Incidentally the result of (b) is refined by the spectral subtraction to make the sound spectrogram more visible.

## CONCLUSIONS

In this paper, the experiment to confirm that the photoacoustic effect using infrared lights can generate audible sounds has been performed. First, the experiment of response speed of a halogen lamp was performed. It is shown that a halogen lamp can be modulated with acoustic signal although the amplitude of higher frequency components is reduced because of the response speed of halogen lamp. Next, the experiments of sound generation using a halogen lamp and a charcoal were performed. The results of these experiments proved that it is possible to generate sinusoidal sounds and a musical sound by focusing modulated light from a halogen lamp on the surface of the charcoal. For the future works, it is possible to generate point a sound source in mid air by focusing light on molecules of greenhouse gases or molecules of H<sub>2</sub>O mist. To apply these molecules, the response speed of the light source and the high absorptive power are required. Considering these requirement, we suggest that the mid infrared laser diode or LED since these have high response speed and narrow bandwidth of light frequency. To use these light sources and greenhouse gases, it is possible to generate a point sound source in mid air in the future.

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