

# Pressure-driven metal-insulator transition in $\text{BaMn}_2\text{P}_2$ : A correlated Mn-pnictide analog of Fe-based superconductors

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We report pressure-induced metallization in  $\text{BaMn}_2\text{P}_2$  based on resistivity measurements in a diamond anvil cell. At ambient pressure, the temperature-dependent resistivity is well described by a two-gap Arrhenius model, yielding intrinsic and extrinsic activation energies of approximately 0.2 and 0.04 eV, respectively. Angle-resolved photoemission spectroscopy (ARPES) shows no detectable spectral weight at the Fermi level within the measured momentum window. The growth of spectral weight at higher binding energies is consistent with the energy scales inferred from transport measurements. Under pressure, the temperature dependence of the resistivity evolves from insulatinglike to mixed-slope behavior and becomes metallic above  $P_c \approx 7$  GPa, with no low-temperature upturn. The resistivity ratio  $R(P) = \rho(100 \text{ K})/\rho(300 \text{ K})$  also drops abruptly near  $P_c$ . A baseline transport model combining Bloch-Grüneisen phonon scattering with a thermally activated carrier density fails to reproduce this sharp change for any smoothly varying activation energy. Temperature- and pressure-dependent x-ray diffraction shows smooth evolution of  $V$  with no symmetry change and no resolvable discontinuity at  $P_c$ . Taken together, these results indicate an abrupt pressure-driven metallization near  $P_c$ , with no evidence for a structural phase transition within our experimental resolution.

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## I. INTRODUCTION

Insulator-to-metal transitions (IMTs) are fundamental phenomena in condensed matter physics. They can be driven by mechanisms such as electron correlations, disorder, or lattice effects, and result in carrier delocalization and a strong reduction in electrical resistivity [1,2]. These transitions often emerge near quantum critical points and are frequently accompanied by competing or coexisting phases such as magnetism, charge order, or superconductivity. Oxides such as cuprates and manganites provide prototypical examples of IMT [3–6].

Among external tuning parameters, pressure provides a clean and continuous means of tuning without introducing substitutional disorder, unlike chemical substitution. By modifying interatomic distances, pressure changes the electronic bandwidth and thus, the ratio of bandwidth to on-site electron-electron interactions. Layered transition-metal

pnictides with half-filled  $3d^5$  configurations have emerged as interesting platforms for exploring pressure-tuned IMTs. For example,  $\text{LaMnPO}$  undergoes metallization near 20 GPa and exhibits suppression of long-range antiferromagnetic (AFM) order above 34 GPa under pressure [7]. Likewise,  $\text{BaMn}_2\text{As}_2$  becomes metallic near 4.5 GPa [8], while in  $\text{BaFe}_2\text{As}_2$ , pressure suppresses magnetic order and induces unconventional superconductivity [9,10].  $\text{LaMnPO}$  exhibits an activation energy of approximately 0.18 eV and a Néel temperature of 375 K at ambient pressure [7,11], while  $\text{BaMn}_2\text{As}_2$  shows an activation energy of  $\sim 0.1$  eV and Néel temperature of 625 K [8].

Within the  $\text{ThCr}_2\text{Si}_2$ -type structure family, transition-metal pnictides exhibit a wide range of electronic ground states.  $\text{BaNi}_2\text{P}_2$  is a conventional superconductor [12,13],  $\text{BaFe}_2\text{P}_2$  exhibits Fermi surface nesting associated with unconventional superconductivity [14,15], and  $\text{BaCo}_2\text{P}_2$  displays flat-band features and correlated metallic behavior [16,17]. In contrast,  $\text{BaMn}_2\text{P}_2$  hosts localized  $\text{Mn}^{2+}$  moments in a half-filled  $3d^5$  configuration, resulting in an AFM insulating ground state with a high Néel temperature ( $T_N = 795 \text{ K}$ ) among the 122 pnictides [18]. The combination of strong local moments, a charge gap, and a layered structure makes  $\text{BaMn}_2\text{P}_2$  a clean platform for exploring pressure-induced bandwidth-controlled IMTs in the absence of chemical disorder.

Although its electronic and magnetic properties have been studied extensively at ambient conditions [18–21], the effect

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of external pressure and the possibility of a pressure-driven IMT remain largely unexplored. Its structural similarity to Fe-based superconductors raises the intriguing possibility that pressure could induce correlated metallic states or even unconventional superconductivity, as observed in the Fe-122 family. To address this question, we investigate the effect of pressure on single-crystalline  $\text{BaMn}_2\text{P}_2$  using a combination of transport, spectroscopic, and structural measurements, and compare our results with available DFT +  $U$  calculations [22].

## II. EXPERIMENTAL DETAILS

$\text{BaMn}_2\text{P}_2$  crystals were grown by flux method using liquid Sn as the flux. Canfield crucible sets consisting of two identical alumina crucibles and a perforated alumina separator disk were used to facilitate hot decantation of the flux [23]. Ba pieces (dendritic, 99.9 % Sigma-Aldrich), Mn powder (325 mesh, 99.95%, Alfa Aesar), red P pieces (99.999 %, Alfa Aesar Puratronic), and 3 mm Sn pellets (99.99 + %, Alfa Aesar Puratronic) were mixed in a molar ratio of 7:2:5.5:60. The reactants were loaded in a lower crucible, a perforated disk was placed on top, and a second crucible was positioned upside down above the disk. All the reaction mixtures were prepared in a dry Ar atmosphere with  $\text{O}_2$  and moisture contents below 0.1 and 1 ppm, respectively. The assembled crucible set was secured with quartz wool inside a quartz ampoule, which was then evacuated and sealed. The ampoule was gradually heated in a furnace to 1413 K, held for 5 h, and then gradually cooled at a rate of 7 K/h to 823 K. The crucible was then quickly removed from the furnace, inverted, and centrifuged to separate the crystals from the Sn flux.  $\text{BaMn}_2\text{P}_2$  single crystals in the form of thin rectangular plates with a metallic luster and typical dimensions up to 0.1 mm in length and width and approximately 0.02 mm in thickness were obtained. The composition of the  $\text{BaMn}_2\text{P}_2$  single crystals was confirmed by energy dispersive x-ray spectroscopy (EDX), and the crystal structure was determined by x-ray diffraction (XRD). The measured tetragonal unit cell parameters are  $a = 4.0388(1) \text{ \AA}$ ,  $c = 13.0640(6) \text{ \AA}$ ,  $V = 213.099(12) \text{ \AA}^3$ , with space group  $I4/mmm$ , in agreement with the literature report [18].

Single crystals of  $\text{BaMn}_2\text{P}_2$  were used for all measurements. The crystals exhibit a layered structure with an easy-cleaving plane perpendicular to the  $c$  axis. Electrical resistivity was measured along the  $ab$  plane using a standard in-line four-probe configuration. Ambient-pressure resistivity measurements were performed in a physical property measurement system (PPMS). Gold wires and silver paste formed the current and voltage contacts. A DC excitation current of  $10^{-7} \text{ A}$  was used. Temperature was swept from 300 to 4 K during cooling and from 4 to 300 K during warming. The sweep was stopped when the measured voltage exceeded the instrument voltage range (95 mV), and data are reported down to the lowest valid temperature.

ARPES measurements were performed at the high-resolution branch of the I05-ARPES beamline at Diamond Light Source [24]. The samples were cleaved *in situ* and measured at 122 K under a base pressure of  $2 \times 10^{-10} \text{ mbar}$ , using 120 eV photons.

High-pressure resistivity measurements were conducted using a diamond anvil cell (DAC) housed in a helium-bath cryostat. The cell employed a custom-fabricated bottom diamond anvil (culet diameter of 250  $\mu\text{m}$ ) with embedded molybdenum electrodes for *in situ* electrical transport measurements, and a standard top diamond anvil (culet diameter of 200  $\mu\text{m}$ ). Gold wires were attached to the exposed ends of the molybdenum electrodes using silver paste to interface them with external instrumentation. Four small gold pads were placed on the bottom culet surface to serve as electrical contacts, and a  $\text{BaMn}_2\text{P}_2$  crystal was positioned so that its flat face contacted all four pads in an in-line geometry. Ruby spheres were placed adjacent to the sample for pressure calibration. A preindented stainless steel gasket (hole diameter 156  $\mu\text{m}$ , thickness 58  $\mu\text{m}$ ) was placed on the bottom anvil. Finely powdered NaCl served as the pressure-transmitting medium. The top diamond anvil was then aligned and sealed to complete the cell assembly.

Pressure was calibrated at room temperature using the ruby fluorescence method with a 380 nm laser [25]. Pressures quoted throughout are the room temperature ruby values recorded immediately before and after each thermal sweep. Because NaCl becomes only quasihydrostatic above a few gigapascals and can support deviatoric stress during temperature sweeps, the effective low-temperature pressure may differ slightly [26,27]. The pressure resolution was approximately  $\pm 0.3 \text{ GPa}$ . Pressure variations between cooling and warming cycles typically remained within this range. A thermal gradient of approximately 1 K across the DAC was estimated from the superconducting transition of a lead sample in a separate load. A DC current between  $10^{-7}$  and  $10^{-4} \text{ A}$  was applied. The current was adjusted at each pressure to keep the voltage above the noise floor and within instrument limits. Current was applied in both directions to cancel voltage offsets. This in-line four-probe configuration suppresses contact-resistance contributions to the measured signal. Resistivity was calculated from the measured voltage drop, assuming a uniform current distribution. Although uncertainties in contact geometry affect the absolute resistivity values, the extracted activation energies are based on relative temperature dependence and are therefore reliable.

XRD measurements were conducted to extract the temperature and pressure dependence of the lattice parameters. Temperature-dependent XRD at ambient pressure was performed under a nitrogen atmosphere by cooling from 400 K to 100 K after an initial heating to 400 K. Pressure-dependent XRD was performed at 300 K using a standard DAC with 100  $\mu\text{m}$  culet. A 4:1 methanol-ethanol mixture served as the pressure-transmitting medium and remains hydrostatic over our pressure range [28,29]. The sample was loaded into a preindented gasket with a thickness of approximately 100  $\mu\text{m}$ . The loading procedure followed that of the high-pressure resistivity measurements, except that no electrical contacts were used.

## III. RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of the resistivity at ambient pressure together with an Arrhenius analysis.

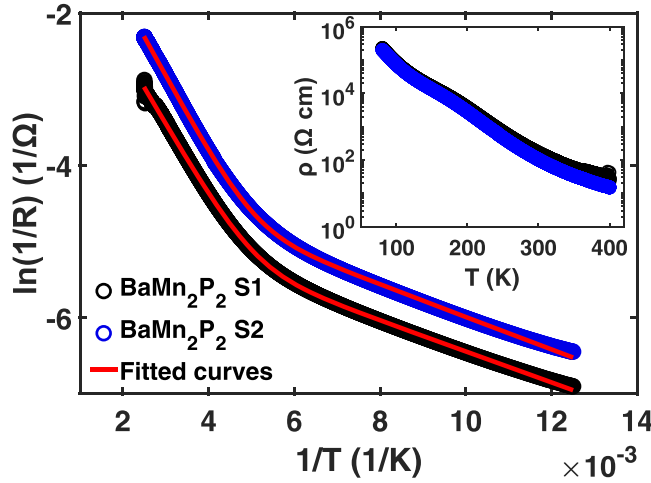


FIG. 1. Arrhenius plot of  $\text{BaMn}_2\text{P}_2$  at ambient pressure, along with fitting curves used to extract activation energies. The slope corresponds to the activation energy. For visual clarity, resistance is used for  $\ln(1/R)$  in the main panel, while all fitting was performed after converting to conductivity. The inset shows the resistivity as a function of temperature, indicating insulating behavior.

The inset shows the raw resistivity  $\rho(T)$ , which exhibits insulating behavior over the full measured temperature range. The main panel replots the same data in Arrhenius form as  $\ln(1/R)$  versus  $1/T$ . Because a straight line in this representation has slope  $-E_a/k_B$ , the change in slope indicates two activation energies in different temperature ranges. The crossover near 200 K marks the temperature at which the dominant channel changes.

To model the two contributions, we fit the conductivity using the following two-gap Arrhenius form:

$$\sigma(T) = \sigma_{\text{int}} \exp\left(-\frac{E_a^{\text{int}}}{k_B T}\right) + \sigma_{\text{ext}} \exp\left(-\frac{E_a^{\text{ext}}}{k_B T}\right). \quad (1)$$

Here,  $E_a$  is the activation energy associated with thermally excited carriers contributing to conduction. Fits to Eq. (1) yield intrinsic activation energies of 0.191(4) and 0.203(3) eV, and extrinsic activation energies of 0.040(1) and 0.042(1) eV. The values in parentheses denote 95% confidence intervals on the last digit. The intrinsic conductivities are  $\sigma_{\text{int}} = 9.02(14)$  and  $24.22(29)$ , while the extrinsic values are  $\sigma_{\text{ext}} = 1.35(5) \times 10^{-3}$  and  $1.91(3) \times 10^{-3}$ , all in units of  $(\Omega \text{ cm})^{-1}$ . From the fit, the conductivity ratios  $\sigma_{\text{ext}}/\sigma_{\text{int}}$  are approximately  $1.5 \times 10^{-4}$  and  $7.8 \times 10^{-5}$  for the two samples. These small ratios show that intrinsic conduction dominates.

Figure 2 presents ARPES measurements on  $\text{BaMn}_2\text{P}_2$ . Panels (a)–(d) are constant energy intensity maps at binding energies of  $-35$ ,  $0$ ,  $70$ , and  $120$  meV. Panel (e) shows an energy-momentum cut along  $\Gamma$  to  $M$ . The cut position is indicated by the red guide line in panel (d). These data show no detectable spectral weight at the Fermi level within the measured momentum window. Figure 2(f) compares the energy distribution curve at  $\Gamma$  with an *in situ* gold reference that fixes  $E_F$ . Shaded energy windows are derived from the Arrhenius analysis in Fig. 1 using the standard estimate  $E_g \approx 2E_a$  for a nondegenerate semiconductor. The wider and narrower windows correspond to the intrinsic and extrinsic activation energies, respectively. The gradual leading edge is consistent with the finite energy resolution and  $k_z$  mixing, which can yield a weak shoulder. A small onset of spectral weight near  $E_F$  could indicate dilute in-gap states that would contribute to the extrinsic channel and are consistent with the

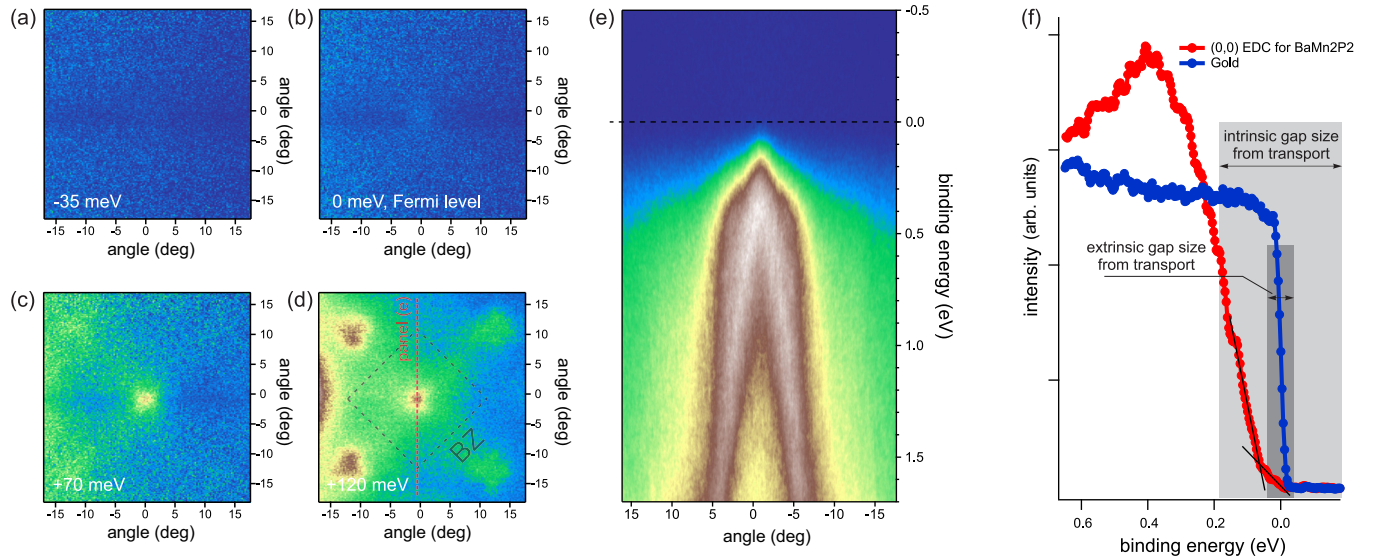


FIG. 2. ARPES data for  $\text{BaMn}_2\text{P}_2$ . (a)–(d) Constant energy maps measured with 120 eV photons at binding energies of  $-35$ ,  $0$ ,  $70$ , and  $120$  meV. The dashed diamond in panel (d) outlines the two-dimensional Brillouin zone. The red line marks the cut used in panel (e). Nearby  $k_z$  values are mixed at this photon energy and the inner potential was not determined, so the absolute  $k_z$  is approximate.  $\Gamma$  is assigned by comparison to DFT, which places the valence-band maximum at  $\Gamma$  [21]. (e) Energy versus momentum image along  $\Gamma$ – $M$  showing no spectral weight at the Fermi level. (f) Energy distribution curve at  $\Gamma$  in red, and a gold reference in blue. Shaded regions are taken from transport shown in Fig. 1 and are shown for comparison only. Black lines are guides to the eye.

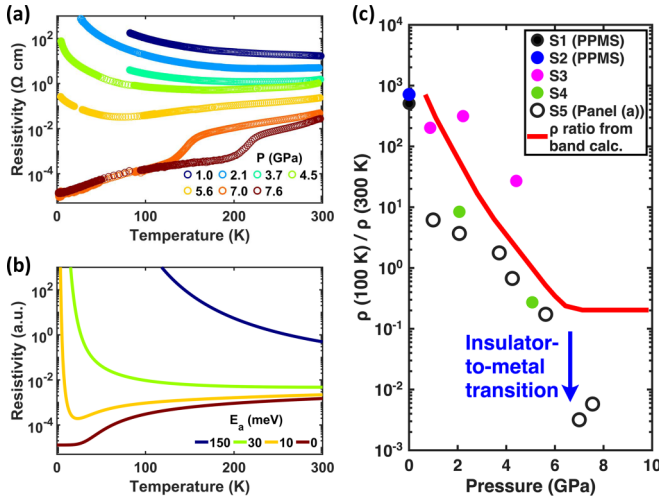


FIG. 3. Pressure-induced IMT in BaMn<sub>2</sub>P<sub>2</sub>. (a) Temperature dependence of the resistivity on cooling under applied pressures. A metallic regime emerges above  $\sim 7$  GPa. (b) Representative model curves of Eq. (2) with fixed  $\Theta_{BG} = 348$  K [18],  $\rho_0 = 1.3 \times 10^{-5}$  Ω cm [the lowest- $T$  value at 7.6 GPa in panel (a)], and  $A = 7.4 \times 10^{-3}$  Ω cm (set to match the 300 K resistivity extrapolated from the high- $T$  trend at 7.6 GPa). Only the activation scale  $E_a$  is varied. (c) Pressure dependence of the resistivity ratio  $R = \rho(100 \text{ K})/\rho(300 \text{ K})$  for five samples. The red line  $R_{\text{calc}}(P)$  is obtained by inserting  $E_a(P) \approx E_g(P)/2$  from DFT +  $U$  [22] into Eq. (2) with the parameters of panel (b). The measured  $R(P)$  exhibits a sharp drop within a narrow pressure interval near  $P_c$ , whereas  $R_{\text{calc}}(P)$  evolves smoothly, consistent with an abrupt step in transport response.

very small  $\sigma_{\text{ext}}$  from transport. Figure 3(a) shows the resistivity  $\rho(T)$  measured on cooling for a single sample across a series of pressures. At low pressure (1.0 and 2.1 GPa),  $\rho(T)$  increases monotonically on cooling over the full measured range with  $d\rho/dT < 0$ . At intermediate pressure (4.5 and 5.6 GPa),  $\rho(T)$  decreases on cooling at high temperature but turns upward again at low temperature. At 7.0 and 7.6 GPa, the low-temperature upturn is suppressed and  $\rho(T)$  decreases throughout the full temperature range, consistent with a strong pressure-induced evolution toward a more conducting state. In addition, the 7.0 and 7.6 GPa curves exhibit pronounced resistivity drops near 150 and 210 K.

To explain this pressure-dependent resistivity change shown in Fig. 3(b), we phenomenologically model the crossover using a Bloch-Grüneisen (BG) phonon kernel multiplied by a thermally evolving carrier factor:

$$\rho(T) = \rho_0 + A \exp(E_a/k_B T) \text{BG}(T, \Theta_{BG}), \quad (2)$$

where  $\rho_0$  is a small residual term and  $A$  sets the electron-phonon scattering contribution. The BG kernel is

$$\text{BG}(T, \Theta_{BG}) = \left( \frac{T}{\Theta_{BG}} \right)^5 \int_0^{\Theta_{BG}/T} \frac{x^5 dx}{(e^x - 1)(1 - e^{-x})}. \quad (3)$$

The factor  $\exp(E_a/k_B T)$  represents activated carrier behavior with an effective activation energy  $E_a$ . The  $\text{BG}(T, \Theta_{BG})$  is the Bloch-Grüneisen kernel for phonon-limited scattering, with  $\Theta_{BG}$  often close to the Debye temperature [30]. The BG factor is used here only as an approximate description of the

temperature dependence of the electron-phonon scattering rate. BaMn<sub>2</sub>P<sub>2</sub> in this range is not a simple degenerate metal, so the expression is an empirical model rather than a full transport calculation. We multiply  $\text{BG}(T, \Theta_{BG})$  by  $\exp(E_a/k_B T)$  to phenomenologically capture the temperature dependence of the mobile-carrier population as the gap closes. In this picture the exponential factor approximates the temperature dependence of the mobile-carrier density, while the BG kernel captures the phonon-limited scattering of those carriers.

For all model curves in Fig. 3(b) and for the model resistivity ratio plotted in Fig. 3(c), we take  $\rho_0 = 1.3 \times 10^{-5}$  Ω cm from the lowest-temperature value at 7.6 GPa in panel (a) and take  $\Theta_{BG} = 348$  K from Ref. [18]. The amplitude  $A = 7.4 \times 10^{-3}$  Ω cm is set by matching  $\rho(300 \text{ K})$  from Eq. (2) to the 300 K resistivity obtained by extrapolating the smooth high-temperature trend at 7.6 GPa in Fig. 3(a), explicitly excluding the jump. With  $\rho_0$ ,  $\Theta_{BG}$ , and  $A$  fixed in this way, only  $E_a$  is varied. For  $E_a \gg k_B T$ , the activated factor is large and  $\rho(T)$  increases rapidly on cooling, consistent with strongly activated transport. As pressure reduces the gap,  $k_B T \gtrsim E_a$  over part of the range, the exponential factor approaches unity and the BG term controls the  $T$  dependence (metalliclike at high  $T$  with a low- $T$  upturn). In the small-gap limit  $E_a \rightarrow 0$ , the BG term dominates over the full temperature range, yielding a  $\rho(T)$  profile that resembles that of a metal. The model curves reproduce these crossovers continuously and serve as a null hypothesis for the pressure evolution in panel (a).

Figure 3(c) summarizes the pressure dependence of  $R(P) = \rho(100 \text{ K})/\rho(300 \text{ K})$ . We choose 100 K to ensure consistent coverage across runs, as electrical contacts were often lost below 80 to 100 K. The red curve  $R_{\text{calc}}(P)$  is computed by mapping the DFT +  $U$  band gap  $E_g(P)$  with  $U = 1.2$  eV to  $E_a(P) \approx E_g(P)/2$  and inserting  $E_a(P)$  into Eq. (2) with the fixed parameters from panel (b). The  $R_{\text{calc}}(P)$  decreases smoothly as the gap closes and then saturates. In contrast, the measured  $R(P)$  shows an abrupt drop within a narrow pressure interval near  $P_c$ . The systematic pressure evolution observed across multiple samples argues against an isolated anomalous run. In the present contact geometry, trivial contact artifacts and unintended parallel current paths are unlikely. We therefore interpret the metallization observed in sample S5 as an intrinsic pressure-driven signal of BaMn<sub>2</sub>P<sub>2</sub>. The stepwise drop in  $R(P)$  in panel (c) and the rapid decrease of  $\rho(T)$  above 7 GPa in panel (a) indicate an abrupt and steplike boundary in the transport response. This comparison shows that a smooth reduction of  $E_a(P)$  alone cannot account for the data. We therefore describe the boundary as abrupt in transport, without assigning a thermodynamic order. A difference between cooling and warming is observed near  $P_c$ , but the warming curves show an additional feature attributable to DAC thermal expansion and pressure drift; we focus on the cooling data. To find out more about the transition, we examined whether the metallization boundary correlates with a specific range of structural parameters. IMTs are often tied to critical structural unit cell volume [31–34]. Microscopic metrics such as Mn–P bond length, Mn–Mn spacing, and the Mn–P–Mn angle are likely more direct, yet the unit-cell volume is an experimentally accessible proxy that aggregates their combined effect. Figure 4(a) shows the temperature dependence of the unit-cell volume at ambient pressure, modeled using a single-mode

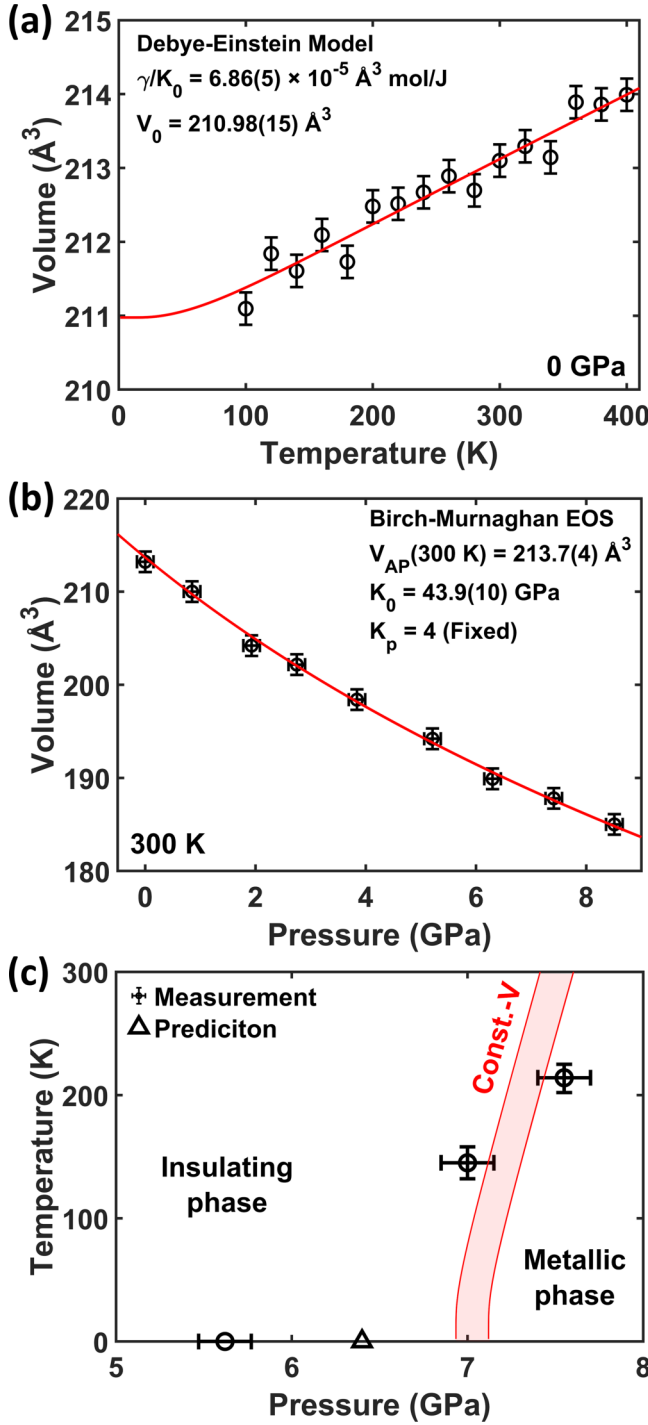


FIG. 4. Temperature and pressure evolution of the unit-cell volume and correlation with metallization. (a) Temperature dependence of unit-cell volume at ambient pressure fitted with a single-mode Debye-Einstein model. (b) Pressure dependence of unit-cell volume at 300 K fitted with a second-order Birch-Murnaghan equation of state. (c)  $T$ - $P$  phase diagram showing resistivity-derived transition points. The point at 5.6 GPa is plotted at 0 K to represent a state that remained fully insulating down to the lowest measured temperature. The diagram also includes a predicted transition point and a constant-volume corridor constructed from the fits in panels (a) and (b). The corridor centered at  $204.9 \pm 0.3 \text{\AA}^3$ .

Debye-Einstein approach that relates internal energy to thermal expansion [35–37]. The internal energy is given by

$$\begin{aligned}
 U(T) &= U_D(T) + U_E(T) \\
 &= 9n_D k_B T \left( \frac{T}{\Theta_D} \right) \int_0^{\Theta_D/T} \frac{x^4 e^x}{(e^x - 1)^2} dx \\
 &\quad + \frac{3}{2} k_B n_E \Theta_E \coth \left( \frac{\Theta_E}{2T} \right),
 \end{aligned} \quad (4)$$

where  $\Theta_D$  and  $\Theta_E$  are Debye and Einstein temperatures, and  $n_D$  and  $n_E$  are their respective weights, such that  $n_D + n_E$  equals the number of atoms per formula unit. The values of  $U(T)$  were derived from the specific heat data reported by Ref. [18]. The volume was then fitted using

$$V(T) = \gamma U(T)/K_0 + V_0, \quad (5)$$

where  $\gamma$  is the Grüneisen parameter,  $K_0$  is the bulk modulus, and  $V_0$  is the zero-temperature unit-cell volume. The fit yields  $\gamma/K_0 = 3.86(5) \times 10^{-5} \text{\AA}^3 \text{mol/J}$  and  $V_0 = 210.98(15) \text{\AA}^3$ .

Figure 4(b) shows the pressure dependence of the unit-cell volume at 300 K, fitted using a second-order Birch-Murnaghan (BM) equation of state. The fit yields  $V_{300 \text{ K}} = 213.7(3) \text{\AA}^3$  and a bulk modulus  $K_0 = 43.9(10) \text{ GPa}$ . The BM fit defines  $V(P)$  over the measured range. We do not analyze the mechanical properties of  $\text{BaMn}_2\text{P}_2$  using parameters such as bulk modulus  $K_0$  here. Our goal is to obtain analytical forms for  $V(T)$  and  $V(P)$ .

Figure 4(c) represents the  $T$ - $P$  phase diagram using the two transition pressures extracted from the resistivity drops with uncertainties, together with the DFT +  $U$  estimate [22] and the fully semiconducting limit extrapolated to 0 K. Then to test whether the transport boundary follows a structural metric, we estimate

$$V(T, P) = \frac{V_{0 \text{ GPa}}(T) V_{300 \text{ K}}(P)}{V(300 \text{ K}, 0 \text{ GPa})}, \quad (6)$$

combining a Debye-Einstein fit for  $V_{0 \text{ GPa}}(T)$  at ambient pressure with a BM fit for  $V_{300 \text{ K}}(P)$ . Standard error propagation for a product gives  $\delta V = V \sqrt{(\delta V_{0 \text{ GPa}}/V_{0 \text{ GPa}})^2 + (\delta V_{300 \text{ K}}/V_{300 \text{ K}})^2}$ . Using  $\delta V_{300 \text{ K}} = 0.216 \text{\AA}^3$  and  $\delta V_{0 \text{ GPa}} = 0.166 \text{\AA}^3$  yields  $\delta V = 0.290 \text{\AA}^3$ . This enables us to draw the constant  $V(T, P)$  corridor across the phase diagram. The midpoint of two resistivity drops near 7.3 GPa and 180 K is chosen with the width of the volume uncertainty, which is  $204.9 \pm 0.3 \text{\AA}^3$ .

The corridor overlaps the resistivity-derived transition points on the  $T$ - $P$  phase diagram within the error range of the transition points. This alignment indicates the data define a narrow corridor of nearly constant volume that crosses the pressure-temperature region where the transport anomaly appears. The correlation is established by two independent measurements, namely transport for the boundary and XRD for the structural metric. Within our sensitivity we detect no crystallographic symmetry change and no resolvable discontinuity in  $V$  at  $P_c$ .

Taken together with the steplike decrease of  $R(P)$ , these observations indicate that the transport anomaly correlates

with a narrow range of unit-cell volume. The transport signature is abrupt and steplike, while the structural lattice remains continuous within our resolution. This difference does not necessarily imply an inconsistency between the two measurements. The XRD experiment was performed at 300 K, where the metallization boundary may lie outside the pressure range accessed in the structural study. Moreover, even if an electronic transition occurs in the same pressure range, its influence on the lattice parameters may be too small to be resolved within our experimental sensitivity. The transport and XRD measurements were also performed under different pressure environments, and this difference may further affect the apparent phase boundary and the sharpness of the transition. As shown in  $\text{BaFe}_2\text{As}_2$  [10], even modest differences in hydrostaticity can influence the observed phase boundary. A similar sensitivity may also contribute to the difference between the sharp transport anomaly and the continuous structural evolution observed here. Internal coordinates such as the pnictogen height and the Mn–P–Mn bond angle can change without producing a measurable jump in  $V$  in a DAC geometry, so a microscopic mechanism of transition cannot be addressed by the present data.

#### IV. CONCLUSIONS

In summary, transport, ARPES, and XRD measurements establish  $\text{BaMn}_2\text{P}_2$  as a gapped insulator at ambient pressure, with activation scales from resistivity consistent with the absence of detectable spectral weight at the Fermi level in ARPES within the measured momentum window. Similar two-gap behavior has been observed in  $\text{BaMn}_2\text{As}_2$ ,  $\text{LiMnAs}$ , and  $\text{LaOMnAs}$  [38,39].

Upon compression,  $\text{BaMn}_2\text{P}_2$  undergoes an abrupt, step-like metallization near  $P_c \approx 7$  GPa. Across this narrow pressure interval, the resistivity drops by roughly two orders of magnitude and the low-temperature upturn vanishes. A baseline transport description combining Bloch-Grüneisen phonon scattering with a thermally activated carrier density evolves smoothly with pressure and fails to reproduce the sharp change. This suggests that the metallization is not captured by a simple continuous reduction of an activation gap.

XRD shows smooth lattice compression with no detectable symmetry change or volume discontinuity near  $P_c$  within our experimental resolution. Mapping the transport boundary onto

the  $P$ - $T$ - $V$  space indicates that metallization occurs when the unit-cell volume approaches a critical range near  $205 \text{ \AA}^3$ , identifying unit-cell volume as a key control parameter.

Comparable Mn-based layered compounds, such as  $\text{LaMnPO}$  and  $\text{BaMn}_2\text{As}_2$ , also exhibit pressure-induced IMTs while retaining AFM order well into the metallic regime [7,8].  $\text{BaMn}_2\text{P}_2$  follows this trend, showing a similar ambient-pressure activation energy ( $\sim 0.2$  eV) and a high Néel temperature, together with a transition to a metallic state under moderate pressure. Comparison with related Mn-based pnictides suggests that AFM order may persist into part of the metallic regime. However, the present measurements do not determine whether the magnetic order survives, weakens, or is suppressed near  $P_c$ . If AFM order persists above  $P_c$ , the data would be consistent with a bandwidth-controlled correlated IMT within an AFM background. If AFM order is substantially weakened or suppressed near  $P_c$ , such a magnetic change could also contribute to the abrupt transport anomaly. Direct magnetic probes under pressure will be required to distinguish between these possibilities. In the metallic regime, the reduced temperature dependence of resistivity further supports the occurrence of a pressure-driven transition. Collectively, these results position  $\text{BaMn}_2\text{P}_2$  as a promising platform for studying bandwidth-controlled IMTs. These results motivate targeted searches under pressure for magnetic states beyond AFM, beginning with the suppression of AFM and possible transitions to ferromagnetic or non-collinear order, and ultimately for a superconducting phase that may emerge if magnetism is sufficiently weakened.

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#### DATA AVAILABILITY

The data that support the findings of this article are openly available [40].

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