Electrical Transport Measurements on Layered La(O,F)BiS$_2$ under Extremely High Pressure

Ryo Matsumoto$^{1,2,*}$, Sayaka Yamamoto$^{2,3}$, Yoshihiro Nemoto$^4$, Yuki Nishimiya$^4$ and Yoshihiko Takano$^{2,3}$

$^1$ International Center for Young Scientists (ICYS), National Institute for Materials Science, Tsukuba 305-0047, Ibaraki, Japan
$^2$ International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science, Tsukuba 305-0047, Ibaraki, Japan; sayaka12243@gmail.com (S.Y.); takano.yoshihiko@nims.go.jp (Y.T.)
$^3$ Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba 305-8577, Ibaraki, Japan
$^4$ Electron Microscopy Analysis Station, National Institute for Materials Science, Tsukuba 305-0047, Ibaraki, Japan; nemoto.yoshihiro@nims.go.jp (Y.N.); nishimiya.yuki@nims.go.jp (Y.N.)

* Correspondence: matsumoto.ryo@nims.go.jp

Abstract: Layered La(O,F)BiS$_2$ exhibits drastic enhancements of the superconducting transition temperature ($T_c$) under high pressure among the BiS$_2$-based superconducting family. However, the high-pressure application beyond a high-$T_c$ phase of the monoclinic structure has not been conducted. In this study, the electrical transport properties in La(O,F)BiS$_2$ single crystal are measured under high pressures up to 83 GPa. An insulating phase without superconductivity is observed under a higher-pressure region above 16 GPa. Moreover, the sample exhibits metallicity and superconductivity above 60 GPa. The newly observed hidden semiconducting phase and reentrant superconductivity have attracted much attention in BiS$_2$-based compounds.

Keywords: superconductivity; high pressure; BiS$_2$

1. Introduction

Layered BiS$_2$-based superconductors, represented as La(O,F)BiS$_2$ [1], have opened various materials science properties, such as their anomalous upper critical field [2,3], thermoelectric performance [4–6], topological features [7], and superconductivity on high-entropy alloys [8], up for further investigation. Among them, the performance of the material at high-pressures has attracted considerable attention. The superconducting transition temperature ($T_c$) in La(O,F)BiS$_2$ at ambient pressure is 2.5 K with maximum F-doping [1]. The original $T_c$ is discretely enhanced with a structural phase transition from tetragonal to monoclinic [9]. Interestingly, the high-pressure phase and enhanced $T_c$ are quenchable to ambient pressure via high-pressure synthesis or annealing at 600–700 °C and 2 GPa [10]. According to theoretical calculation [11] and experimental observation of the isotope effect [12], the paring mechanism of superconductivity in the ambient tetragonal phase is unconventional. In contrast, the isotope effects on the high-pressure monoclinic phase suggest conventional phonon-mediated superconductivity [13]. Most layered BiS$_2$-based superconductors exhibit similar high-pressure effects [14–17]. Therefore, investigating the high-pressure effects on BiS$_2$-based materials is important for understanding its superconducting mechanism and increasing the maximum $T_c$.

The high-pressure study of La(O,F)BiS$_2$ is important because it has the highest $T_c$ among the BiS$_2$-based superconductors. La(O,F)BiS$_2$ exhibits superconductivity with a maximum $T_c$ = 2.5 K at ambient pressure by F doping into O in the parent compound of insulating LaOBiS$_2$ with a direct bandgap of 0.8–1.0 eV [1,18]. The electrical transport property under high pressure on polycrystalline La(O,F)BiS$_2$ has been investigated up to 18 GPa, and the $T_c$ exhibits a “dome-like” feature [9]. $T_c$ suddenly jumps up to 10.7 K by applying pressure at around 1 GPa, and monotonically decreased with increasing...
the pressure up to 18 GPa. Recently, similar high-pressure effects of $T_c$ enhancement and quench of higher-$T_c$ phase have been reported for single-crystalline La(O,F)BiS$_2$ [19]. However, the high-pressure study of La(O,F)BiS$_2$ above 18 GPa beyond a high-$T_c$ phase of the monoclinic structure has not been conducted.

A reemergence of superconductivity in a higher pressure region after the “dome-like” feature of $T_c$ has been reported in several materials. It attracts considerable attention because different superconducting properties compared with the original $T_c$, for instance, higher $T_c$ and robust superconductivity, are often observed. K$_x$Fe$_2$Se$_2$ and (Li$_{1-x}$Fe$_x$)OHFe$_{1+y}$Se at ambient pressure exhibit superconductivity at 30 K and 41 K. The superconductivity in these materials is rapidly suppressed by applying pressure. After further compression, K$_x$Fe$_2$Se$_2$ and (Li$_{1-x}$Fe$_x$)OHFe$_{1+y}$Se show reentrant superconductivity with higher $T_c$ of 48.7 K and 50 K than those of the original superconducting phase [20–22].

Recently, highly robust reentrant superconductivity in quasi-2D kagome metal CsV$_3$Sb$_5$ has been reported [23]. Inspired by the discoveries of the reentrant superconductivity, we conducted electrical transport measurements on superconducting La(O,F)BiS$_2$ under high pressure of up to 83 GPa using a diamond anvil cell (DAC) with a boron-doped diamond micro-electrode. A reemergence of superconductivity was observed in La(O,F)BiS$_2$ under 60 GPa. The in-situ Raman spectroscopy under high pressure and transmission electron microscope (TEM) observation of the recovered sample were performed to analyze the crystal structure.

2. Experimental Procedures

La(O,F)BiS$_2$ single crystals were grown using the high-temperature flux method based on that reported in the literature [24,25]. The starting materials of La$_2$S$_3$, Bi, Bi$_2$S$_3$, Bi$_2$O$_3$, and BiF$_3$ were weighed with a nominal composition of LaO$_{0.5}$F$_{0.5}$BiS$_2$ (total 0.8 g). CsCl and KCl flux with a molar ratio of 5:3 (total 5 g) were mixed using a mortar and were sealed in a quartz tube. The sample was heated at 900 °C for 10 h, cooled slowly to 600 °C at a rate of 1 °C/h, and then naturally cooled to room temperature in the furnace. The products were washed using distilled water after the sample was opened in the air. For comparison, the undoped LaOBiS$_2$ was also synthesized using the same method.

The chemical compositions of the products were determined by scanning electron microscopy (SEM) equipped with energy-dispersive X-ray spectroscopy (EDX) using a JSM-6010LA (JEOL) instrument. An X-ray diffraction (XRD) pattern of the obtained sample was collected using a Mini Flex 600 (Rigaku) with Cu Ka radiation ($\lambda = 1.5418$ Å). Refinement of the lattice parameters was performed by a Rietveld analysis using RIETAN-FP program [26]. In refinement, the tiny impurity peaks near 27° were excluded. The temperature dependence of the resistance in the range of 300 to 0.2 K at ambient pressure was measured by a four-probe method using an adiabatic demagnetization refrigerator option on a physical properties measurement system (Quantum Design). The high-pressure generation and the in-situ transport measurements were performed using a DAC with boron-doped diamond electrodes [27–29]. The anvil culet and gasket hole had diameters of 300 μm and 200 μm, respectively. The sample space was composed of SUS316 stainless steel, a cubic boron nitride pressure-transmitting medium, and a ruby powder pressure sensor. The generated pressure was determined using the ruby fluorescence method [30] and Raman shift of diamond [31] at room temperature. The Raman spectrum of the sample and fluorescence spectrum of ruby were acquired using an inVia Raman microscope (RENISHAW). TEM observation and atomic-resolution EDX mapping were conducted for the recovered sample from DAC using JEM-ARM200F (JEOL) to analyze the sample crystal structure further. The sample fabrication for TEM observation was performed using focused ion beam (FIB) apparatus JIB-4000 (JEOL).
3. Results and Discussion

The obtained sample of La(O,F)BiS$_2$ was evaluated at ambient pressure using the SEM/EDX observation, XRD analysis, and transport measurements. The inset of Figure 1a shows an SEM image of the obtained La(O,F)BiS$_2$ single crystal exhibiting a well-developed plate-like shape. The compositional ratio (La:Bi:S) was determined as 1.099:1.72 by normalizing La = 1 in the EDX analysis, which is consistent with the nominal cation composition. The upper pattern of Figure 1a shows the XRD signal from one piece of La(O,F)BiS$_2$ single crystal. The pattern only exhibited 00l diffraction peaks, indicating that the sample was a highly oriented crystal. The middle data of Figure 1a show the XRD pattern of the powdered La(O,F)BiS$_2$ single crystal with the fitting result of the Rietveld refinement. The green bars and blue spectrum indicate a peak position of the determined structure and a differential curve for the fitting. The analysis revealed that the sample crystallized with a tetragonal structure. The obtained lattice parameters and reliability factor were $a = 4.0729(2)$ Å, $c = 13.5001(16)$ Å, $R_{wp} = 10.3\%$. The EDX and XRD analyses establish that single crystal La(O,F)BiS$_2$ was obtained.

Figure 1. (a) XRD patterns with Cu Kα radiation ($\lambda = 1.5418$ Å) of the obtained La(O,F)BiS$_2$. The upper pattern is from one piece of single crystal. The middle data show the pattern from the powdered single crystal with the fitting result of Rietveld refinement. The green bars and blue spectrum indicate a peak position of the determined structure and a differential curve for the fitting. The inset shows an SEM image for one piece of single crystal. (b) Temperature dependence of normalized resistance in La(O,F)BiS$_2$ and LaOBiS$_2$ single crystals at ambient pressure.

Figure 1b shows the temperature dependence of normalized resistance at ambient pressure in single crystal of La(O,F)BiS$_2$, and undoped LaOBiS$_2$ as a reference. The undoped LaOBiS$_2$ exhibited no superconductivity down to 0.2 K. In contrast, the doped sample La(O,F)BiS$_2$, at ambient pressure, exhibited an onset $T_c$ of 1.7 K. According to the detailed structural analysis using a single crystalline XRD in the literature [25], LaO$_{1-x}$F$_x$BiS$_2$ with an actual F concentration $x \sim 0.23$ and $-0.46$ show the lattice constant $c = 13.547(4)$ and 13.345(4) Å, respectively. The actual F concentration $x$ of the obtained crystal in this study was estimated to be less than 0.23 because the lattice constant $c = 13.5001(16)$ Å was smaller than that of the previous report. In addition, based on the relationship between $T_c$ and the amount of F ($x$) in the LaO$_{1-x}$F$_x$BiS$_2$ single crystal reported in the literature [32], the value of $x$ was estimated to be less than 0.23, which was consistent with the estimated value from the XRD analysis.

Figure 2a shows the temperature dependence of resistance in La(O,F)BiS$_2$ single crystal under high pressure of 7.0 to 37 GPa. The sample exhibits a sharp drop to zero resistance at 7.0 GPa, corresponding to superconductivity. $T_c$ is drastically enhanced from that of ambient pressure because of the structural phase transition, as reported in a previous high-pressure study on single crystals [19]. $T_c$ monotonically decreased with the increasing
The superconducting transition could not be observed in the measured temperature range above 16 GPa, and the temperature dependence of the resistance exhibited a semiconducting tendency. In contrast, the semiconducting behavior was suppressed under further compression above 37 GPa, as seen in Figure 2b. At 60 GPa, a reemergence of superconducting transition was observed at around 3 K. In general, the pressure distribution in the sample chamber was quite large and affected the measured resistance under the extremely high-pressure region of the DAC. In particular, the semiconducting feature often remained after the insulator to metal transition due to the pressure distribution [33]. Therefore, the sample was considered to be metallic above 60 GPa, although the temperature dependence of the resistance was still semiconducting. As $T_c$ gradually increased, the resistance at the lowest temperature approached zero with the increasing pressure up to 83 GPa. The appeared drop of resistance was gradually suppressed by applying a magnetic field, as represented in Figure 2c. Such suppression was further evidence of the higher-pressure phase of superconductivity in La(O,F)BiS$_2$. The inset of Figure 2c shows the temperature dependence of the upper critical field $B_{c2}$. $T_c$ was determined from the intersection point between the straight line of the normal resistance region and the extended line from resistance after the superconducting transition. $B_{c2}(0)$ was estimated to be 2.6 T under 79 GPa from the parabolic fitting. From the Ginzburg–Landau (GL) formula, $B_{c2}(0) = \Phi_0/2\pi\xi(0)^2$, where $\Phi_0$ is the fluxoid and the coherence length at zero temperature $\xi(0)$ is estimated to be 11.2 nm.

Raman spectroscopy is often used to discuss the structure and vibration modes in the BiS$_2$-based compounds [19,34,35]. Figure 3a displays the Raman spectra of the La(O,F)BiS$_2$ single crystal up to 83 GPa from the ambient pressure. At ambient pressure, La(O,F)BiS$_2$ exhibited a Raman-active mode of $A_{1g}$ originating from the in-plane vibrations of Bi and S atoms at the gamma point [34]. At ambient pressure, the peaks at around 70 cm$^{-1}$ and 123 cm$^{-1}$ were clearly visible, identified as $A_{1g}$ symmetry. The positions of the corresponding peaks were slightly shifted to a higher wavenumber at 1.2 GPa. As reported in precise Raman analysis for La(O,F)BiS$_2$ single crystal [19], the original $A_{1g}$ mode disappeared, and new peaks appeared at 2.7 GPa. The change in the Raman spectrum suggested the struc-

![Figure 2](image-url)
tural phase transition from tetragonal to monoclinic with the discrete enhancement of $T_c$ in La(O,F)BiS$_2$. The observed peaks gradually shifted to a higher wavenumber with increasing the pressure up to 9.6 GPa. The intensity of the Raman peaks from the monoclinic structure became small above 13 GPa, suggesting an emergence of a new structure corresponding to the semiconducting phase without superconductivity. All the Raman peaks disappeared under further compression above 60 GPa, signaling another new structure or metallization. The reemergence of superconducting transition was observed in this pressure range. When pressure decreased to 15 GPa and ambient pressure, the Raman peaks were not recovered.

Figure 3. (a) Raman spectra of La(O,F)BiS$_2$ single crystal up to 83 GPa from the ambient pressure. The peak labeled “15 GPa(dec)” are the data from the decompression process. (b) Pressure dependence of $T_c^{\text{onset}}$ and $T_c^{\text{zero}}$ in La(O,F)BiS$_2$ single crystal up to 83 GPa.

Figure 3b shows the pressure dependence of $T_c$ in La(O,F)BiS$_2$ single crystal up to 83 GPa. At ambient pressure, the original $T_c$ with a tetragonal structure is 1.7 K (SC1). The $T_c$ is suddenly enhanced up to 8.2 K with applied pressure above 1 GPa due to the phase transition to a monoclinic structure (SC2). The steep reduction of $T_c$ with increasing the pressure in the monoclinic phase up to 13 GPa was possibly due to a phonon-hardening effect in conventional Bardeen–Cooper–Schrieffer type superconductors [36,37], as seen in the Raman analysis. The sample exhibited a semiconducting nature without superconductivity between 16 GPa and 50 GPa. Above 60 GPa, reentrant superconductivity was observed (SC3). Although the $T_c$s of SC3 was not higher than that of SC2, as in the case of Fe-based materials [20–22], quite robust pressure dependence of $T_c$ against the pressure was confirmed, such as Kagome metal [23]. In addition, the reentrant $T_c$ continued to enhance with increasing the pressure up to 83 GPa. For future research, the further application of pressure is expected to present the “dome-like” feature of $T_c$ in the SC3 phase of La(O,F)BiS$_2$. 
The TEM observation was conducted for the recovered sample of La(O,F)BiS$_2$ and as-grown La(O,F)BiS$_2$ single crystal in order to understand the origin of phase “SC3”. Figure 4a,b displays the scanning ion microscope images (SIM) of the as-grown and recovered La(O,F)BiS$_2$ single crystals before the TEM observation, respectively. The specimens were fabricated from the square region in (a) and (b) by the FIB, and their cross-sections were analyzed as seen in (c) and (d), respectively. Figure 4e shows a high-angle annular dark-field scanning TEM image taken with the incident beam parallel to the [10] direction of the as-grown La(O,F)BiS$_2$ single crystal. No distortion and stacking faults were observed in the scanning TEM image for the analyzed area. In contrast, the scanning TEM image for the recovered sample was highly distorted with amorphous parts, as seen in Figure 4f. Such an amorphous-like structure can be seen in the broader region in the recovered sample (see Figure S1). This is consistent with the disappearance of Raman peaks above 60 GPa. Figure 4g,h shows the atomic-resolution EDX mapping for certain expanded parts of the as-grown and recovered samples. The layered structure composed of alternate stacks of conducting layers BiS$_2$ and reservoir blocking layers La(O,F) was observed in both samples. Here, the blocking layer (La,O,F) in the recovered sample seemed to become thin compared with the original one (images with guidelines for the comparison are seen in Figure S2). The in-situ observation of the crystal structure under the pressure corresponding to phase “SC3” using XRD was expected in the future for a more detailed discussion on the origin of the reentrant superconductivity.

![Figure 4. Scanning ion microscope images (SIM) of the (a) as-grown and (b) recovered La(O,F)BiS$_2$ single crystals. SIM images of the specimen for TEM observation of the (c) as-grown and (d) recovered samples. High-angle annular dark-field scanning TEM images for the (e) as-grown and (f) recovered samples. Atomic-resolution EDX mapping images for the (g) as-grown and (h) recovered samples.](image)

4. Conclusions

The electrical transport property in layered La(O,F)BiS$_2$ single crystal was investigated under high pressure up to 83 GPa. The existence of a high-pressure phase with a higher $T_c$ of this material has already been investigated. This study successfully observed the high-pressure semiconducting phase without superconductivity and the reentrant superconductivity. The semiconducting phase exhibited different Raman peaks from the superconducting monoclinic structure. In addition, the reentrant superconducting phase showed no Raman peak, and the recovered sample had an amorphous-like morphology. Therefore, the crystal structures of newly observed phases were different from the original tetragonal and monoclinic structures. Because the reentrant superconductivity was robust against the pressure and the $T_c$ continued to enhance up to 83 GPa, further appli-
cation of pressure was expected. As a future investigation, the in-situ XRD analysis is expected to explain the origin of the reentrant superconductivity. The discovery of two high-pressure phases is important in order to understand further physics in the BiS$_2$-based superconductors.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/condmat7010025/s1, Figure S1: Wide view of high-angle annular dark field scanning TEM images for the recovered samples, Figure S2: Comparison between two EDX mapping images with a guideline of the blocking layers.

**Author Contributions:** Conceptualization, R.M.; Data curation, S.Y.; Investigation, R.M., S.Y., Y.N. (Yoshihiro Nemoto) and Y.N. (Yuki Nishimiya); Resources, Y.T.; Supervision, Y.T.; Visualization, R.M. and S.Y.; Writing—original draft, R.M.; Writing—review & editing, S.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Japan Science and Technology Agency grant number JP-MJMI17A2 and Japan Society for the Promotion of Science grant number 19H02177, 20H05644, and 20K22420.

**Data Availability Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Acknowledgments:** This work was partly supported by the JST-Mirai Program (grant no. JP-MJMI17A2) and JSPS KAKENHI (grant nos. 19H02177, 20H05644, and 20K22420). The fabrication of the diamond electrodes was partly supported by the NIMS Nanofabrication Platform in Nanotechnology Platform Project sponsored by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan. The TEM observation was carried out with the support of NIMS Electron Microscopy Analysis Station, Nanostructural Characterization Group. R.M. would like to acknowledge ICYS Research Fellowship, NIMS, Japan.

**Conflicts of Interest:** The authors declare no conflict of Interest.

**References**

1. Mizuguchi, Y.; Demura, S.; Deguchi, K.; Takano, Y.; Fujihisa, H.; Gotoh, Y.; Izawa, H.; Miura, O. Superconductivity in Novel BiS$_2$-Based Layered Superconductor LaO$_{1-x}$xFxBiS$_2$. *J. Phys. Soc. Jpn.* 2012, 81, 114725. [CrossRef]
2. Mizuguchi, Y.; Miyake, A.; Akiba, K.; Tokunaga, M.; Kajitani, J.; Miura, O. Anisotropic upper critical field of the BiS$_2$-based superconductor LaO$_{0.5}$F$_{0.5}$BiS$_2$. *Phys. Rev. B.* 2014, 89, 174515. [CrossRef]
3. Matsumoto, R.; Yamamoto, S.; Adachi, S.; Sakai, T.; Irifune, T.; Takano, Y. Diamond anvil cell with boron-doped diamond heater for high-pressure synthesis and in situ transport measurements. *Appl. Phys. Lett.* 2021, 119, 053502. [CrossRef]
4. Nishida, A.; Miura, O.; Lee, C.-H.; Mizuguchi, Y. High thermoelectric performance and low thermal conductivity of densified LaO$_{1-x}$F$_x$BiS$_2$. *Appl. Phys. Express* 2015, 8, 111801. [CrossRef]
5. Goto, Y.; Miura, A.; Sakagami, R.; Kamiyama, Y.; Moriyoshi, C.; Kuroiwa, Y.; Mizuguchi, Y. Synthesis, Crystal Structure, and Thermoelectric Properties of Layered Antimony Seleniums REOSbSe$_2$ (RE = La, Ce). *J. Phys. Soc. Jpn.* 2018, 87, 074703. [CrossRef]
6. Matsumoto, R.; Nagao, M.; Ochi, M.; Tanaka, H.; Hara, H.; Adachi, S.; Nakamura, K.; Murakami, R.; Yamamoto, S.; Irifune, T.; et al. Pressure-induced insulator to metal transition of mixed valence compound Ce(O,F)SbS$_2$. *J. Appl. Phys.* 2019, 125, 075102. [CrossRef]
7. Yang, Y.; Wang, W.-S.; Xiang, Y.-Y.; Li, Z.-Z.; Wang, Q.-H. Triplet pairing and possible weak topological superconductivity in BiS$_2$-based superconductors. *Phys. Rev. B* 2013, 88, 094519. [CrossRef]
8. Sogabe, R.; Goto, Y.; Mizuguchi, Y. Superconductivity in REO$_{0.5}$F$_{0.5}$BiS$_2$ with high-entropy-alloy-type blocking layers. *Appl. Phys. Express* 2018, 11, 053102. [CrossRef]
9. Tomita, T.; Ebata, M.; Soeda, H.; Takahashi, H.; Fujihisa, H.; Gotoh, Y.; Mizuguchi, Y.; Izawa, H.; Miura, O.; Demura, S.; et al. Pressure-Induced Enhancement of Superconductivity and Structural Transition in BiS$_2$-Layered LaO$_{1-x}$xFxBiS$_2$. *J. Phys. Soc. Jpn.* 2014, 83, 063704. [CrossRef]
10. Mizuguchi, Y.; Hiroi, T.; Kajitani, J.; Takatsu, H.; Kadowaki, H.; Miura, O. Stabilization of high-T$_c$ phase of BiS$_2$-based superconductor LaO$_{0.5}$F$_{0.5}$BiS$_2$ using high-pressure synthesis. *J. Phys. Soc. Jpn.* 2014, 83, 053704. [CrossRef]
11. Morice, C.; Akashi, R.; Koretsune, T.; Saxena, S.S.; Arita, R. Weak phonon-mediated pairing in BiS$_2$ superconductor from first principles. *Phys. Rev. B* 2017, 95, 180505. [CrossRef]
12. Hoshi, K.; Goto, Y.; Mizuguchi, Y. Selenium isotope effect in the layered bismuth chalcogenide superconductor LaO$_{0.6}$F$_{0.4}$Bi(S,Se)$_2$. *Phys. Rev. B* 2018, 97, 094509. [CrossRef]
13. Yamashita, A.; Usui, H.; Hoshi, K.; Goto, Y.; Kuroki, K.; Mizuguchi, Y. Possible pairing mechanism switching driven by structural symmetry breaking in BiS$_2$-based layered superconductors. *Sci. Rep.* 2021, 11, 230. [CrossRef] [PubMed]

14. Demura, S.; Deguchi, K.; Mizuguchi, Y.; Sato, K.; Horii, R.; Yamashita, A.; Yamaki, T.; Haru, H.; Watanabe, T.; Denholme, S.J.; et al. Coexistence of Bulk Superconductivity and Magnetism in CeO1–xFeBiS2. *J. Phys. Soc. Jpn.* 2015, 84, 043709. [CrossRef]

15. Tanaka, M.; Nagao, M.; Matsumoto, R.; Kataoka, N.; Ueta, I.; Tanaka, H.; Watauchi, T.; Takeya, H.; Takano, Y. Superconductivity and its enhancement under high pressure in “F-free” single crystals of CeOFeBiS$_2$. *J. Alloy. Compd.* 2017, 722, 467–473. [CrossRef]

16. Fujioka, M.; Matsumoto, R.; Yamaki, T.; Denholme, S.J.; Tanaka, M.; Takeya, H.; Yamaguchi, T.; Takahashi, H.; Takano, Y. Observation of a Pressure-Induced Phase Transition for Single Crystalline LaO$_{0.5}$F$_{0.5}$BiSe$_3$ Using a Diamond Anvil Cell. *J. Phys. Soc. Jpn.* 2015, 84, 95001. [CrossRef]

17. Selvan, G.K.; Kanagaraj, M.; Muthu, S.E.; Jha, R.; Awana, V.P.S.; Arumugam, S. Hydrostatic pressure effect on Tc of new Bi$_2$-based Bi$_4$O$_7$S$_2$ and NdO$_{0.5}$F$_{0.5}$BiS$_2$ layered superconductors. *Phys. Status Solidi 2013*, RKL 7, 510.

18. Miura, A.; Mizuguchi, Y.; Takei, T.; Kumada, N.; Magome, E.; Moriyoshi, C.; Kuroiwa, Y.; Tadanaga, K. Structures and optical absorption of Bi$_2$O$_2$S and LaOFeBi$_2$. *Solid State Commun.* 2016, 227, 19–22. [CrossRef]

19. Yamamoto, S.; Matsumoto, R.; Adachi, S.; Takano, Y. High-pressure effects on La(O,F)BiS$_2$ single crystal using diamond anvil cell with dual-probe diamond electrodes. *Appl. Phys. Express* 2021, 14, 043001. [CrossRef]

20. Sun, L.; Chen, X.-J.; Guo, J.; Gao, P.; Huang, Q.-Z.; Wang, H.; Fang, M.; Chen, X.; Chen, G.; Wu, Q.; et al. Re-emerging superconductivity at 48 kelvin in iron chalcogenides. *Nature 2012*, 483, 67–69. [CrossRef]

21. Selvan, G.K.; Kanagaraj, M.; Muthu, S.E.; Jha, R.; Awana, V.P.S.; Arumugam, S. Hydrostatic pressure effect on Tc of new Bi$_2$-based Bi$_4$O$_7$S$_2$ and NdO$_{0.5}$F$_{0.5}$BiS$_2$ layered superconductors. *Phys. Status Solidi 2013*, RKL 7, 510.

22. Shihi, P.; Sun, J.; Wang, S.; Jiao, Y.; Chen, K.; Sun, S.; Lei, H.; Uwatoko, Y.; Wang, B.; Cheng, J. High-Tc superconductivity up to 55 K under high pressure in a heavily electron doped Li$_{0.36}$(NH$_3$)$_2$Fe$_2$Se$_2$ single crystal. *Phys. Rev. B* 2018, 97, 020508(R). [CrossRef]

23. Chen, X.; Zhan, X.; Wang, X.; Deng, J.; Liu, X.-B.; Chen, X.; Guo, J.-G.; Chen, X. Highly Robust Reentrant Superconductivity in CsV$_3$Sb$_5$ under Pressure. *Chin. Phys. Lett.* 2021, 38, 057402. [CrossRef]

24. Demura, S.; Deguchi, K.; Mizuguchi, Y.; Sato, K.; Horii, R.; Yamashita, A.; Yamaki, T.; Haru, H.; Watanabe, T.; Denholme, S.J.; et al. Coexistence of Bulk Superconductivity and Magnetism in CeO1–xFeBiS2. *J. Phys. Soc. Jpn.* 2015, 84, 043709. [CrossRef]

25. Miura, A.; Mizuguchi, Y.; Takei, T.; Kumada, N.; Magome, E.; Moriyoshi, C.; Kuroiwa, Y.; Tadanaga, K. Structures and optical absorption of Bi$_2$O$_2$S and LaOFeBi$_2$. *Solid State Commun.* 2016, 227, 19–22. [CrossRef]

26. Chen, X.; Zhan, X.; Wang, X.; Deng, J.; Liu, X.-B.; Chen, X.; Guo, J.-G.; Chen, X. Highly Robust Reentrant Superconductivity in CsV$_3$Sb$_5$ under Pressure. *Chin. Phys. Lett.* 2021, 38, 057402. [CrossRef]

27. Matsumoto, R.; Sasama, Y.; Fujioka, M.; Irifune, T.; Takei, T.; Tanaka, M.; Yamaguchi, T.; Takeya, H.; Takano, Y. Note: Novel diamond anvil cell for electrical measurements using boron-doped metallic diamond electrodes. *Rev. Sci. Instrum.* 2016, 87, 076103. [CrossRef] [PubMed]

28. Matsumoto, R.; Irifune, T.; Tanaka, M.; Takeya, H.; Takano, Y. Diamond anvil cell using metallic diamond electrodes. *Jpn. J. Appl. Phys.* 2017, 56, 05FC01. [CrossRef]

29. Matsumoto, R.; Yamashita, A.; Haru, H.; Irifune, T.; Adachi, S.; Takeya, H.; Takano, Y. Diamond anvil cells using boron-doped diamond electrodes covered with undoped diamond insulating layer. *Appl. Phys. Express* 2018, 11, 053010. [CrossRef]

30. Mao, H.K.; Bell, P.M.; Shaner, J.W.; Steinberg, D.J. Specific volume measurements of Cu, Mo, Pd, and Ag and calibration of the ruby $R_1$ fluorescence pressure gauge from 0.06 to 1 Mbar. *J. Appl. Phys.* 1978, 49, 3276–3283. [CrossRef]

31. Akahama, Y.; Kawamura, H. High-pressure Raman spectroscopy of diamond anvil to 250 GPa: Method for pressure determination in the multimegabar pressure range. *J. Appl. Phys.* 1996, 94, 3748–3751. [CrossRef]

32. Higashinaka, R.; Miyazaki, R.; Mizuguchi, Y.; Miura, O.; Aoki, Y. Low-Temperature Enhancement in the Upper Critical Field of Underdoped LaO$_1$–xFe$_2$Bi$_2$ (x = 0.1–0.3). *J. Phys. Soc. Jpn.* 2018, 83, 075004. [CrossRef]

33. Matsumoto, R.; Hou, Z.; Haru, H.; Adachi, S.; Tanaka, H.; Yamamoto, S.; Saito, Y.; Takeya, H.; Irifune, T.; Terakura, K.; et al. Crystal Growth, Structural Analysis, and Pressure-Induced Superconductivity in a AgIn$_3$Se$_9$ Single Crystal Explored by a Data-Driven Approach. *Inorg. Chem.* 2019, 59, 325–331. [CrossRef] [PubMed]

34. Wu, S.F.; Richard, P.; Wang, X.B.; Lian, C.S.; Nie, S.; Wang, J.T.; Wang, N.L.; Ding, H. Raman scattering investigation of the electron-phonon coupling in superconducting Nd(O,F)BiS$_2$. *Phys. Rev. B* 2014, 90, 054519. [CrossRef]

35. Tian, Y.; Zhang, A.; Liu, K.; Ji, J.; Liu, J.; Zhu, X.; Wen, H.-H.; Jin, F.; Ma, X.; He, R.; et al. Raman scattering in superconducting NdO$_1$–xFeBi$_2$S$_5$ crystals. *Supercond. Sci. Technol.* 2015, 29, 15007. [CrossRef]

36. Lorenz, B.; Meng, R.L.; Chu, C.W. High-pressure study on MgB$_2$. *Phys. Rev. B* 2001, 64, 012507. [CrossRef]

37. McMillan, W.L. Transition Temperature of Strong-Coupled Superconductors. *Phys. Rev.* 1968, 167, 331–344. [CrossRef]