INTRODUCTION

The viscosity of the Earth’s outer core is of fundamental importance to understanding the evolution, present state, and dynamic process of the Earth’s core. Seismic, geodetic, and geomagnetic observations and theory, however, give a wide range in estimated viscosity of the Earth’s outer core from $10^{-4}$ to $10^{12}$ Pa-s (Secco 1995). Another approach to the viscosity of the core is to investigate the viscosity of molten iron alloys at pressures ($P$) and temperatures ($T$) conditions considered appropriate for the core. Poirier (1988) estimated the viscosity of iron melt in the core is $6 \times 10^{-3}$ Pa-s by the semi-empirical relationship between activation energy for viscosity of liquid metal and melting temperature. Alfè and Gillan (1998a, 1998b) also showed the viscosity of Fe-S melt is about $10^{-2}$ Pa-s at core $P$ and $T$ by a first principles calculation. Recent viscosity measurements (Dobson et al. 2000) also showed the viscosity of Fe-FeS melt to be about $10^{-2}$ Pa-s at 2.5 GPa. Thus, we are confident that the viscosity of the Fe-FeS melt is close to a typical value ($10^{-2}$ Pa-s) of viscosity for liquid metal even at high pressures.

predicted the viscosity of Earth’s outer core to range from $10^{-4}$ to $10^4$ Pa-s, based on these data. Brazhkin (1998) also reported a very large activation volume of viscosity for pure iron liquid, suggesting a glassy state of the inner core.

The aim of this study is to determine the viscosity of molten iron alloys at high pressure by Stokes’ viscometry using synchrotron X-ray radiographic observations. This is a reliable method for investigating the liquid viscosity under pressure and potentially can measure viscosity as low as $10^{-2}$ Pa-s (Kanzaki et al. 1987; Dobson et al. 1996; Dingwell 1998).

EXPERIMENTS

We carried out the high-pressure X-ray radiography experiments by using synchrotron radiation at BL04B1 of SPring-8, Japan. The high-pressure X-ray system SPEED-1500 was used, which is composed a 6–8 double-stage high-pressure apparatus driven by a 1500 ton uniaxial press, and an X-ray diffractometer (Utsumi et al. 1998). The sample cell assembly is illustrated in Figure 1. The starting material was sub-micrometer fine powder of Fe (99.99% pure) and synthetic FeS (99.9% pure) mixed to a composition of Fe$_{61}$S$_{39}$, which is about 3 at% rich in sulfur relative to the eutectic composition of the system Fe-FeS at 5 to 7 GPa reported by Usselman (1975). The Fe$_{61}$S$_{39}$ sample was enclosed in the BN sample capsule, which had been deoxidized under N$_2$ atmosphere at 2273 K. Temperature was measured just above the BN sample capsule using a W3%Re–W25%Re thermocouple, with no pressure correction. Pressure was determined from the equation of state of BN (unpublished data) and MgO (Jamieson et al. 1982), which were used as sample capsule and X-ray window, respec-