Conventional Superconductivity at 190 K at High Pressures

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January 25, 2015 (HP90). The highest critical temperature of superconductivity (T_c) has been achieved in cuprates [1]: T_c =133 K [2] at ambient pressure and 164 K at high pressures [3]. As the nature of superconductivity in these materials is still not disclosed, the prospects for a higher T_c are not clear. In contrast the Bardeen-Cooper-Schrieffer (BCS) phonon mediated theory of superconductivity gives a guide for achieving high T_c: it should be a favorable combination of high frequency phonons, strong coupling between electrons and phonons, and high density of states. These conditions can be fulfilled for metallic hydrogen and covalent hydrogen dominant compounds [4, 5]. Numerous subsequent calculations supported this idea and predicted T_c=100-235 K for many hydrides [6], but only moderate T_c=17 K has been observed experimentally [7].

In the presented work [8] we studied experimentally sulfur hydride (H_2S). We found that it transforms at P~90 GPa to a metal and superconductor with T_c increasing with pressure to ~60 K at P<~150 GPa (Figure 1a,b) in general agreement with recent calculations of T_c=80 K for H_2S [9]. In contrast to the calculations we found a dramatic increase of T_c at higher pressures (Figure 1b). Moreover we found superconductivity with T_c≈190 K in a H_2S sample pressurized to P>150 GPa at T>220 K (Figure 2). The superconductivity was proved from (a) the drop of the resistivity to a value ~100 times lower in comparison with copper, (b) the shift of the superconducting transition step with magnetic field, and (c) the strong isotope effect measured with D_2S evidencing a major role of phonons in this superconductivity.

The sharp increase of T_c to ~150 K with pressure (Figure 1b) and the near 190 K superconductivity in sulphur hydride (Figure 2a,b) are both most likely associated with the dissociation of H_2S to SH_n (n>2) hydrides plus elemental sulfur. Precipitation of sulfur might be of particular interest, because sulfur forms impurities or clusters in a host lattice which can promote an increase of T_c through surface enhanced effects, instabilities, and disproportionation which are common features of high temperature superconductors. Calculations [10] supported this hypothesis: H_3S has been found stable at P>50 GPa. The superconductive high pressure phases of H_3S found in the theoretical study of the $(H_2S)_2H_2$ system [11] have T_cs of ~ 160 K and 190 K – in agreement with our experimental values (Figures 1,2).

Further theoretical works also considered H_3S as responsible for the high temperature superconductivity [12-14]. Hirsch and Marsiglio proposed hole superconductivity as an alternative explanation [15]. Interestingly, metallic H_3S can be viewed essentially as atomic metallic hydrogen stabilized with sulfur [12].

High T_c can be expected in a wide range of hydrogen-containing materials. Hydrogen atoms seem to be indispensable to provide the high frequency modes in the phonon spectrum and the strong electron-phonon coupling.

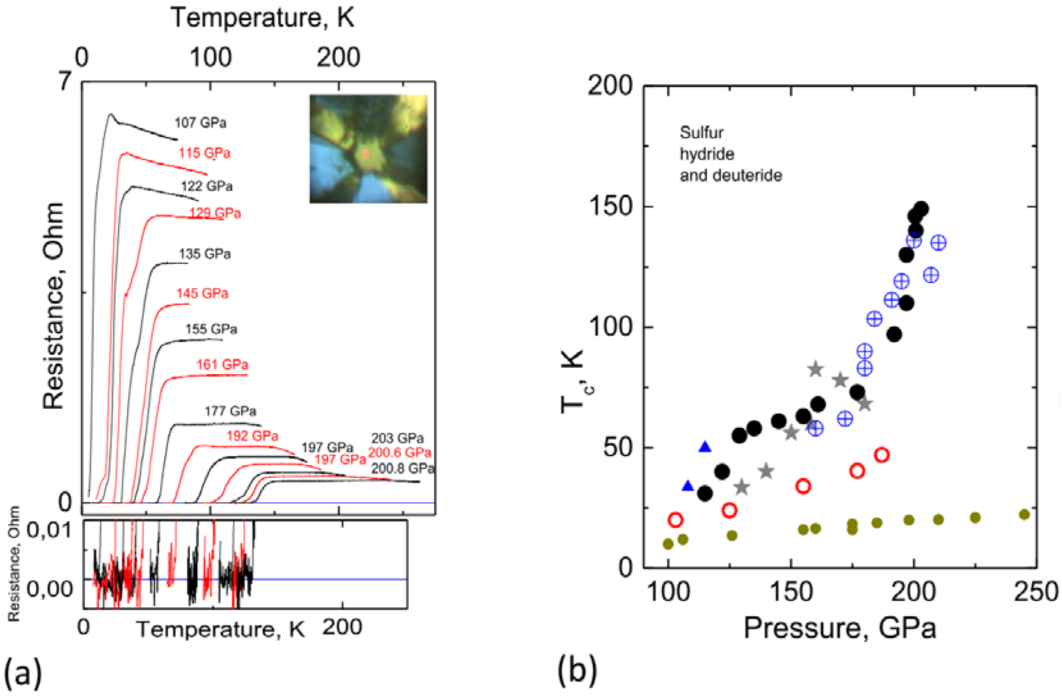

Fig. 1. Temperature dependence of resistance of sulfur hydride and sulfur deuteride measured at different pressures. Resistance was measured with four electrodes deposited on a diamond anvil. (a) Sulfur hydride as measured at the growing pressures. Plots at pressures <135 GPa were scaled (reduced in 5-10 times) for easier comparison with the higher pressure steps. (b) Data were obtained when pressure was applied in the 100-190 GPa pressure range at 100-150 K and higher temperatures at P~200 GPa when T_c sharply increased. Black points are data from Figure 1a. Blue points - other runs. Red points are measurements of D_2S. Dark yellow points are T_cs of pure sulfur. Grey stars are calculations from [9].

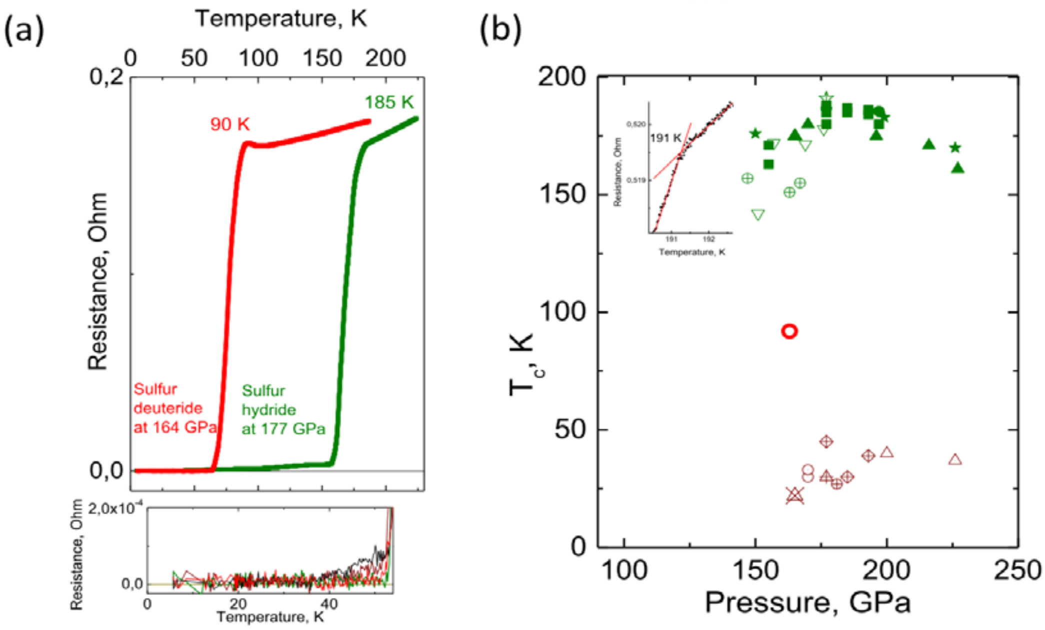

Fig. 2. Pressure dependence of critical superconducting temperature T_c on pressure. Comparison of the superconducting steps of sulfur deuteride and hydride at similar pressures. (b) Higher T_c~190 K found when pressure P> 150 GPa was applied in combination with 220-300 K temperatures. The 190 K step is accompanied with another step with T_c~30 K (wine points). The red point is T_c for D_2S sample (Figure 2a).

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