

Absence of superconductivity in a new FeS-based compound (FeOOH)FeS

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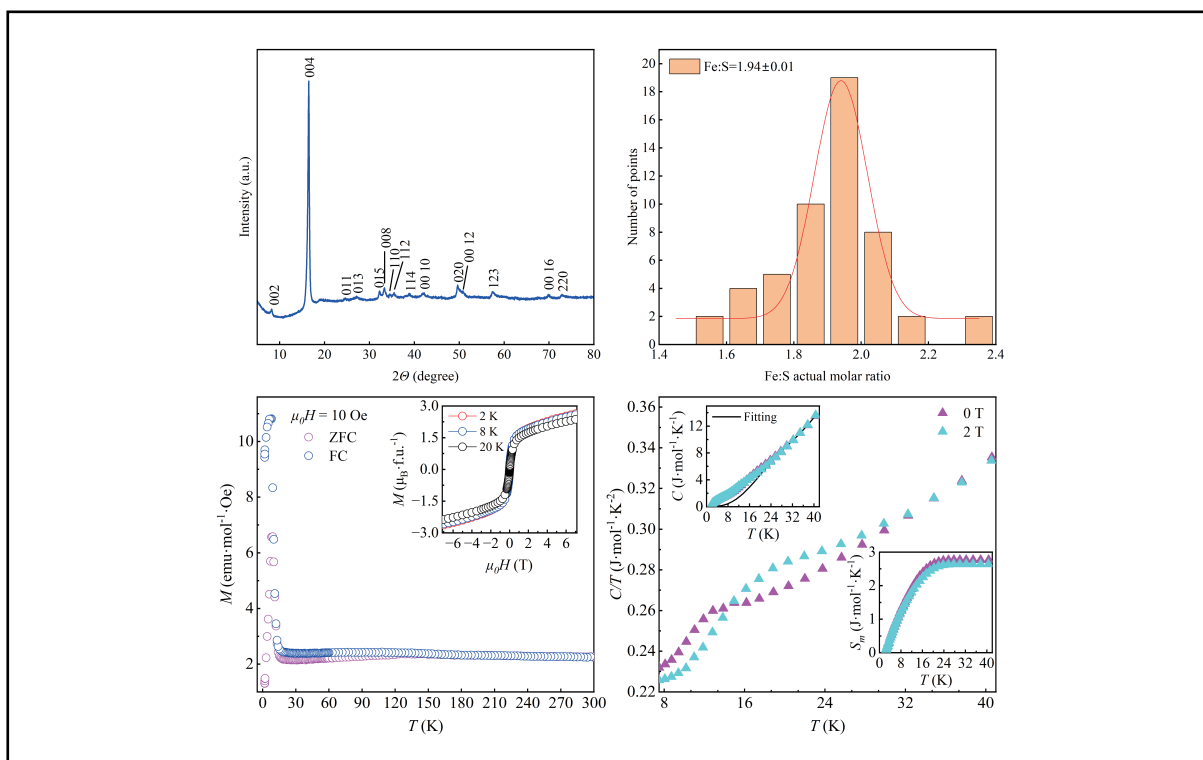
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Graphical abstract



Hydrothermal synthesis of (FeOOH)FeS reveals a ferromagnetic ground state and sheds new light on the absence of superconductivity in FeS-based compounds.

Public summary

- A novel FeS-based compound, (FeOOH)FeS, was successfully synthesized in a single step using a simple hydrothermal method.
- Magnetic susceptibility and specific heat measurements reveal that (FeOOH)FeS undergoes a ferromagnetic transition at 15 K, with the peak observed near 10 K likely associated with the onset of a superparamagnetic state.
- We propose that the absence of superconductivity in (FeOOH)FeS is likely not directly caused by Fe vacancies within the FeS layers, offering a new perspective for understanding the lack of superconductivity in most FeS-based compounds.

Absence of superconductivity in a new FeS-based compound (FeOOH)FeS

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Supporting Information

Abstract: We successfully synthesized the tetragonal FeS-based compound (FeOOH)FeS through a hydrothermal method and optimized the ratio of the starting reaction materials Fe and Na₂S·9H₂O. Magnetic susceptibility and specific heat measurements revealed that (FeOOH)FeS undergoes a ferromagnetic transition at 15 K, whereas the peak observed at approximately 10 K in the magnetic susceptibility curve is closely related to the system entering a superparamagnetic state. Importantly, on the basis of the specific heat results, the Debye temperature and average phonon velocity in (FeOOH)FeS are calculated to be 108.2 K and 1026.3 m·s⁻¹, respectively. We suggest that the absence of superconductivity in (FeOOH)FeS may not be linked to the Fe vacancy in the FeS layer, offering a new explanation for the absence of superconductivity in most FeS-based compounds.

Keywords: hydrothermal method; Fe-based compound; (FeOOH)FeS; magnetism

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1 Introduction

Fe(Se,S) superconductors, as important members of the Fe-based superconductor family, have attracted significant attention because of their simple structure, highly tunable chemical composition, and two-dimensional layered parent structure formed by a tetrahedral arrangement of Fe atoms with Se or S atoms^[1–3]. Notably, while FeSe-based intercalation compounds exhibit easily tunable superconductivity^[4], FeS-based compounds tend to lose superconductivity and display semiconductor-like behavior, sparking extensive debate about the underlying physical mechanisms^[5–11]. Most researchers believe that intercalation causes a small number of Fe atoms to precipitate from the FeS layers, forming Fe vacancies and thereby destroying superconductivity. However, Lin et al.^[7] suggested that the superconductivity in LiOHFeS is associated with the *c*-axis length, whereas Zhou et al.^[8] proposed that it depends on both the lattice structure and the level of electron doping.

Overall, the current understanding of FeS-based compounds remains limited, primarily due to the scarcity of such compounds. Therefore, synthesizing new materials is essential for gaining deeper insights into the intrinsic physics of the FeS-based system. Currently, all FeS-based compounds are synthesized via the solvothermal method rather than the traditional solid-phase method because S tends to volatilize easily and has a high saturated vapor pressure, making it unfavorable for reactions. For example, (C₂H₈N₂)_xFeS, Li_x(C₂H₈N₂)_yFeS, and Na_x(C₂H₈N₂)_zFeS were successfully synthesized with amine as the solvent^[10], whereas

(Li_{0.85}Fe_{0.15}OH)FeS^[6], [(Na_{0.5}Fe)(OH)₂]FeS^[8], and (Na_{0.58}OH)Fe_{0.92}S^[9] were synthesized with water as the solvent. Notably, the LiOHFeS single crystal^[7], which was successfully synthesized via the ion-exchange method, is also considered a type of solvothermal synthesis.

In this work, we successfully synthesized a novel FeS-based compound, (FeOOH)FeS, via a hydrothermal method. We conducted a detailed structural characterization and systematically studied its magnetic, heat capacity, and transport properties while also discussing the possible reasons for the absence of superconductivity in (FeOOH)FeS. Our work adds a new member to the FeS-based family, providing a new material for understanding the physical properties of FeS-based systems.

2 Experimental section

2.1 Synthesis of FeS

The reduced iron powder (Fe, 99.99%, Alfa Aesar) and sodium sulfide nonahydrate (Na₂S·9H₂O, ≥98%, Aladdin) were mixed at a molar ratio of 1 : 1 and placed into a 25 mL Teflon-lined stainless-steel autoclave, followed by the addition of 15 mL of deionized water^[12]. The sealed autoclave was maintained at 170 °C for approximately one week to obtain pure-phase tetragonal FeS.

2.2 Synthesis of (FeOOH)FeS

Tetragonal (FeOOH)FeS was synthesized via a hydrothermal method. Reduced iron powder (Fe, 99.99%, Alfa Aesar) and

sodium sulfide nonahydrate ($\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$, $\geq 98\%$, Aladdin) were mixed at a nominal molar ratio of 1 : 0.6, along with 18 mL of deionized water. The mixture was sealed in a 25 mL Teflon-lined stainless-steel autoclave and heated at 170 °C for 20 d (as described in detail in Fig. S1 in Supporting information). After cooling, the resulting samples were obtained by washing the reaction mixture several times with deionized water and ethanol, followed by drying in a vacuum chamber at room temperature for 1 d.

2.3 Characterization

The characterization of the (FeOOH)FeS samples was conducted via various techniques. X-ray diffraction (XRD) data of the samples were collected with a Philips X-ray diffractometer equipped with Cu $K\alpha$ radiation ($\lambda = 1.5418 \text{ \AA}$) at 40 kV and 40 mA. The morphology and actual molar ratio of (FeOOH)FeS were analyzed by scanning electron microscopy (SEM, JEOL JSM-6700F), high-resolution transmission electron microscopy (HRTEM, Talos F200X), and energy-dispersive X-ray spectroscopy (EDX, JEOL-2100F). The valence of the elements in (FeOOH)FeS was detected via X-ray photoelectron spectroscopy (XPS, Kratos AXIS SUPRA+). Thermogravimetric analysis combined with Fourier transform infrared spectroscopy (TG-FTIR, TL9000) was conducted to determine the composition of (FeOOH)FeS at a heating rate of 10 °C·min⁻¹ from room temperature to 500 °C under a helium flow (30 mL·min⁻¹). Raman spectroscopy, with an excitation wavelength of 532 nm, was performed on a high-resolution Raman spectrometer (HORIBA JY LabRAM HR Evolution) to analyze the valence states of (FeOOH)FeS. Magnetic property measurements were carried out via Magnetic Property Measurement System 3 (MPMS3, Quantum Design), whereas specific heat and resistivity measurements via the standard four-probe method were performed via Physical Property Measurement System (PPMS, Quantum Design). The magnetic properties were measured through a field cooled warming (FCW) process, and the specific heat was measured through the relaxation method.

3 Results and discussion

As shown in Fig. 1, the lattice parameters of (FeOOH)FeS were refined by a least-squares fit using more than 15 XRD peaks, and it belongs to the body-centered tetragonal crystal structure lattice with $a = b = 3.6705 \text{ \AA}$, $c = 21.491 \text{ \AA}$, and angles $\alpha = \beta = \gamma = 90^\circ$ (Table 1).

In contrast to FeS, which presents relatively dispersed micron-sized flakes (Fig. S2), the surface morphology of (FeOOH)FeS generally has a rectangular shape and adheres to each other, as shown in Fig. 2a. Furthermore, EDX element mapping revealed a uniform distribution of Fe and S within the test area, and it is worth noting that O was concentrated on the sample, whereas the O detected around the sample was due to unavoidable interference from O₂ (Fig. 2b). The EDX spectrum further confirmed that (FeOOH)FeS contains Fe, S, and O, but it should be noted that H is too light to be detected (Fig. 2c). In addition, owing to the poor conductivity of the sample, a certain amount of Pt was sputtered onto the surface during EDX testing, resulting in a noticeable presence of Pt in

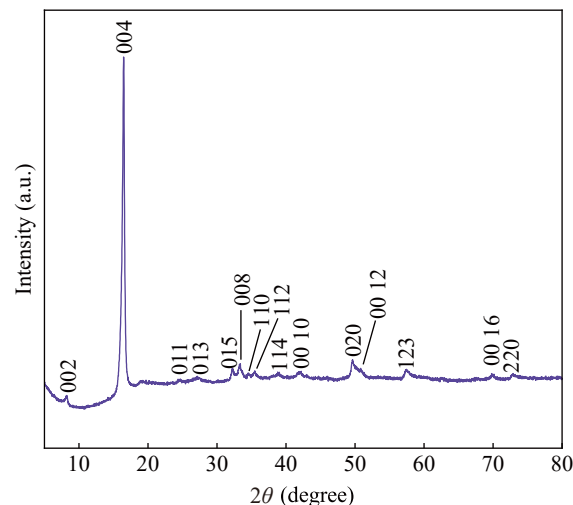


Fig. 1. XRD pattern of (FeOOH)FeS. Almost all the main peaks can be indexed to a tetragonal structure with $a = b = 3.6705 \text{ \AA}$ and $c = 21.491 \text{ \AA}$.

Table 1. Crystal indexing data of (FeOOH)FeS.

$d_{\text{obs.}}$	$d_{\text{cal.}}$	hkl
10.735	10.745	002
5.375	5.373	004
3.630	3.618	011
3.273	3.267	013
2.777	2.791	015
2.689	2.686	008
2.598	2.595	110
2.533	2.523	112
2.331	2.337	114
2.152	2.149	0010
1.837	1.835	020
1.786	1.791	0012
1.605	1.600	123
1.345	1.343	0016
1.299	1.298	220

the element spectrum. To accurately determine the Fe : S ratio of the (FeOOH)FeS samples, we performed Gaussian fitting on EDX data from multiple tests (Fig. 2d)^[12,13], resulting in an Fe : S ratio of 1.94014 ± 0.01035 .

To confirm the crystal structure, we conducted HRTEM and corresponding selected area electron diffraction (SAED) tests on different regions of (FeOOH)FeS (Fig. 3). The yellow parallelogram in Fig. 3c represents a hexagonal crystal system, where the measured d -spacing of 2.66 Å is in close agreement with the d -spacing of 2.55 Å for the (100) plane in FeOOH (PDF #01--077--0247). This slight deviation may result from the influence of the FeS substructure on the FeOOH lattice parameters. The red rectangle in Fig. 3c indicates diffraction spots from a tetragonal crystal system, in which the (200) diffraction spot is attributed to the synthesized (FeOOH)FeS. However, the appearance of the (110) diffraction spot, which is forbidden in a body-centered tetragonal

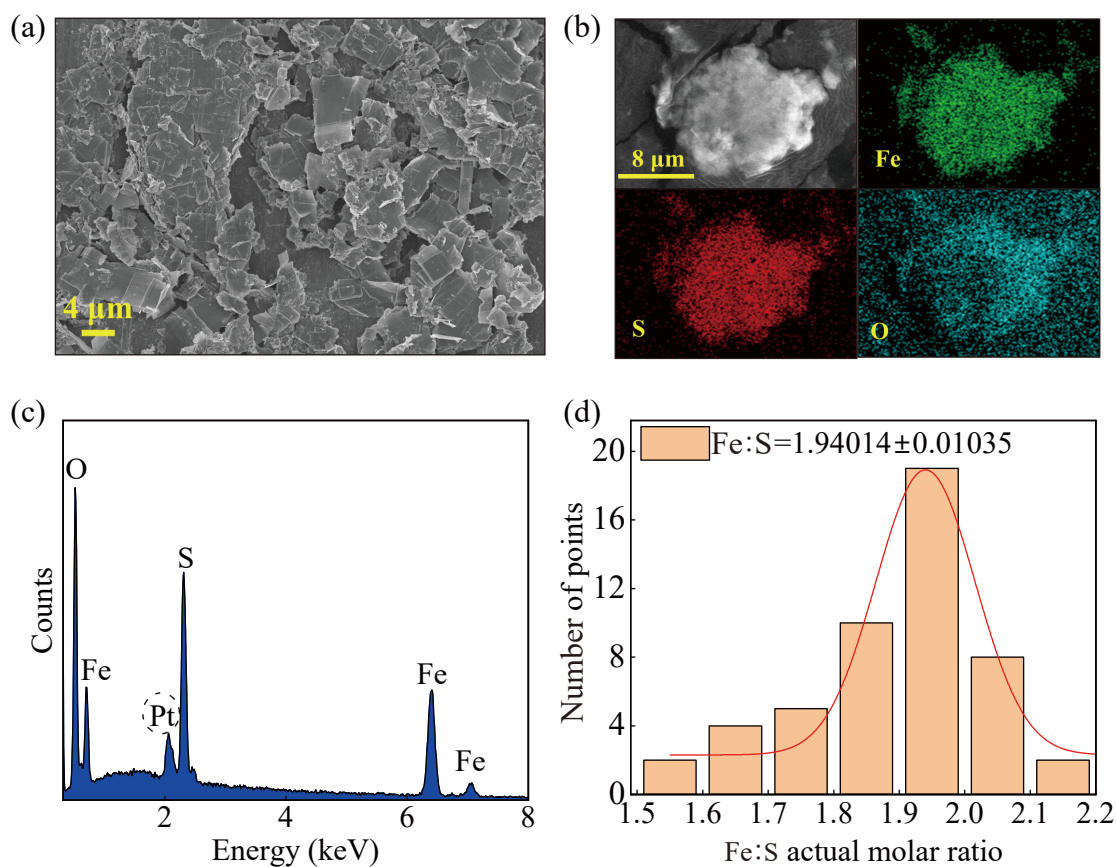


Fig. 2. Micromorphology and elemental composition of (FeOOH)FeS. (a) SEM. (b) EDX elemental mapping. (c) EDX spectrum. (d) The actual molar ratios of Fe and S. The red solid line is fitted by the Gaussian function, and the experimental data are from the EDX.

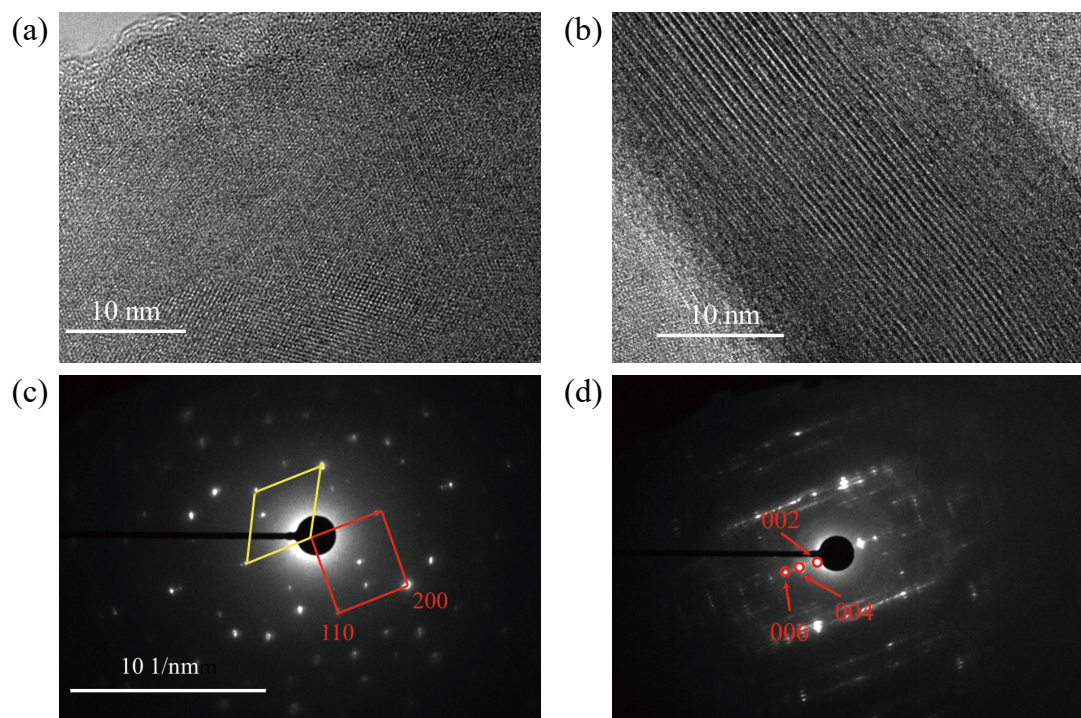


Fig. 3. (a, b) HRTEM images of (FeOOH)FeS in different selected regions. (c, d) The corresponding selected area electron diffraction (SAED) images of (a) and (b), respectively.

lattice, suggests that the sample is in a metastable phase and decomposes into the tetragonal FeS parent phase under electron beam irradiation. The FeS phase belongs to a primitive tetragonal lattice with a lattice constant of $a = 3.68 \text{ \AA}$, which is close to that of (FeOOH)FeS. As shown in Fig. 3b, the layered structure of (FeOOH)FeS is clearly visible, and further, the (00l) planes can also be identified in Fig. 3d.

Notably, although (FeOOH)FeS has a distinct layered structure (Fig. 3b), we remain cautious in categorizing it definitively as an intercalation compound. Conventionally, intercalation compounds are synthesized via a two-step process: first, a layered host (such as FeS) is prepared, followed by a secondary reaction to introduce guest species into the inter-layer space. In contrast, the (FeOOH)FeS compound in this study was synthesized via a simple one-step hydrothermal method, in which the FeS framework and the potential intercalant may have formed simultaneously. Therefore, we currently lack direct evidence confirming the successful intercalation of FeOOH species into the FeS host structure. Further structural characterization and kinetic studies are needed to clarify the nature of this compound.

To investigate the thermal stability of (FeOOH)FeS, we

tested its TG curve under a He atmosphere. As the temperature increases from $30 \text{ }^{\circ}\text{C}$ to $205 \text{ }^{\circ}\text{C}$ (Fig. 4a), the mass of (FeOOH)FeS decreases by approximately 0.8%, primarily due to the evaporation of adsorbed water from the surface of the sample. As the temperature continues to rise, the TG curve rapidly decreases, and at approximately $350 \text{ }^{\circ}\text{C}$, the mass of the system decreases by approximately 5%. When it exceeds $350 \text{ }^{\circ}\text{C}$, the mass remains stable and does not change further, as shown in Fig. 4a. Moreover, we further analyzed the composition of volatile substances in the system at different calcination temperatures, as shown in Fig. 4b. At $30 \text{ }^{\circ}\text{C}$, the infrared spectrum only shows a small fluctuation at approximately 2400 cm^{-1} . However, when the temperature increases to $200 \text{ }^{\circ}\text{C}$, peaks corresponding to water are observed in the $1300\text{--}1900 \text{ cm}^{-1}$ and $3500\text{--}3900 \text{ cm}^{-1}$ ranges^[14]. At $281 \text{ }^{\circ}\text{C}$, which corresponds to the temperature range where the system decomposes rapidly, the intensity of the water-related peaks increases. Furthermore, at $500 \text{ }^{\circ}\text{C}$, the intensity of the water-related peaks decreases significantly.

After testing the TG curve of the sample ($T = 500 \text{ }^{\circ}\text{C}$), we collected it and conducted XRD, as shown in Fig. 4c. Under He gas flow, (FeOOH)FeS primarily decomposes into

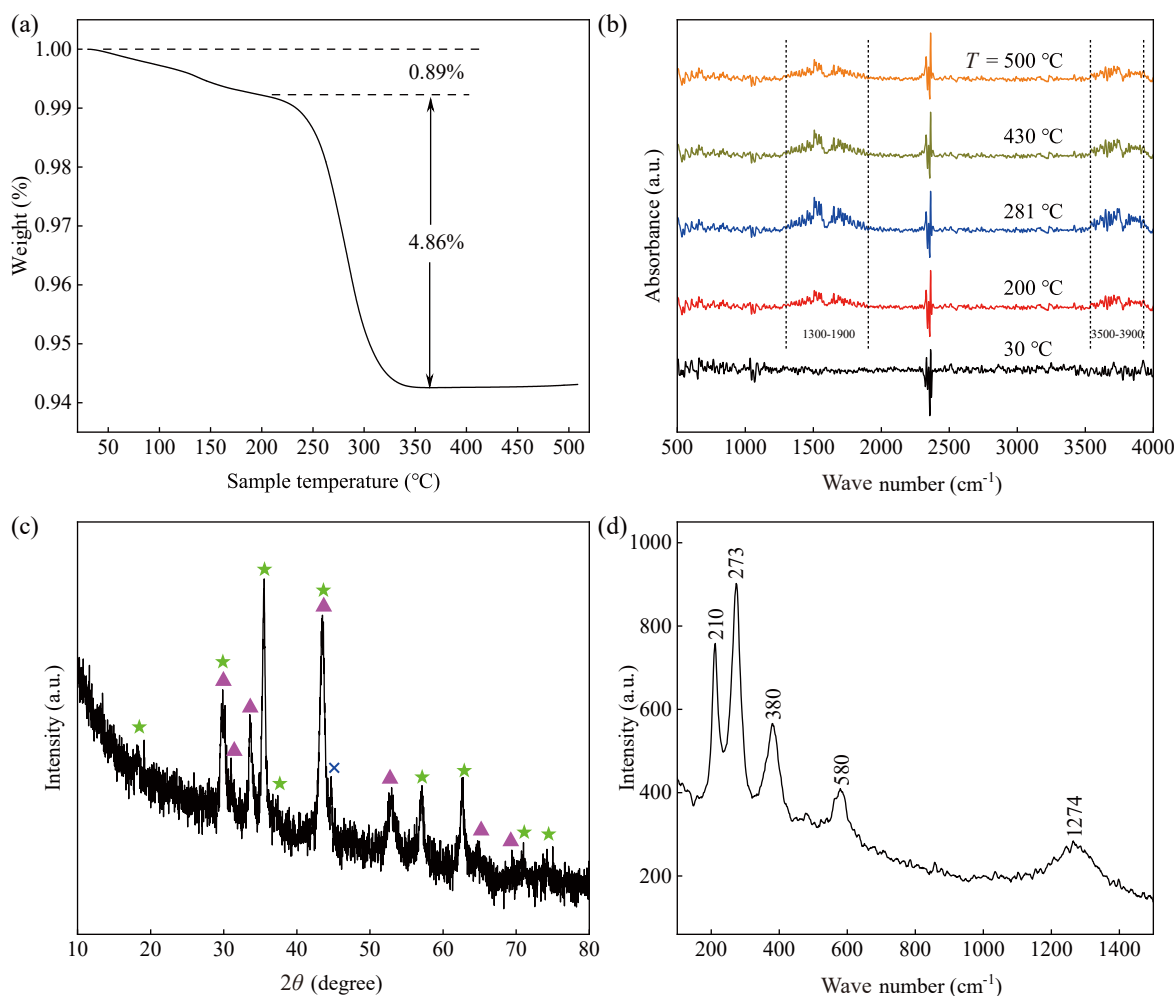


Fig. 4. (a) Thermogravimetric (TG) curve of (FeOOH)FeS in a flowing He atmosphere from $30 \text{ }^{\circ}\text{C}$ to $500 \text{ }^{\circ}\text{C}$. (b) Detection of the collected gases during the TG process. (c) XRD pattern of the product calcined at $500 \text{ }^{\circ}\text{C}$ under He gas flow; $\blacktriangle$ represents $h\text{-FeS}$, $\times$ represents Fe, and $\star$ represents Fe_3O_4 . (d) Raman spectroscopy at $30 \text{ }^{\circ}\text{C}$.

hexagonal-phase FeS (*h*-FeS) and Fe₃O₄ as the temperature increases from 30 °C to 500 °C. In an oxygen-deficient high-temperature environment, the chemical bond between OH and Fe in the (FeOOH)FeS crystal breaks, resulting in the formation of water between OH groups, while the remaining oxygen reacts with Fe to produce Fe₃O₄. As shown in Fig. 4d, the room temperature Raman results of (FeOOH)FeS reveal strong peaks at 210 cm⁻¹ and 273 cm⁻¹, which are typically attributed to the asymmetric and symmetric stretching modes of low-crystallinity FeS^[15]. The peak at 380 cm⁻¹ may originate from α -FeOOH^[15], but it is not clear which chemical bonds play a key role, while the peak at 1274 cm⁻¹ is likely due to the bending vibrations of the O–H bonds in α -FeOOH^[16,17]. Moreover, the Raman peak located at 580 cm⁻¹ originated from the vibration of Fe–O chemical bonds.

The characteristic peaks of O, S, and Fe can be obtained through the XPS spectrum of (FeOOH)FeS, further confirming the valence of the elements in the compound. Like those of α -FeOOH^[18], the O 1s XPS spectra can be well divided into three peaks corresponding to 529.74 eV (Fe–O), 531.28 eV (Fe–OH), and 532.71 eV (O–H) (Fig. 5a). The S 2p XPS spectra can be decomposed into two main peaks: S²⁻ 2p_{1/2} at 162.41 eV and S²⁻ 2p_{3/2} at 161.33 eV^[19]. The Fe 2p XPS spectra can be decomposed into several peaks due to the different valences in (FeOOH)FeS: Fe²⁺ 2p_{1/2} at 719.8 eV, Fe²⁺ 2p_{3/2} at 707.56 eV, Fe⁺³ 2p_{1/2} at 723.61 eV, and Fe⁺³ 2p_{3/2} at 710.28 eV^[18,19].

Compared with the tetragonal superconductor FeS (Fig. S3), (FeOOH)FeS appears to lack superconductivity within the entire temperature range (Fig. 6a and Fig. S4). The zero-field-cooling (ZFC) and field-cooling (FC) magnetic susceptibility curves exhibit a weak temperature dependence between 15 K and 300 K, with a bifurcation appearing at approximately 130 K. Below 15 K, the magnetic susceptibility curve rises sharply, peaking at approximately 10 K, before rapidly decreasing below 10 K. In view of this, we can infer that the system undergoes a ferromagnetic/ferrimagnetic transition at approximately 15 K.

To investigate the physical origin of the peak in the magnetic susceptibility curve at approximately 10 K, we performed AC magnetic susceptibility tests within this temperature range, as shown in Fig. 6b. The real and imaginary parts of the AC magnetic susceptibility clearly exhibit a peak near 10 K with no significant frequency dependence, suggesting the absence of a spin glass state or a cluster glass state in the (FeOOH)FeS system^[20,21]. Importantly, considering the size

effect in the sample (Fig. 6a), this unusual magnetic behavior at approximately 10 K is likely related to superparamagnetic relaxation, with the particle size influencing the maximum of the peak^[22–24]. The superparamagnetism phenomenon often occurs in magnetic samples at the nanometer scale, but in some magnetic samples at the micron meter or submicron meter scale, their magnetic susceptibility curves also exhibit superparamagnetism behavior at low temperatures, such as those of Sr₆(Co_{0.8}Fe_{0.2})₅O₁₅^[22]. Moreover, across the entire range of sweeping magnetic fields from 0 T to 7 T, 7 T to –7 T, and –7 T to 7 T, (FeOOH)FeS exhibits ferromagnetic properties, the coercive field is approximately 0.025 T, and the effective magnetic moment is approximately 2.5 μ_B at 7 T and 2 K (inset of Fig. 6a).

The specific heat (*C*) curve at 0 T from the cooling test reveals a shoulder-like behavior at approximately 15 K (Fig. 6c), which shifts to higher temperatures as the magnetic field increases to 2 T. This behavior aligns with the magnetic susceptibility results, confirming the occurrence of a ferromagnetic transition in the system. To gain a clearer understanding of the magnetic specific heat (*C_m*), the phonon contribution to the specific heat at 0 T was subtracted via the formula $C_{ph} = \beta T^3 + \beta_5 T^5 + \beta_7 T^7$, (solid line in the inset of Fig. 6c)^[25], and the coefficients $\beta = 9.24 \times 10^{-4}$ J·mol⁻¹·K⁻⁴, $\beta_5 = -1.09 \times 10^{-6}$ J·mol⁻¹·K⁻⁴, and $\beta_7 = 5.94 \times 10^{-4}$ J·mol⁻¹·K⁻⁴ were obtained.

Furthermore, using the formulas^[26] $\Theta_D = \frac{\hbar v_p}{k_B} \left(\frac{6\pi^2 N s}{V} \right)^{\frac{1}{3}}$ and $\beta = \frac{12\pi^4 R s}{5 \Theta_D^3}$, the Debye temperature Θ_D and average sound velocity v_p of (FeOOH)FeS are 108.2 K and 1026.3 m·s⁻¹, respectively, where *N*, *s*, *V*, and *R* represent the number of molecules per mole, the number of atoms in each molecule, the volume of the unit cell, and the universal gas constant, respectively. Furthermore, we calculated the magnetic entropy (*S_m*) in the (FeOH)FeS system via $S_m = \int_0^T \frac{C_m}{T} dT = \int_0^T \frac{C - C_{ph}}{T} dT$ (Fig. 6c) and obtained saturated magnetic entropies of 2.76 J·K⁻¹·mol⁻¹ and 2.63 J·K⁻¹·mol⁻¹ at 40 K at 0 T and 2 T, respectively.

The electrical transport results show that no superconducting state is detected throughout the entire testing temperature range, as shown in Fig. 6d. As the temperature decreases, the resistivity increases sharply from 62.94 Ω ·mm at 300 K to 1.06×10^7 Ω ·mm at approximately 6 K, indicating semiconductor-like behavior. This trend closely resembles the temperature-dependent resistivity behavior observed in FeS

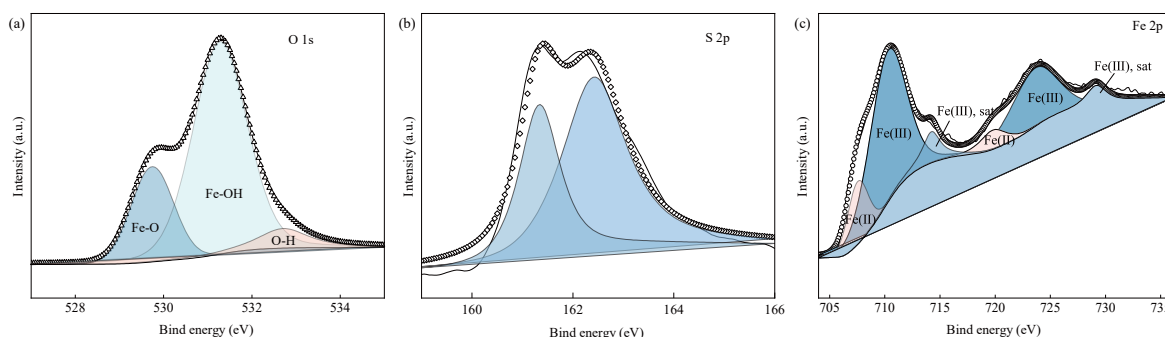


Fig. 5. XPS spectra of (FeOOH)FeS. (a) O 1s spectrum. (b) S 2p spectrum. (c) Fe 2p spectrum.

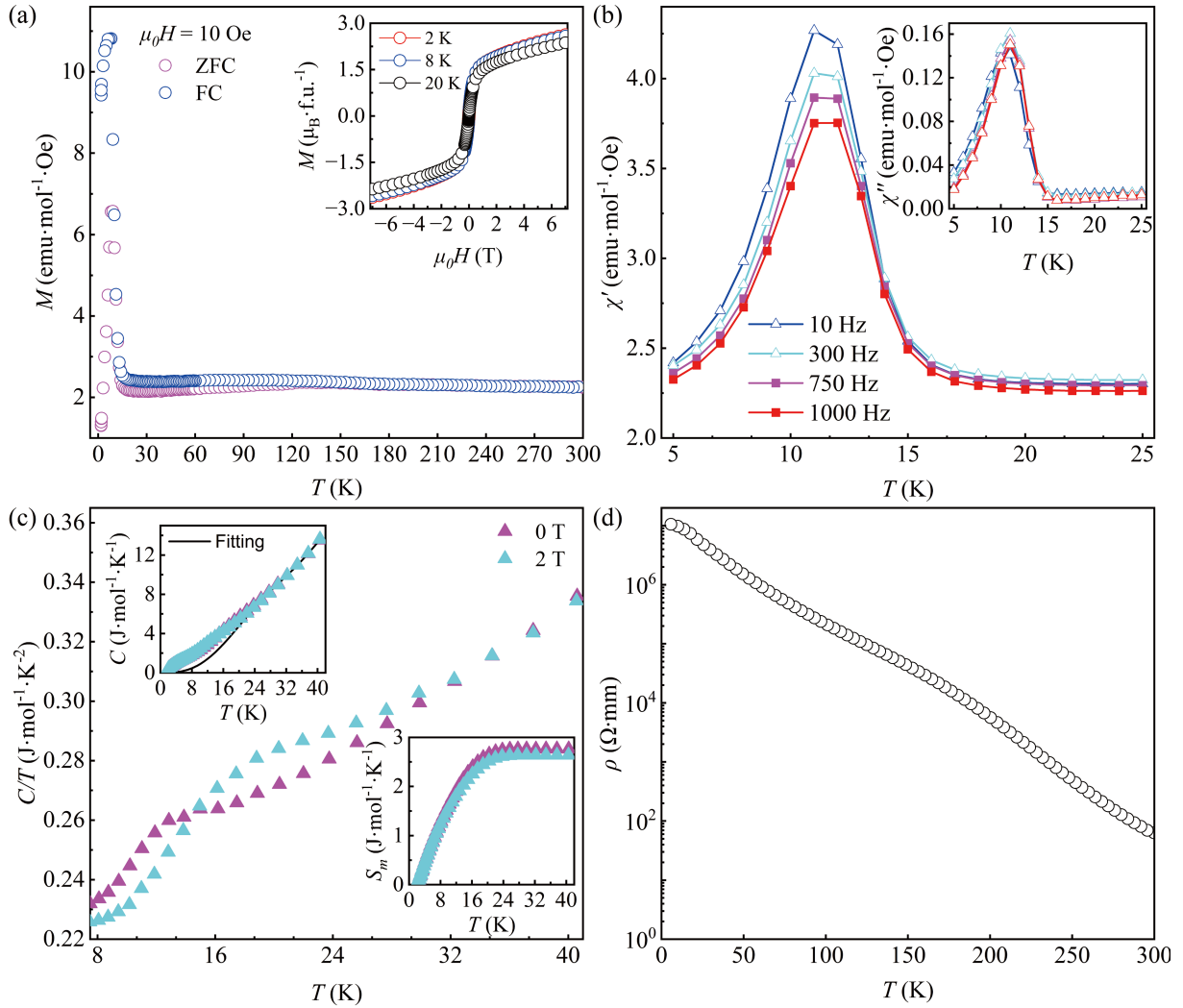


Fig. 6. Magnetic, specific heat and transport properties of (FeOOH)FeS. (a) ZFC and FC magnetic susceptibilities. Inset: isothermal magnetization $M(H)$ at various temperatures. (b) Real part of the AC susceptibility (χ') measured at zero DC field with frequencies ranging from 10–1000 Hz. The inset shows the imaginary principle of the AC susceptibility (χ''). (c) Specific heat under 0 T and 2 T. Upper inset: the solid lines represent data fitting via the phonon specific heat formula $C_{ph} = \beta T^3 + \beta_5 T^5 + \beta_7 T^7$. Lower inset: the magnetic entropy S_m . (f) Temperature dependence of the resistivity of (FeOOH)FeS measured at 0 T.

Table 2. Different types of FeS-based compounds.

Sample name	SC/NSC	T_c /K	Reference
(FeOOH)FeS	NSC	–	Our result
(C ₂ H ₈ N ₂) _x FeS	NSC	–	[10]
Li _x (C ₂ H ₈ N ₂) _y FeS	NSC	–	[10]
Na _x (C ₂ H ₈ N ₂) _y FeS	NSC	–	[10]
(Na _{0.58} OH)Fe _{0.92} S	NSC	–	[9]
K _{1.1} Fe _{1.6} S ₂	NSC	–	[8]
[(Na _{0.5} Fe)(OH) ₂]FeS	NSC	–	[8]
[(Li _{0.8} Fe _{0.2})OH]FeS	NSC	–	[11]
(Li _{0.85} Fe _{0.15} OH)FeS	NSC	–	[6]
(Li _{0.8} Fe _{0.2})OHFeS	NSC	–	[5]
LiOHFeS	NSC	–	[7]
LiOHFeS	SC	2.8	[7]
(Li _{0.85} Fe _{0.15} OH)FeS	SC	3–8	[8]

SC represents the superconductor, NSC represents the nonsuperconductor, and T_c represents the superconducting transition temperature.

intercalation compounds, such as (C₂H₈N₂)_xFeS, (Na_{0.58}OH)Fe_{0.92}S, Li_x(C₂H₈N₂)_yFeS, and Na_x(C₂H₈N₂)_yFeS^[9,10] (Table 2). Furthermore, we analyzed the resistance data via the variable range hopping (VRH) model, $\rho = \rho_0 \exp\left[\left(\frac{T_0}{T}\right)^4\right]$ ^[27], (red solid line in Fig. S5a), and the small polaron hopping (SPH) model, $\rho(T)/T \propto \exp(E_p/k_B T)$ ^[6], (blue solid line in Fig. S5b). We found that both models reasonably fit the data in the temperature range from 190 K to 295 K.

In our recent work^[12], we confirmed that superconducting FeS has an Fe-to-S molar ratio of 1.155–1.274, which is consistent with the findings of Berner^[28] and Sines et al.^[29], who reported that superconductivity is not observed in the FeS system when the Fe-to-S molar ratio approaches 1 : 1. Regarding the form in which excess Fe exists in the FeS superconducting system, we argue that the slightly excess Fe atoms in the superconducting phase are likely incorporated into the tetragonal lattice, either adsorbed on or weakly bound to the FeS layer. This situation is similar to depositing K atoms on

the surface of $(\text{Li}_{0.8}\text{Fe}_{0.2}\text{OH})\text{FeSe}$, where the number of deposited K atoms can significantly tune the superconductivity of $(\text{Li}_{0.8}\text{Fe}_{0.2}\text{OH})\text{FeSe}$, despite the absence of stable chemical bonds between the K atoms and $(\text{Li}_{0.8}\text{Fe}_{0.2}\text{OH})\text{FeSe}$ ^[30].

For $(\text{FeOOH})\text{FeS}$, the distance between the nearest neighbor FeS layers expands, and the subtle interaction between slightly excess Fe atoms and the FeS layer is disrupted during the chemical reaction, resulting in the release of these Fe atoms into the solution. Therefore, our experimental results indicate that even if there are no Fe vacancies in the FeS layer, the desorption of excess adsorbed Fe atoms during the synthesis process alone can cause $(\text{FeOOH})\text{FeS}$ to lose its superconductivity, further revealing that the absence of superconductivity in $(\text{FeOOH})\text{FeS}$ may not be directly related to the vacancy of Fe atoms in the FeS layer.

4 Conclusions

In conclusion, a new FeS-based compound, $(\text{FeOOH})\text{FeS}$, was successfully synthesized via a hydrothermal method. Unlike the parent tetragonal FeS, this compound has a tetragonal crystal structure. As the temperature decreases, $(\text{FeOOH})\text{FeS}$ undergoes a ferromagnetic transition at approximately 15 K, whereas the peak observed near 10 K in the magnetic susceptibility curve is associated with the system transitioning into a superparamagnetic state. The specific heat results indicate that the Debye temperature and average phonon sound velocity in $(\text{FeOOH})\text{FeS}$ are 108.2 K and 1026.3 $\text{m}\cdot\text{s}^{-1}$, respectively.

Supporting information

The supporting information for this article can be found online at <https://doi.org/10.52396/JUSTC-2025-0043>.

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Conflict of interest

The authors declare that they have no conflict of interest.

Biographies

Wen Xie is currently a master's student in the Department of Chemistry, University of Science and Technology of China (USTC), under the supervision of Prof. Kaibin Tang and Prof. Han-Shu Xu. Her research mainly focuses on the synthesis and characterization of iron-based materials.

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Han-Shu Xu is currently an Associate Professor in the Department of Applied Physics, Anhui Medical University. He received his Ph.D. degree from Hefei National Research Center for Physical Sciences at the Microscale, University of Science and Technology of China, in 2019, under the supervision of Prof. Kaibin Tang and Prof. Yoshiteru Maeno. His research mainly focuses on the single-crystal growth of novel quantum materials, particularly quantum frustrated magnetic systems and unconventional superconductors.

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