Capacitive level meter for liquid hydrogen

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Abstract

A capacitive level meter working at low temperatures was made to use in magnetic refrigerator for hydrogen liquefaction. The liquid level was measured from the capacitance between parallel electrodes immersed in the liquid. The meter was tested for liquid nitrogen, hydrogen, and helium. The operation was successful using an AC capacitance bridge. The estimated sensitivity of the meter is better than 0.2 mm for liquid hydrogen. The meter also worked with pressurized hydrogen.

Keywords: Hydrogen(B), Dielectric properties(C), Level Detection(D)

Hydrogen energy is considered a good alternative to fossil fuels, because burning hydrogen does not produce greenhouse gases. Liquid hydrogen should be useful for efficient, economic transport and storage because of the low density of gaseous hydrogen. We have tested a magnetic refrigerator for hydrogen liquefaction[1, 2] and have successfully liquefied hydrogen gas that was slightly above the boiling point using Carnot cycle. In order to measure liquid hydrogen level precisely, we have constructed a liquid meter.

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There are several methods to measure cryogenic liquid. A survey of level detection techniques for He II is given in Ref. [3]. Superconducting wire level gauges that used MgB_2 sheathed tube were developed[4, 5, 6]. We tested this type level sensor in our previous study. However, the heat input was not small. So, we decided to use a capacitive level meter because of high accuracy, sensitivity, no heat input, and insensitivity to magnetic field. Commercially available capacitive liquid sensor are made for industrial tanks. Then, they cannot fit our magnetic refrigerator. A cylindrical capacitor constructed of the concentric plates which allows a cryogenic fluid to be the dielectric is frequently used in capacitive liquid level mater. The capacitance becomes large when the radii of the concentric plates are close. However, capillary rise of liquid is inversely proportional to the spacing and is affected by temperature variation of viscosity that is possible for magnetic refrigerator. We compared the capacitance change between multi-parallel plates and concentric plates capacitors with the same gap. A capacitor with multi-parallel plates was used as the sensor of our present study in order to increase the signal. The basic structure is similar to that was constructed for liquid xenon by Sawada et al.[7]. The capacitor was composed of 8 capacitor plates separated with polyacetal spacers so that total 7 sets of parallel capacitors were made. Figure 1 schematically shows the level meter structure and electric connection. Commercially available circuit boards that had 1.6 mm thick glass-fabric-base epoxy resin substrate covered with 35μm thickness copper were used as capacitance plate. The copper electrodes with 30 mm wide and 35 mm high were achieved by etching and gilded. The electrodes were connected in order not to have influence from substrates as shown in Fig. 1. The spacing

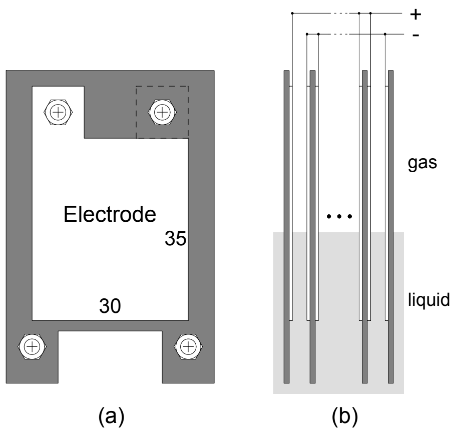

Figure 1: Capacitance plate of the level meter. (a) Copper electrodes that are obtained by etching. (b) Electrodes connection. Each plate had the same polarity.

between the electrodes were designed as 0.8 mm, considering sensitivity and fluctuation due to temperature dependent viscosity.

The capacitance was measured using an AC bridge (Andeen Hagerling, 2700A) at the frequency of 1 kHz. Two coaxial cables were used as lead wires and outer conductors worked as guard in order to form three terminal capacitor.

We tested the meter with liquid nitrogen, helium, and hydrogen. The meter was immersed into these liquids stored in glass Dewar flasks at 0.1 MPa. In the calibration, the liquid level was measured with a ruler by eyes. Fluctuation of the capacitance due to the agitation of liquid surface by boil off gas was decreased by increasing in the averaging time of the AC bridge.

The capacitance changes between empty and full liquid were 38.7, 20.2, and 3.9 pF for liquid nitrogen, hydrogen, and helium, respectively. The capacitance change is expressed as $\Delta C = (\epsilon_{r,liq.} - \epsilon_{r,gas})\epsilon_0 \frac{S}{d}$, where S and d are

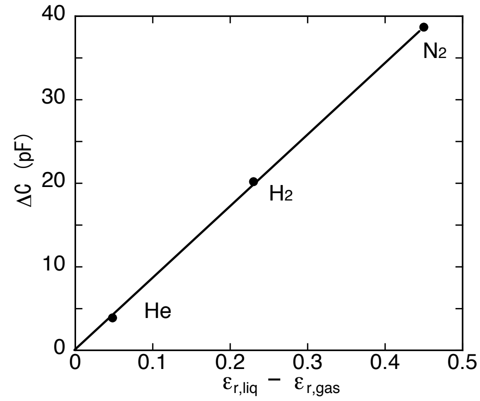

Figure 2: Capacitance change for liquid helium, hydrogen, and nitrogen as a function of specific dielectric constant difference between liquid and gas. The spacing of electrodes was obtained from the linear dependence.

area and spacing of electrodes; $\epsilon_{r,liq.}$, $\epsilon_{r,gas}$, and ϵ_0 are specific dielectric constant of liquid, gas, and dielectric constant of vacuum, respectively. As shown in Fig. 2, these change is proportional to the dielectric constant difference between liquid and gas, $\epsilon_{r,liq.} - \epsilon_{r,gas}$. The actual spacing of the electrodes were determined as 0.75 mm from the slope in Fig. 2 and in good agreement with the thickness of the spacers, considering the thickness of copper electrodes.

Figure 3 shows capacitance change of the level meter in liquid hydrogen. The capacitance varied linearly with liquid level in the active region of electrodes. This means that the electrode parallelism was good. The scattering of the data was ascribed to the error by reading of the scale and agitation of the liquid surface due to boiling. The estimated sensitivity of the meter is better than 0.2 mm from the reading of the AC bridge.

We tested the meter with pressurized hydrogen at 0.2 MPa. Pressure was increased by closing the relief valve of the cryostat. Capacitance was

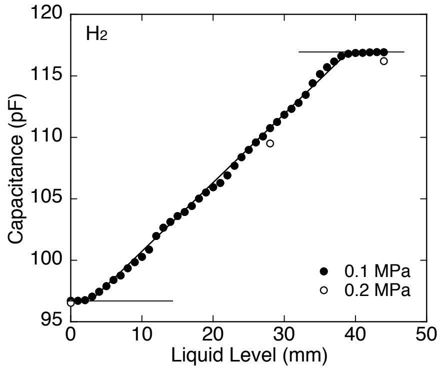

Figure 3: Capacitance change of the level meter obtained in liquid hydrogen at 0.1 and 0.2 MPa.

measured at 0.2 MPa in three cases where liquid levels were below, above, and at 28 mm of the active region of the meter as shown in Fig. 3. Hydrogen was in liquid-gas coexisting state so that the temperature also increased along with the vapor pressure curve. Capacitance changes at 0.2 MPa can be elucidated by dielectric change of liquid and gas hydrogen with pressure. When the meter was empty, difference in dielectric constant of gas hydrogen between 0.1 and 0.2 MPa was so small that capacitance was unchanged. Capacitance decreased at 0.2 MPa when liquid level were above and at the active region of the meter. Thermal expansion of liquid hydrogen was the origin of the change. The decrease in capacitance reasonably agreed with the reduction of dielectric constant due to thermal expansion. It was confirmed that the meter worked with pressurized liquid hydrogen.

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