Evaluations of pressure-transmitting media for cryogenic experiments with diamond anvil cell*

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The fourteen kinds of pressure-transmitting media were evaluated by the ruby fluorescence method at room temperature, 77 K using the diamond anvil cell (DAC) up to 10 GPa in order to find appropriate media for use in low temperature physics. The investigated media are a 1:1 mixture by volume of Fluorinert FC-70 and FC-77, Daphne 7373 and 7474, NaCl, silicon oil (polydimethylsiloxane), Vaseline, 2-propanol, glycerin, a 1:1 mixture by volume of n-pentane and isopentane, a 4:1 mixture by volume of methanol and ethanol, petroleum ether, nitrogen, argon and helium. The nonhydrostaticity of the pressure is discussed from the viewpoint of the broadening effect of the ruby R_1 fluorescence line. The R_1 line basically broadens above the liquid-solid transition pressure at room temperature. However, the nonhydrostatic effects do constantly develop in all the media from the low-pressure region at low temperature. The relative strength of the nonhydrostatic effects in the media at the low temperature region is discussed. The broadening effect of the ruby R_1 line in the nitrogen, argon and helium media are significantly small at 77 K, suggesting that the media are more appropriate for cryogenic experiments under high pressure up to 10 GPa with the DAC. The availability of the three media was also confirmed at 4.2 K.

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I. INTRODUCTION

The development of the diamond anvil cell (DAC) has revolutionized high-pressure research in various scientific fields such as physics, chemistry, geophysics, materials science and biology [1, 2]. Various types of experiments can be performed with the DAC. For instance, X-ray diffraction experiments, optical absorption and reflectivity measurements, Raman and Brillouin scattering studies, and transport and thermal measurements under high pressure above 10 GPa have become possible. These methods have been successfully applied in low temperature physics where many interesting pressure-induced phenomena such as superconductivity have been extensively studied [3, 4].

In high-pressure experiments, nonhydrostatic effects such as inhomogeneous pressure distribution (pressure gradient) and uniaxial (deviatoric) stress need to be reduced because the effects can strongly influence the physical state of a sample. It is important to use a pressure-tranmistting medium in a pressure region where it is in a liquid state. However, a liquid medium solidifies through a liquid-solid transition on cooling from room temperature. The shear stress of a solid medium causes nonhydrostatic pressure in the low temperature region.

The purpose of the present study is to evaluate the pressure-qualities of media used in low temperature physics, and in particular for the strongly correlated electron system in which novel types of physical phenomena such as non-Fermi liquid behavior or unconventional superconductivity have been extensively studied [5, 6]. The electronic state of the system is generally sensitive to small amounts of impurities or nonhydrostatic effects. A recent example is the case of the "FeAs-based superconductor" $CaFe_2As_2$ in which superconductivity was discovered above 0.5 GPa in high-pressure studies using organic media [7, 8], while it was not observed with a helium medium [9]. This discrepancy may result from sensitive structural instability to the uniaxial stress of the compound. nonhydrostatic effects cannot be avoided in the low temperature region. It is necessary to compare quantitatively the strength of the nonhydrostatic effects of various kinds of pressure-media.

Most of previous studies on pressure-media have concerned the hydrostaticity of the pressure at room temperature [10–13]. Very few studies have been carried out on the pressure-qualities of media in the low temperature region up to 3 GPa [14, 15]. In this study, therefore, the fourteen kinds of pressure-transmitting media were studied by the ruby fluorescence technique up to 10 GPa at room temperature, 77 and 4.2 K.

II. EXPERIMENTAL

The fourteen kinds of investigated media are a 1:1 mixture by volume of Flourinert FC-70 and FC-77 (Flourinert FC70/77, Sumitomo 3M), Daphne 7373 and 7474 (Idemitsu Kosan), NaCl, Vaselin, silicon oil (polydimethylsiloxane with a kinematic viscosity of 1 $mm^2 \cdot s^{-1}$, Shin-Etsu Chemical), 2-propanol, glycerin, 1:1 mixture by volume of n-pentane and isopentane (pentane mixture), a 4:1 mixture by volume of methanol and ethanol (4:1 M-E mixture), petroleum ether (Wako Chemical Industries), nitrogen, argon and helium. The

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