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Electric response induced by second sound in superfluid helium

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The electric response of superfluid helium was measured when a second sound standing wave was generated in a resonator cavity. The results were qualitatively in agreement with that of other research laboratories, but the normalized signal strength was one order of magnitude larger reflecting the difference in electrode structure. The temporal phase difference between the electric oscillation and the temperature oscillation was measured and compared with the analysis. The result excluded a hypothesis that the electric response was induced by the velocities of the relative motion of normal and superfluid components of liquid helium. We suggested a hypothetical explanation of the electric response based on the oscillation of chemical potential of electrons in helium atoms. The effect of an external dc electric field was examined and no effect was observed. The heater power dependence of the temperature oscillation and the electric oscillation showed the qualitative agreement with the original experiment.

Keywords: superfluid helium, second sound, resonance, electric activity, electric response.

1. Introduction

The relationship between the second sound in He II and its electrical characteristics was first observed by Rybalko [1]. In the experiment, a second sound resonance cavity with a heater on one end and an electrode on the other end was used. When a second sound standing wave was generated by the heater in the cavity, an ac electric potential with respect to the ground was observed on the electrode with the same frequency as the second sound. This is an extraordinary result because liquid helium is electrically neutral and does not exhibit spontaneous polarization. He tested the reverse effect as well: When an ac voltage was applied conversely to the electrode, a corresponding temperature oscillation was observed by a bolometer at the other end of the cavity. The second experiment was done using a torsional oscillator [2], and the third experiment was done using a microwave resonator [2,3]. The results of the second and the third experiments were consistent with the first experiment [1]. After these experiments, a lot of theories [4–9] have been presented in order to understand this curious phenomenon. However, definite theory has not been presented so far, and the discussion on the experimental results is still going on.

Chagovets carried out similar experiments [10] concerning the second sound resonance recently in different cell size and obtained qualitatively similar results as those in Ref. 1 He also performed the experiment [11] to detect the electric response at excitation of first sound with a similar configuration, except that the heater was replaced with a piezoelectric mechanical oscillator. His result indicates that the first sound also induces an electric response in He II [11], similar to the second sound. However, this result is contradictory with the experimental result of Ref. 1 which did not show any evidence of the electric response at the excitation of the first sound. In Ref. 11, the author estimated the pressure oscillation of the first sound and the corresponding electric oscillation of the experiment in

Ref. 1, and he concluded that the absence of the electric response at the excitation of the first sound waves in Ref. 1 may be caused by insufficient power of the first sound oscillations. Since the experiments to search for the electric response due to the first sound have been carried out by only two researchers so far and their results are contradictory, the data are not enough to get a definite conclusion at this moment. This should be clarified by the accumulation of the experimental results in different condition.

Although the experimental results are intriguing and extraordinary, the experiments concerning the electric response have been carried out in only two laboratories. The original experiment was done by Rybalko [1] and the following two experiments were done by Rybalko and coworkers [2,3] in Kharkov. The first and second sound resonance experiments were replicated by Chagovets [9–11] in Prague. A comparison of the data would give information to understand the physics of this system, and so it is necessary to do the experiments with different equipment and in different laboratories.

The experimental data obtained so far are limited to the amplitude. Data on the temporal phase difference between the electric oscillation and the temperature oscillation have not yet been published. These data are important in the analysis of the relationship between the induced electric field and the second sound oscillation.

The purpose of this research is fourfold. Firstly, this research aims to replicate the resonance experiment and to confirm whether or not superfluid helium is electrically activated by a second sound wave. We used a new electrode structure, both for efficient detection of the signal and to reduce interference caused by the heater voltage that comes through a stray capacitance. A cavity with a cross section area which is one order larger than that of Chagovets [9,10] and two orders larger than that of Rybalko [1,2] was used. Secondly, it is to get information on the temporal phase difference between the electric oscillation and the temperature oscillation. We will discuss about the possible reason of the electric response comparing the experimental phase difference with the theoretical analysis. Thirdly, it is to confirm if the effect of an external dc electric field on the electric oscillation, which has been suggested according to the theoretical consideration in Ref. 8. Fourthly, this research aims to confirm the heater power dependence of the electric and the temperature oscillations is consistent with the original experiment [9].

2. Experimental

Figure 1 shows the experimental setup which is divided into 3 parts according to the temperature range. The low temperature part is a second sound cavity immersed in liquid helium. The middle temperature part is an amplifier with a field effect transistor (FET) placed in the cold helium vapor. The room temperature part is a lock-in-amplifier

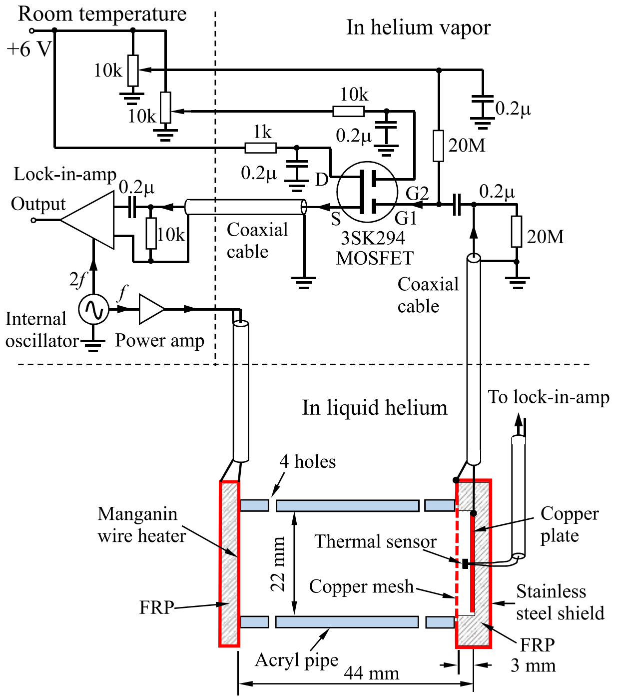

Fig. 1. Schematic experimental setup. The electric measurement and the second sound measurement were carried out in the separate runs, but a special care was taken to keep the temperature as same as possible.

(LIA) with an internal oscillator, a power amplifier, and some controllers. The cylindrical cavity is made of 1 mm thick acryl pipe with 22 mm inner diameter and 44 mm length. It has 4 holes of 1 mm diameter at the top and bottom to admit the liquid helium in the cavity.

A heater is fixed on one end of the acryl pipe, and a pair of electrodes and a thermal sensor are fixed on the other end. The heater is made of a Manganin wire (0.2 mm in diameter, 1.35 m long, 77.6 Ω resistance) which is wound on a square plate made of fiber-reinforced-plastic (FRP). Since the wire is wound on both sides of the FRP plate, the actual area which is exposed to the inside of the cavity is 26% of the total area, *i.e.*, 20.2 Ω is the effective resistance contributing to the excitation of the second sound in the cavity. An ac electric current with a frequency of f was fed from the internal oscillator of the LIA to the heater through the power amplifier and the coaxial cable. Because the heat was generated with the double frequency of the heater current, the LIA was referenced with the second harmonic frequency $2f$.

The pair of the electrodes is made as follows. A copper plate on a printed circuit board is etched in a round shape with a diameter of 22 mm which is the same size as the inner diameter of the acryl pipe. This electrode is electrically connected to the inner conductor of the coaxial cable. The other electrode is a mesh made of copper wires with a diameter of 0.3 mm and with a wire-to-wire distance of 2.2 mm, so that the liquid helium can go through easily but the electric field with a frequency of f generated by the heater is shut out by a shielding effect. This mesh electrode is electrically connected to the outer conductor of the coaxial cable. These two electrodes are fixed in parallel with a distance of 3 mm. To assure the electric shielding on the backside of the electrode, as shown in Fig. 1, the copper plate electrode is surrounded by a stainless steel foil connected to the outer conductor of the coaxial cable which is connected to the signal ground. The mesh electrode is glued on the end of the acryl pipe as shown in Fig. 1. The oxide layer of the electrode surfaces was removed by citric acid before assembly.

A commercially available chip resistor (1.3×2×0.5 mm) made of ruthenium oxide (RuO_x) thick film with a nominal resistance of 10 kΩ in room temperature was used as a thermal sensor for the second sound detection. The resistance at 1.7 K was approximately 35 kΩ. This thermal sensor connected to a coaxial cable was placed at the center of the copper electrode located at the end of the cavity. A constant dc current of 1 μA was passed through the sensor and the ac signal voltage was measured by the LIA. When the electric activity measurement was going on, the coaxial cable connected to the sensor was disconnected from the measuring circuit at room temperature and was grounded in order not to carry a noise to the copper electrode.

The signal voltage V_m is given by $V_m = q/C_{\text{in}}$, where q is the charge induced on the copper electrode and C_{in} is the capacitance of the input circuit of the measurement system. If we use a coaxial cable all the way from the low temperature electrodes to room temperature part, the input capacitance is 200–300 pF. If we insert an FET amplifier after the electrodes to make the input capacitance as low as possible, it is possible to get a larger signal. A 3SK294 MOS FET chip was chosen due to its very small input capacitance of 2.5 pF, and we adopted a source follower circuit for making a high input impedance. Additionally, a small capacitance coaxial cable was made which connected the electrodes and the FET amplifier. The FET amplifier was placed in the helium vapor, as it might be affected by the heat wave caused by the second sound if it was in the liquid helium. The total input capacitance was $C_{\text{in}} = 26.7$ pF which was a value in parallel connection of the electrodes, the input coaxial cable, the input capacitance of the FET chip, and the rest of electric wirings. The net input impedance of the FET amplifier was ~10 MΩ. The FET amplifier was electrically shielded by wrapping it with a stainless steel foil connected to the ground. The characteristics of the FET amplifier at low temperature were not significantly different from those at room temperature. The actual amplification factor (ac output voltage divided by ac input voltage) of the source follower was 0.93 less than unity, and it functioned as an impedance converter with a low input capacitance.

Before conducting the experiment, it was confirmed that the phase shift of the excitation voltage through the power amplifier and the signal voltage through the FET amplifier has no phase shift in the present experimental frequency range of 100–700 Hz.

3. Results and discussion

3.1. Second sound resonance

A standing wave due to the second sound resonance arises when the half wavelength λ/2 multiplied by a natural number is equal to the cavity length L. In this condition, the resonance frequencies f_n are given by the next equation.

$$2f_n = \frac{v_2}{\lambda_n} = \frac{nv_2}{2L}, \tag{1}$$

where n is the natural number, f_n and λ_n are the frequency and the wavelength of the nth resonance mode, respectively, and v_2 is the velocity of the second sound [13]. The factor 2 on the left side appears because the second sound oscillates with the double frequency of the heater current.

The root mean square (rms) temperature oscillation T_a can be converted from the measured rms value of the voltage U_a and the constant dc current I passing through the thermal sensor.

$$T_a = \left|\frac{dR}{dT}\right|^{-1} \frac{U_a}{I}, \tag{2}$$

where R is the resistance of the thermal sensor, and T is the absolute temperature.

Figure 2 shows the resonance spectra of the second sound at three different temperatures. The heater power in the cavity was $P/S = 8.95 \cdot 10^{-4}$ W/cm^2, where P is the heater power and $S = 3.8$ cm^2 is the cross section of the cavity cylinder. We could observe the first 6 modes of resonance, but it was difficult to record higher mode resonances due to a large damping. The resonance frequencies,

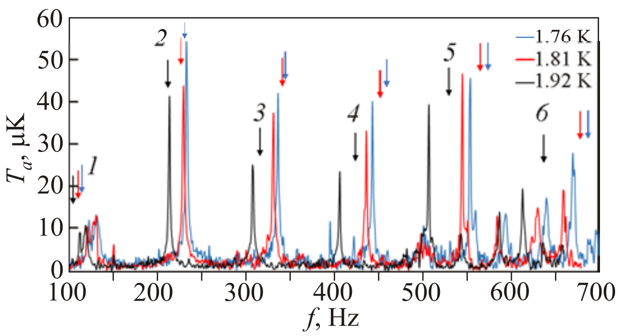

Fig. 2. (Color online) Spectra of the second sound in different temperatures. The numbers labeled near the peaks represent the mode of resonances. Arrows indicate the calculated resonance frequencies.

calculated from the velocity of the second sound and the length of the cavity, are shown by arrows in the figure. The numbers labeled near the arrows represent the modes of the resonances. The measured frequencies of the peaks agree with the calculated ones for the 2nd mode resonance, but they show a lower frequency than the calculated ones for the higher mode resonances. Conversely, the first mode resonance shows a higher frequency than the calculated one. The reason for this small discrepancy is unclear but it might be due to a so-called open end correction. There are some spurious resonance peaks especially near the 1st and 6th mode resonances.

3.2. Electric response by the excitation of second sound

The rms voltage V_m measured by the LIA was converted to the rms value of the electric charge oscillation q_a induced on the electrode. The conversion equation is the following.

$$q_a = C_{\text{in}} V_a = 26.7 \cdot 10^{-12} \cdot V_m / 0.93, \qquad (3)$$

where V_a is the rms voltage on the electrode and the factor 0.93 is an amplification factor of the FET amplifier. In order to compare our results with other laboratories' data, we normalized the temperature oscillation T_a with a power per unit area P/S and the Q-factor of the resonance Q. The electric oscillation was also normalized with P/S, the Q-factor, and the area of the electrode S. As a result, the parameters can be expressed as follows:

Temperature oscillation:

$$T_a / \{(P/S)Q\} = T_a S / PQ \ (\mu\text{K} \cdot \text{cm}^2 \cdot \text{W}^{-1}); \qquad (4)$$

Electric oscillation:

$$q_a / \{(P/S)QS\} = q_a / PQ \ (\text{fC} \cdot \text{W}^{-1}). \qquad (5)$$

We measured the voltage between the electrodes while we were sweeping the frequency with a rate of 0.1 Hz/s around the resonance frequencies. The heater power per unit area P/S was the same as for the second sound measurement in the previous subsection, P/S = 8.95·10^{-4} W/cm^2. The clearest results with the least spurious signals were found for the 5th mode resonances.

Left part of Fig. 3 shows the 5th mode resonance curves of the electric (q_a) and the temperature (T_a) oscillations around the resonance frequency at T = 1.76 K. Both oscillations show the same resonance frequency f_5 = = 553.9 Hz, and the Q-factors of the both peaks are the same Q = 369. Similar results were obtained at different temperatures for the 5th mode resonance. The measured temporal phases of the electric oscillation φ_e and the tem-

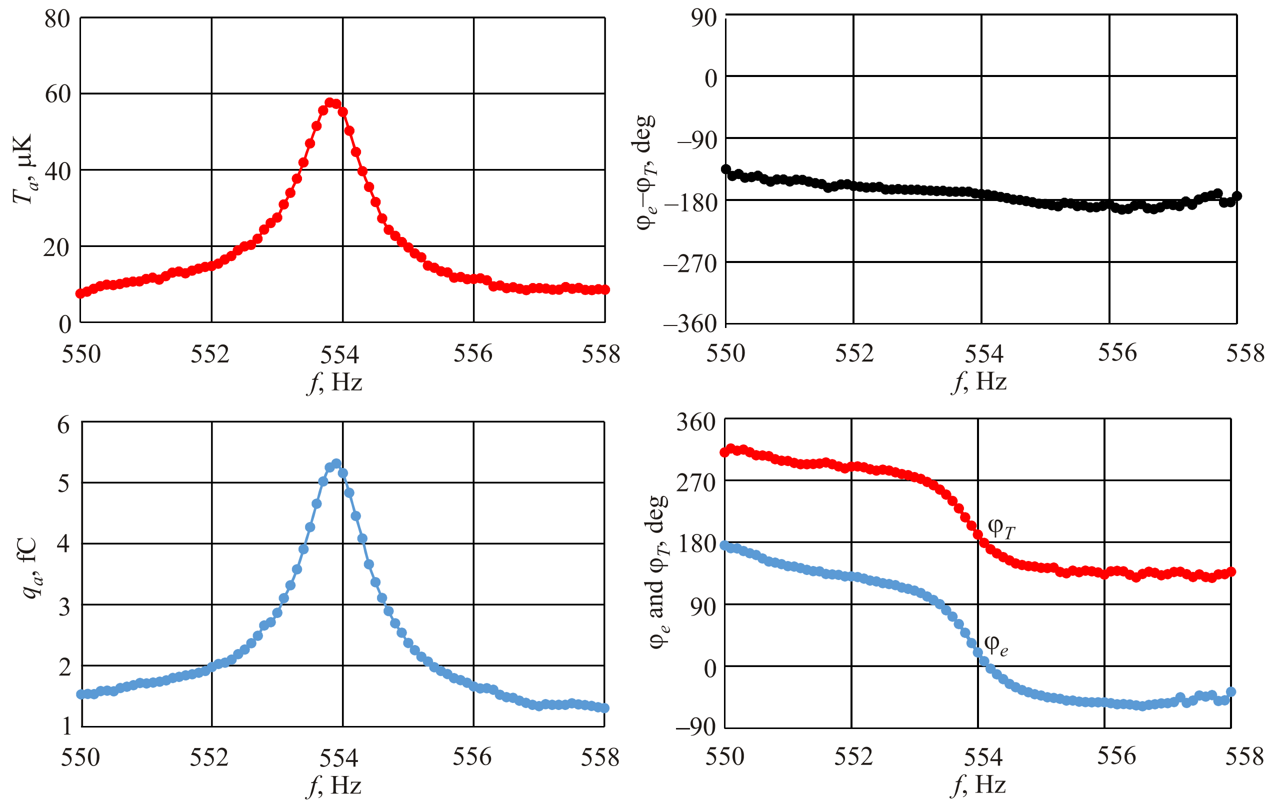

Fig. 3. (Color online) Left: spectra of the rms electric (q_a) and temperature (T_a) oscillations. Right: the temporal phases of the electric (φ_e) and temperature (φ_T) oscillations, and the phase difference $\varphi_e - \varphi_T$. The resonance frequency is f = 553.9 Hz. All the data are for 5th mode resonance at 1.76 K. Similar results were obtained in other mode resonances and at other temperatures. The graph shows that the absolute temporal phase difference is close to $|\varphi_e - \varphi_T| \cong 180$ deg.

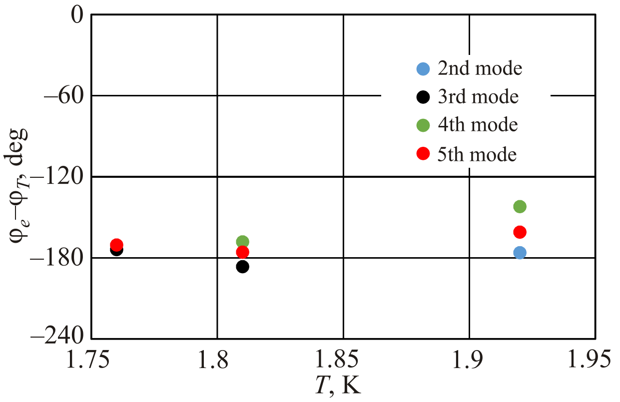

Fig. 4. (Color online) The temporal phase differences between the electric φ_e and the temperature φ_T oscillations at the resonance frequencies. The data shown here are taken from the relatively clear oscillations accompanied by less spurious signals. As the temperature increases, the error at data increases since the signal contains more spurious signals. The data points seem to be lying around $|\varphi_e - \varphi_T| \cong 180$ deg.

perature oscillation φ_T for the 5th mode are shown in the right part of Fig. 3. In other modes of oscillation, the graphs were less clear than the 5th mode, due to the spurious peaks present in the data. In principle, however, similar results were obtained in other modes. The temporal phase difference $\varphi_e - \varphi_T$ at the resonance frequency is plotted in Fig. 4 for different modes and temperatures.

The other modes of resonances showed similar results as for the 5th mode, though they showed stronger spurious signals. In some modes of oscillation, the resonances were smeared and it was difficult to get clear phase data. All the results are summarized in Table 1. From this table, we can see the following features.

Firstly, as the number of the mode increases, the normalized peak value of the electric oscillation dramatically decreases while the peak value of the temperature oscillation gently decreases. This suggests that the number of superfluid components in the liquid affects the electric oscillation.

Secondly, the normalized peak value of the 1st mode electric oscillation is much bigger than higher modes. To compare with the results of Chagovets [9], we picked up from his graph the signal voltage of the electric oscillation $5.0 \cdot 10^{-7}$ V, and the temperature oscillation $5.0 \cdot 10^{-5}$ K, at $T = 1.725$ K which is close to our temperature $T = 1.76$ K. Using these values and his input capacitance $C_{\text{in}} = 260$ pF, Q-factor $Q \sim 60$, and the surface area of the electrode $S = 0.385$ cm^2, we can calculate from Eqs. (3), (4), and (5) the value $q_a/PQ = 6.3$ fC·W^{-1} and $T_a S/PQ = 931$ μK·cm^2·W^{-1} for the first mode resonance. In contrast, our result at $T = 1.76$ K shown in Table 1 is $q_a/PQ = 99.9$ fC·W^{-1} and $T_a S/PQ = 270$ μK·cm^2·W^{-1}. Our value of the electric charge oscillation q_a/PQ is 16 times larger than that of Chagovets even though the temperature oscillation $T_a S/PQ$ is smaller.

This large difference might be explained by the difference in structure of the electrodes. In Ref. 9, a Corbino-like electrode is used, which detects the potential difference in the direction most efficiently perpendicular to the motion of helium atoms driven by the second sound. On the other hand, our electrode detects the potential difference in the direction parallel to the motion of helium atoms. The electric potential difference seems to be produced naturally along the direction parallel to the propagation direction of the second sound.

Let us now estimate the Seebeck effect of the electrodes due to the second sound wave. Since the Seebeck coefficient S_e of copper in room temperature is of the order of 1 μV/K, it is naturally expected that $S_e << 1$ μV/K in the temperature range 1 K < T < 2 K. A thermoelectric power V_{th} caused by the temperature difference between the copper electrodes can be calculated by $V_{\text{th}} = S_e \delta T$, where δT is the temperature difference between the electrodes. If we use the value $\delta T = 50$ μK taken from the Fig. 2, $V_{\text{th}} << 50$ pV can be obtained. This value is 5 orders

Table 1. Comparison of the normalized peak value and the Q-factor of the temperature oscillation and the electric charge oscillation in 1st to 6th mode resonance frequencies. $P/S = 8.95 \cdot 10^{-4}$ W/cm^2 and $S = 3.8$ cm^2.

	T, K	1st	2nd	3rd	4th	5th	6th
$T_a S/PQ$ (μK·cm^2·W^{-1})	1.76	270	601	409	205	149	143
	1.81	337	571	270	239	156	127
	1.92	256	471	228	119	147	146
q_a/PQ (fC·W^{-1})	1.76	99.9	21.6	5.6	9.0	3.5	1.6
	1.81	44.4	6.1	8.1	5.7	0.6	0.9
	1.92	52.4	3.3	2.2	7.4	0.8	1.0
Q-factor of temperature oscillation	1.76	41	93	105	193	369	197
	1.81	33	85	165	125	454	169
	1.92	49	97	154	226	390	137
Q-factor of electric charge oscillation	1.76	32	54	135	127	369	353
	1.81	37	153	83	118	389	165
	1.92	45	152	147	239	220	205

of magnitude smaller than the typical signal value of the electric oscillation in the order 1 μV or more. From this estimation, it can be concluded that the Seebeck effect of the copper electrodes is negligible.

3.3. Phase difference between the electric and temperature oscillations

We consider the spatial and temporal phases of the temperature oscillation and the velocity oscillation of liquid helium. As is well known, since the density of the normal state ρ_n is a function of temperature [14], the temperature oscillation $T - T_0$ is in proportion to the density oscillation $\rho_n - \rho_{n0}$ in a linear approximation, where T_0 and ρ_{n0} are the average temperature and the average value of ρ_n, respectively. Then, we can write the proportionality relationship with a constant α_1,

$$T - T_0 = \alpha_1 (\rho_n - \rho_{n0}). \tag{6}$$

We introduce a symbol $\mathbf{j}_n$ to denote the velocity density vector of the normal component. Since the heat is transferred by $\mathbf{j}_n$ in a space where the second sound is generated, the vector $\mathbf{j}_n$ is related to the density oscillation $\rho_n - \rho_{n0}$ by the equation of continuity within a linear approximation and without damping of energy,

$$\frac{\partial}{\partial t}(\rho_n - \rho_{n0}) = -\alpha_2 \operatorname{div} \mathbf{j}_n, \tag{7}$$

where t is the time, and α_2 is a constant. Substituting Eq. (6) into Eq. (7), we get the following equation with a constant α_3,

$$\frac{\partial}{\partial t}(T - T_0) = -\alpha_3 \operatorname{div} \mathbf{j}_n. \tag{8}$$

In the following three subsections, based on the Eq. (8), we will discuss about the temporal phase difference between the temperature oscillation and the velocity oscillation for (a) standing wave, (b) progressive wave, and (c) mixed state of the standing wave and the progressive wave.

3.3.1. Standing wave (*resonant regime*)

If we assume that the temperature oscillation in the resonant condition has a form

$$T - T_0 = \sqrt{2} T_a \cos(kx + \varphi_1) \cos(\omega t + \varphi_2), \tag{9}$$

we obtain from Eq. (8) the velocity density of the normal component along the x axis

$$j_{nx} = \sqrt{2} T_a \frac{\omega}{k\alpha_3} \cos\left(kx + \varphi_1 + \frac{\pi}{2}\right) \cos\left(\omega t + \varphi_2 + \frac{\pi}{2}\right), \tag{10}$$

where T_a is the rms value of the temperature oscillation, k is the wave number of the spatial oscillation, x is the position on the cavity axis with the origin set at the heater position, φ_1 and φ_2 are the spatial phase at $x = 0$ and the initial temporal phase, respectively, and ω is the angular frequency of the excitation heater current. From Eq. (9) and Eq. (10), it is concluded that the absolute value of the spatial phase difference between the temperature oscillation and the velocity density oscillation is π/2, and the temporal phase difference is also π/2.

In the actual resonating cavity, the velocity of the oscillating atoms is zero at the position on the heater and on the electrode, and inversely the temperature oscillation is maximum there. Thus, the spatial phase of the velocity wave is shifted by π/2 from the temperature wave. The Eqs. (9) and (10) are in agreement with the actual situation. This supports the validity of these equations.

The integral of the electric field or the polarization along the distance x is equal to the voltage. Therefore, the temporal phase difference between the voltage and the electric field or polarization is 0 or π. If we assume that the electric field or polarization is induced by the velocity of the normal component, the temporal phase difference between the voltage and the temperature oscillation must be π/2 or –π/2, because the temporal phase difference between the velocity and the temperature is expected to be π/2 or –π/2 as shown by Eqs. (9) and (10). However, it is seen from Fig. 4 that the observed phase difference is close to π (=180 deg). This experimental fact excludes the hypothesis that the electric field or polarization is induced by the velocities of the relative motion of the normal and superfluid components.

3.3.2. Progressive wave (*non-resonant regime*)

If we assume that the temperature oscillation of a progressive wave has a form

$$T - T_0 = \sqrt{2} T_a \cos(\pm kx + \omega t + \varphi), \tag{11}$$

we obtain from Eq. (8) the velocity density of the normal component along the x axis

$$j_{nx} = \mp \sqrt{2} T_a \frac{\omega}{k\alpha_3} \cos(\pm kx + \omega t + \varphi), \tag{12}$$

where φ is the initial phase at $x = 0$. As shown in the preceding subsection (a), the temporal phase difference between the voltage and the electric field or polarization is 0 or π. If we assume that the electric field or polarization is induced by the velocity of the normal component, it follows from Eqs. (11) and (12) that the temporal phase difference between the temperature oscillation and the voltage oscillation is 0 or π.

3.3.3. Mixed state of the standing wave and the progressive wave

When the standing and the progressive waves are mixed, the absolute value of the temporal phase difference takes an intermediate value between 0 and π. Combining the results of preceding two cases (a) and (b), the absolute value of the phase difference is expected to be $\pi/2$ at the resonance frequency and it varies continuously to 0 or π as the excitation frequency is swept away from the resonance frequency to a non-resonance frequency. However, the experimental phase difference shown in the right upper part of Fig. 3 is close to $|\varphi_e - \varphi_T| \cong \pi$, and it is virtually constant over the range starting from a resonance frequency to a non-resonance frequency. This discrepancy also rules out the hypothesis that the electric field or polarization is induced by the velocities of the relative motion of the normal and superfluid components.

3.4. Relationship between the temperature oscillation and the electric oscillation

Chagovets [9] measured the heater power dependence of the temperature and the electric oscillations. We attempted to replicate this experiment. The results are shown in Fig. 5. The value T_a first increases linearly with the heater power, and saturates at P/S ~ 10 mW/cm^2, which is 1/3 of that in [9]. This difference might be due to the difference in cavity size. The value q_a linearly increases and then starts decreasing at P/S ~ 7 mW/cm^2, which is in agreement with that in [9]. Although there are some differences, it was confirmed that the general feature of the heater power dependence is the same.

As shown in Fig. 5, both amplitudes of the temperature oscillation and the electric oscillation increase linearly with

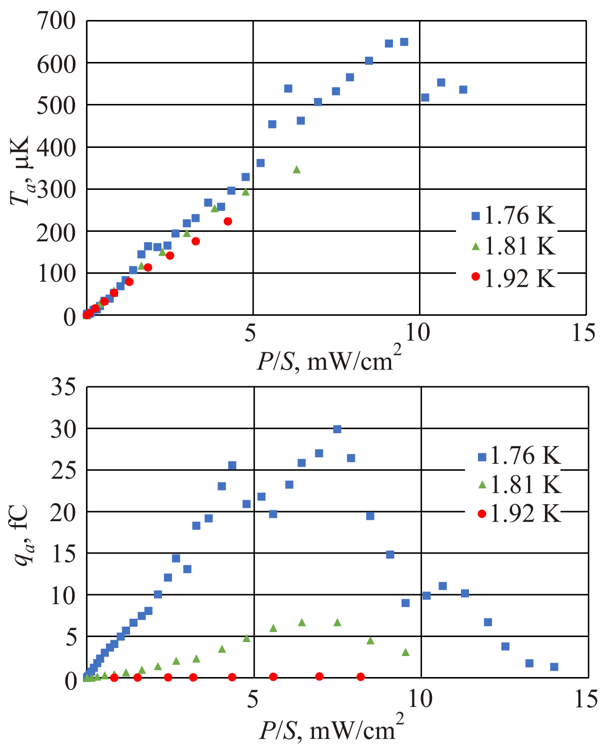

Fig. 5. Heater power dependence of the temperature oscillation T_a and the electric charge oscillation q_a. In high power or high temperature, it was difficult to keep the temperature constant and to get a stable resonance.

the heater power around our experimental condition P/S = = 8.95·10^{-4} W/cm^2. The amplitude of the electric oscillation is in proportion to the temperature oscillation.

Since the temporal phase difference between the electric and the temperature oscillations is $-\pi$ as shown in Fig. 4, if we put the standing wave of the temperature oscillation

$$T - T_0 = \sqrt{2}T_a \cos(kx)\cos(\omega t + \varphi_2), \tag{13}$$

then the voltage oscillation V can be written as

$$V = \sqrt{2}\alpha T_a \cos(kx)\cos(\omega t + \varphi_2), \tag{14}$$

where α is a constant with a negative sign. With Eqs. (13) and (14), we can write V in proportion to $T - T_0$,

$$V = \alpha(T - T_0). \tag{15}$$

This equation is supported by the relationship between T_a and q_a shown in Fig. 5, in a linear approximation where the heater power is low.

Here, we present our hypothetical suggestion to explain the electric response shown by Eq. (15). Since the density ratio of the normal and superfluid components ρ_n/ρ_s is a function of the temperature [14], the temperature fluctuation induces the change in chemical potential $\Delta\mu$ of the electrons in helium atoms. If we assume that the voltage oscillation is caused by the oscillation of the chemical potential of the electrons in helium atoms, we can naturally derive Eq. (15), as $\Delta\mu \propto T - T_0$. This should be confirmed by other experiments in the future.

3.5. Effect of external constant electric field

Adamenko and Nemchenko [8] developed a theory based on the motion of quantized vortex rings (QVR). They claim that, when a velocity **w** of the QVR is present, an electric field develops in the He II. The reasons for this are an anisotropic dependence of the QVR energy on its momentum when **w** is present and the existence of a QVR dipole moment. They considered the case where the dipole moment of a QVR is made up of its intrinsic dipole moment plus the dipole moment created by an external field. Based on their theory, they suggested to conduct a new experiment to apply a constant external electric field.

According to their suggestion [8], we applied a dc voltage in the interval 0 V to 10 V between the electrodes while we were measuring the ac voltage signal at the resonance frequency in different temperatures and in different oscillation modes. The results showed that there were no effects of the dc voltage on the ac signal strength. Our results suggest that the possibility of electric activity due to QVR is low.

4. Conclusion

We examined the electric activation of the superfluid helium through second sound wave in a resonating cavity one or two orders larger in size than those used previously by other researchers [1,9,10,15]. The electrode structure was designed to detect the electric response efficiently. The results showed much larger signals than other experiments [1,9]. Analysis together with the measured value of the temporal phase difference between the electric oscillation and the temperature oscillation excluded the hypothesis that the electric field or the polarization was induced by the velocities of the relative motion of the normal and superfluid components. We suggested a hypothetical explanation of the electric response based on the oscillation of the chemical potential of electrons in helium atoms. Application of an external dc electric field did not affect the electric response, suggesting a low possibility of QVR theory [8]. The heater power dependence of the electric and temperature oscillation was measured and it replicated the original experiment [9].

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Електричний відгук, який викликано другим звуком у надплинному гелії

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Виміряно електричний відгук надплинного гелію при генерації стоячої хвилі другого звуку в порожнині резонатора. Отримані результати якісно узгоджуються з результатами інших дослідницьких лабораторій, але нормований рівень сигналу був на порядок більше, що викликано іншою структурою електродів. В роботі вимірювалася та аналізувалася різниця фаз між електричним коливанням і коливанням температури. В результаті дослідження було виключено гіпотезу про те, що електричний відгук був викликаний швидкостями відносного руху нормальної та надплинної складових рідкого гелію. Ми припустили гіпотетичне пояснення електричного відгуку, заснованого на коливанні хімічного потенціалу електронів в атомах гелію. Також вивчався вплив зовнішнього dc електричного поля, і при цьому ніякого впливу не було виявлено. Залежність коливань температури та електричних коливань від потужності нагрівача показала якісну згоду з вихідним експериментом.

Ключові слова: надплинний гелій, другий звук, резонанс, електрична активність, електричний відгук.

Электрический отклик, вызванный вторым звуком в сверхтекучем гелии

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Измерен электрический отклик сверхтекучего гелия при генерации стоячей волны второго звука в полости резонатора. Полученные результаты качественно согласуются с результатами других исследовательских лабораторий, но нормированный уровень сигнала был на порядок больше, что обусловлено иной структурой электродов. В работе измерялась и анализировалась разность фаз между электрическим колебанием и колебанием температуры. В результате исследования была исключена гипотеза о том, что электрический отклик был вызван скоростями относительного движения нормальной и сверхтекучей составляющих жидкого гелия. Мы предположили гипотетическое объяснение электрического отклика, основанного на колебании химического потенциала электронов в атомах гелия. Также изучалось влияние внешнего dc электрического поля, и при этом, никакого влияния не было обнаружено. Зависимость колебаний температуры и электрических колебаний от мощности нагревателя показала качественное согласие с исходным экспериментом.

Ключевые слова: сверхтекучий гелий, второй звук, резонанс, электрическая активность, электрический отклик.