The magnetic, thermal, and transport properties of polycrystalline BaRu$_2$As$_2$ and SrRu$_2$As$_2$ samples were investigated by means of magnetic susceptibility $\chi(T)$, electrical resistivity $\rho(T)$, and heat capacity $C_p(T)$ measurements. The temperature ($T$) dependence of $\rho$ indicates metallic character for both compounds with residual resistivity ratios $\rho(300\,\text{K})/\rho(2\,\text{K})$ of 17 and 5 for the Ba and Sr compounds, respectively. The $C_p(T)$ results reveal a low-$T$ Sommerfeld coefficient $\gamma = 4.9(1)$ and $4.1(1)\,\text{mJ/mol K}^2$ and Debye temperature $\Theta_D = 271(7)\,\text{K}$ and $274(4)\,\text{K}$ for the Ba and Sr compounds, respectively. The $\chi(T)$ was found to be diamagnetic with a small absolute value for both compounds. No transitions were found for BaRu$_2$As$_2$ above 1.8 K. The $\chi(T)$ data for SrRu$_2$As$_2$ exhibit a cusp at $\sim 200\,\text{K}$, possibly an indication of a structural and/or magnetic transition. We discuss the properties of BaRu$_2$As$_2$ and SrRu$_2$As$_2$ in the context of other ThCr$_2$Si$_2$-type and ZrCuSiAs-type transition metal pnictides.

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I. INTRODUCTION

The recent discovery of superconductivity in the layered oxide compound LaFeAsO$_{1-x}$F$_x$ with superconducting transition temperature $T_c = 26\,\text{K}$ has generated great excitement. Subsequently a series of compounds LnFeAsO$_{1-x}$F$_x$ (e.g., Ln = Ce, Nd, and Sm) (abbreviated as 1111) have been reported with $T_c$ ranging from 10 K to $55\,\text{K}$ where the high $T_c$ of 55 K was reached for SmFeAsO$_{1-x}$F$_x$. All these compounds crystallize in a tetragonal unit cell of ZrCuSiAs structure type. Later on another series of compounds A$_{1-x}$Fe$_2$As$_2$ (A = Ba, Sr, Ca, and Eu) (122) (Refs. 7,8,9,10,11) with the tetragonal ThCr$_2$Si$_2$ structure type was discovered where the maximum $T_c$ achieved was 38 K.

A common feature of both 1111 and 122 compounds is the identical FeAs layers separated by the LnO or A layers perpendicular to the crystallographic c-axis. Undoped metallic parent compounds of both types show a spin-density wave (SDW) which coexists with a distorted structure at temperatures $T < 200\,\text{K}$ (Ref. 12). Superconductivity in both series is sometimes assumed to be intimately connected with the SDW anomaly in the FeAs layers. Electron or hole doping suppresses both the SDW and structural transition and facilitates the superconductivity. However, it is still unresolved whether the structural transition and/or the magnetism associated with the SDW play a vital role for the occurrence of superconductivity. There exist a few 122 compounds BaNi$_2$P$_2$, BaNi$_2$As$_2$, LaRu$_2$P$_2$, CsFe$_2$As$_2$, and KFe$_2$As$_2$ where even the undoped compound itself shows superconductivity at low temperatures. It is of interest to look for further new systems with different transition metal ions where one can try to achieve an enhanced $T_c$.

Motivated by the above progress, we turned our attention towards Ru-based layered compounds. So far in the Ru series, LaRu$_2$P$_2$ which has the ThCr$_2$Si$_2$-type structure is known to have $T_c = 4.1\,\text{K}$ at BaRu$_2$As$_2$ and SrRu$_2$As$_2$ compounds also crystallize in the body-centered tetragonal ThCr$_2$Si$_2$ structure with space group $I4/mmm$. The reported lattice constants are $(a = 4.152\,\text{Å}, c = 12.238\,\text{Å})$ and $(a = 4.168\,\text{Å}, c = 11.179\,\text{Å})$ for the Ba and Sr compounds, respectively (Ref. 13). As shown in Fig. 1, Ru atoms in a square lattice are coordinated by As to form infinite RuAs layers and the layers are separated by Ba layers, similar to the AFe$_2$As$_2$ compounds. Because BaRu$_2$As$_2$ and SrRu$_2$As$_2$ are isoelectronic to the above undoped AFe$_2$As$_2$ compounds, a comparison of the properties of these two series of compounds is of great interest. A detailed investigation of the physical properties of the Ru compounds has not been reported yet. Herein we report a detailed characterization of polycrystalline BaRu$_2$As$_2$ and SrRu$_2$As$_2$ by means of magnetic susceptibility $\chi(T)$, electrical resistivity $\rho(T)$, and heat capacity $C_p(T)$ measurements. We will discuss the properties of BaRu$_2$As$_2$ and SrRu$_2$As$_2$ in the context of other ThCr$_2$Si$_2$-type and ZrCuSiAs-type transition metal pnictides. From this comparison, it appears that a large Stoner enhancement of the conduction electron spin susceptibility is needed for high $T_c$ in this class of materials.

II. EXPERIMENTAL DETAILS

Polycrystalline samples of BaRu$_2$As$_2$ and SrRu$_2$As$_2$ were prepared by solid state reaction techniques using elemental Ba (99.999% pure), Sr (99.99% pure), Ru (99.9996% pure), and As (99.999% pure). The stoichiometric mixtures in an Al$_2$O$_3$ crucible were sealed inside an evacuated quartz tube. At first, the elements were heated slowly up to $610\,\text{°C}$ at a rate of $80\,\text{°C/hr}$, kept there for 10 hours and then heated up to $850\,\text{°C}$ and kept there for 20 hours. The samples were then progressively fired at $950\,\text{°C}$ and $1000\,\text{°C}$ for 20 hours, each followed
FIG. 1: (Color online) Crystal structure of BaRu$_2$As$_2$ with the tetragonal ThCr$_2$Si$_2$-type structure showing RuAs layers and Ba layers alternating along the c-axis.

by one intermediate grinding and pelletization. For the final firing at 1000 °C, the pellets were wrapped in a Ta foil before sealing in the quartz tube. All the sample handling was carried out inside a He-filled glove box. Our repeated attempts to grow crystals using Sn, Pb, and In fluxes followed by slow cooling failed.

The samples were characterized using a Rigaku Geigerflex powder X-ray diffractometer and Cu K$_\alpha$ radiation ($\lambda_{K\alpha} = 1.54182$ Å). The powder pattern evidenced almost single phase material with a small impurity peak of about 2 and 3 percent relative intensity for the Ba and Sr compounds, respectively, which is suspected to arise from unreacted Ru. Unlike the Sr compound, for the Ba compound there appears another tiny impurity peak at the position expected for the strongest peak of BaCO$_3$ at $2\theta \approx 25^\circ$ (marked by a star) which has about 1.5% relative intensity. These impurities should not measurably affect the $\chi(T)$ or $C_p(T)$ data but may have an unknown effect on the $\rho(T)$ data. Rietveld refinements of the data were carried out using the GSAS package. Figure 2 shows the Rietveld refinement fit to the x-ray powder diffraction pattern for BaRu$_2$As$_2$. All the peaks except for the above impurity peak (see inset of Fig. 2) could be indexed and fitted based on the ThCr$_2$Si$_2$ structure with $I\bar{4}/mmm$ space group. The goodness of the fit is 5.3% and 7.5% for the Ba and Sr compounds, respectively. The obtained lattice parameters are $[a = 4.15248(8)$ Å, $c = 12.2504(3)$ Å] and $[a = 4.1713(1)$ Å, $c = 11.845(4)$ Å] for the Ba and Sr compounds, respectively. These values are close to the above previously reported ones. Our refined $z$ parameters for the As atoms are 0.3527(1) for BaRu$_2$As$_2$ and 0.3612(2) for SrRu$_2$As$_2$.

The magnetization $M$ and magnetic susceptibility $\chi(T) = M/H$, where $H$ is the applied magnetic field, were measured in the temperature $T$ range $1.8 \, \text{K} \leq T \leq 300 \, \text{K}$ on polycrystalline samples in a commercial Quantum Design SQUID (superconducting quantum interference device) magnetometer. DC resistivity $\rho(T)$ was measured using a standard 4-probe technique by applying a current of 5 mA, and heat capacity $C_p(T)$ was measured on a small piece of sample with mass about 8 mg. Both $\rho(T)$ and $C_p(T)$ measurements were performed on sintered pellets using a Quantum Design Physical Property Measurement System.

### III. EXPERIMENTAL RESULTS AND ANALYSIS

Figure 3 shows the temperature dependence of resistivity $\rho(T)$ for BaRu$_2$As$_2$ and SrRu$_2$As$_2$. With decreasing temperature, $\rho(T)$ decreases for both compounds to a residual resistivity at 2 K of about 9.7 $\mu\Omega$ cm and 2300 $\mu\Omega$ cm for the Ba and Sr compounds, respectively. This type of temperature dependence suggests metallic behavior of the compounds. We did not observe any clear anomaly that might be associated with an SDW down to 2 K. The residual resistivity ratio $\rho(310 \, \text{K})/\rho(2 \, \text{K})$ was
found to be about 17 and 5 for the Ba and Sr compounds, respectively. These values are comparable to those reported for polycrystalline (Ba,Sr)Fe$_2$As$_2$.

The heat capacity $C_p$ at zero field for BaRu$_2$As$_2$ and SrRu$_2$As$_2$ is shown in Fig. 4. We did not observe any clear anomaly associated with a SDW or structural transition down to 2 K. However, the small anomaly at about 200 K for SrRu$_2$As$_2$ may be a real effect in view of the cusp at the same temperature found in the measurement of $\chi(T)$ below. The value of $C_p$ at room temperature is about 120 J/mol K which is close to the Dulong Petit lattice heat capacity value $C_p = 15R \approx 125$ J/mol K expected for our compounds. As shown in the inset of Fig. 4, $C_p(T)/T$ vs. $T^2$ is almost linear at low-$T$ ($T < 8$ K) and was fitted by the expression $C_p/T = \gamma + \beta T^2$, where $\gamma$ is the Sommerfeld coefficient of electronic heat capacity and the second term accounts for the lattice contribution with coefficient $\beta$. The resultant $\gamma$ and $\beta$ values are $[4.9(1)$ mJ/mol K$^2$ and 0.49(4) mJ/mol K$^4$] and $[4.1(1)$ mJ/mol K$^2$ and 0.49(2) mJ/mol K$^4$] for the Ba and Sr compounds, respectively.

The density of states at the Fermi energy for both spin directions $N(E_F)$ can be estimated using the value of $\gamma$ in the following relation:

$$\gamma = \frac{\pi^2}{3} k_B^2 N(E_F) (1 + \lambda_{ep})$$  \hspace{1cm} (1)

where $\lambda_{ep}$ is the electron-phonon coupling constant. As a first approximation we set $\lambda_{ep} = 0$, which gives $N(E_F) = 2.1(1)$ states/(eV f.u.) (f.u. stands for formula unit) and 1.7(1) states/(eV f.u.) for the Ba and Sr compounds, respectively. These densities of states are comparable with our previously reported value of 2.0(4) states/(eV f.u.) for BaRh$_2$As$_2$ estimated in the same way from heat capacity measurements. In BaRh$_2$As$_2$, band structure calculations indicate that the maximum contribution to $N(E_F)$ comes from the Rh $4d$ states. From $N(E_F)$ one can calculate the bare Pauli paramagnetic spin susceptibility of the conduction carriers $\chi_P$ using:

$$\chi_P = \mu_B^2 N(E_F)$$  \hspace{1cm} (2)

where $\mu_B$ is the Bohr magneton. This gives $\chi_P \approx 6.8 \times 10^{-5}$ cm$^3$/mol and $5.5 \times 10^{-5}$ cm$^3$/mol for the Ba and Sr compounds, respectively. These values are comparable to that found in BaRh$_2$As$_2$. From the value of $\beta$, one can also estimate the Debye temperature $\Theta_D$ using the expression:

$$\Theta_D = \left( \frac{12\pi^4 n Rn}{5\beta} \right)^{1/3}$$  \hspace{1cm} (3)

where $n$ is the number of atoms per formula unit ($n = 5$ for our compounds). The above $\beta$ values yield $\Theta_D = 271(7)$ K and 271(4) K for the Ba and Sr compounds, respectively, which are comparable to the values of 280 K (Ref. 28) and 246(3) K (Ref. 29) reported for isostructural BaMn$_2$As$_2$.

For both the magnetic susceptibility $\chi(T)$ and magnetization $M(H,T)$ measurements we carried out, the data were corrected for the contribution of the empty sample holder, which was not negligible. The $\chi \equiv M/H$ as a function of temperature in a field $H = 1$ T is shown in Fig. 5, where the $M$ data are corrected for the contributions from ferromagnetic impurities as determined from the $M(H)$ isotherm data in Fig. 4 below. $\chi(T)$ at high temperatures.
temperatures is negative and weakly temperature dependent. At low temperatures, $\chi(T)$ shows a Curie-like upturn. For the Ba compound this upturn is much stronger than the Sr one. This upturn is attributed to extrinsic paramagnetic impurities and/or magnetic defects in the samples, as now discussed.

Magnetization $M$ as a function of applied magnetic field $H$ was measured at different temperatures. Figure 4 shows the $M(H)$ isotherms at different temperatures for both compounds measured up to $H = 5.5$ T. For both compounds $M(H)$ shows a negative curvature below a field of 1 T at all temperatures due to the saturation of ferromagnetic impurities. To estimate the saturation magnetization $M_s$ of the ferromagnetic impurities, we fitted magnetization isotherms at high temperatures [$\geq 50$ K for BaRu$_2$As$_2$ and $\geq 25$ K for SrRu$_2$As$_2$] to a straight line ($M_s + \chi(H)$) above 1 T, as shown by the straight line fits in Fig. 4. The $M_s$ was found to be nearly independent of $T$ with values of about 0.247 G cm$^3$/mol and 0.081 G cm$^3$/mol at low temperatures for the Ba and Sr compounds, respectively. The near constant values of $M_s$ versus temperature indicate that the Curie temperature(s) of the ferromagnetic impurities are significantly above 300 K. The low-$T$ $M_s$ values correspond to the contributions of the equivalent of 20 molar ppm and 6.6 molar ppm of Fe metal impurities to the $M$ of the Ba and Sr compounds, respectively. The plotted magnetic susceptibilities at $H = 1$ T as given above by the filled symbols in Fig. 4 are given by $\chi(T) = (M(T) - M_s(T))/H$.

For a quantitative estimation of the paramagnetic impurity contribution giving rise to the upturns in the susceptibilities at low temperatures, we fitted our $M(H)$ data for $1 \leq H \leq 5.5$ T at 1.8 K, 3 K, 5 K and 7 K for the Ba compound and 1.8 K, 3 K, 5 K and 5 K for the Sr compound simultaneously by the equation

$$M = M_s + \chi_0 H + f_{\text{imp}} N_A g_{\text{imp}} \mu_B S_{\text{imp}} B_{\text{imp}}(x)$$  \hspace{1cm} (4)$$

where $M_s$ is the above-determined low-temperature ferromagnetic impurity saturation value, $f_{\text{imp}}$ is the molar fraction of the impurities, $N_A$ is Avogadro’s number, $g_{\text{imp}}$ is the impurity $g$-factor, $S_{\text{imp}}$ is the impurity spin, $B_{\text{imp}}(x)$ is the Brillouin function and $\chi_0$ is the intrinsic susceptibility of the sample. The modified argument of the Brillouin function is $x = g_{\text{imp}} \mu_B S_{\text{imp}} H/k_B(T - \theta_{\text{imp}})$ where $\theta_{\text{imp}}$ is the Weiss temperature due to impurity interactions. To reduce the number of fitting parameters, the impurity $g$-factor was set to $g_{\text{imp}} = 2$. The obtained fitting parameters ($\chi_0$, $f_{\text{imp}}$, $S_{\text{imp}}$, and
\( \theta_{\text{imp}} \) are \([-2.3(1) \times 10^{-5}] \text{ cm}^3/\text{mol}, 0.0284(3) \text{ mol\%}, 1.85(3), \) and \(-0.46(6) \text{ K}\) and \([-3.62(6) \times 10^{-5}] \text{ cm}^3/\text{mol}, 0.0092(1) \text{ mol\%}, 1.62(4), \) and \(-1.2(1) \text{ K}\) for the Ba and Sr compounds, respectively. The Curie constant \( C_{\text{imp}} \) of the paramagnetic impurities was calculated using \( C_{\text{imp}} = f_{\text{imp}} N_A g_{\text{imp}}^2 \mu_B^2 S_{\text{imp}} (S_{\text{imp}} + 1)/3k_B \) which yields \( C_{\text{imp}} \approx 0.754 \times 10^{-3} \text{ cm}^3/\text{K/mol} \) and \(1.95 \times 10^{-3} \text{ cm}^3/\text{K/mol} \) for the Ba and Sr compounds, respectively. Our intrinsic \( \chi(T) \) data are corrected for both the ferromagnetic impurity and paramagnetic impurity contributions are shown in Fig. 5 as open symbols. The low-\( T \) \( \chi_0 \) values obtained from the magnetization isotherm analysis are also plotted as filled stars in Fig. 5 and are, of course, in agreement with the intrinsic \( \chi(T) \) data.

From the open symbols in Fig. 5 the intrinsic susceptibilities of BaRu\(_2\)As\(_2\) and SrRu\(_2\)As\(_2\) are diamagnetic over the whole \( T \) range, becoming somewhat more negative with decreasing \( T \). A diamagnetic susceptibility is not unprecedented for a transition metal compound, as, for example, for LaRu\(_2\)P\(_2\) [Ref. 22] and OsB\(_2\) and RuB\(_2\). As shown in the inset of Fig. 5, the intrinsic \( \chi(T) \) of SrRu\(_2\)As\(_2\) shows a (reproducible) small cusp around 200 K in contrast to the smooth behavior observed in BaRu\(_2\)As\(_2\). This cusp for SrRu\(_2\)As\(_2\) is qualitatively similar to the cusp seen for 1111 and 122 parent compounds and attributed to structural/SDW transitions. The temperature of the cusp is similar to the temperature of the small anomaly in \( C_p(T) \) in Fig. 4 so the latter anomaly may not be an artifact.

IV. DISCUSSION

The intrinsic \( \chi(T) \) of a metal can be written as \( \chi = \chi_D + \chi_VV + \chi_P \), where \( \chi_D \) includes the orbital diamagnetism of the core electrons (\( \chi_{\text{core}} \)) and the orbital Landau diamagnetism (\( \chi_L \)) of the conduction electrons, \( \chi_{VV} \) is the orbital Van Vleck paramagnetism, and \( \chi_P \) is the Pauli spin paramagnetism of the conduction electrons. For an extended system it is difficult to calculate \( \chi_D \) due to intercell currents. Nevertheless one can roughly estimate the \( \chi_{\text{core}} \) of the compounds assuming anionic picture, where (Ba or Sr), Ru, and As are in 2+, 2+, and 3− oxidation states, respectively. This estimate will give the upper limit to \( \chi_{\text{core}} \). In this way \( \chi_{\text{core}} \) was calculated to be \(-1.6 \times 10^{-4} \text{ cm}^3/\text{mol} \) and \(-1.43 \times 10^{-4} \text{ cm}^3/\text{mol} \) for the Ba and Sr compounds, respectively. Since \( \chi_P \) is positive, when added to the negative \( \chi_{\text{core}} \), the result is a reduced positive value or even a negative value of \( \chi \). Using the \( \chi_P \) values obtained from the above heat capacity data analysis, the sum of \( \chi_{\text{core}} \) and \( \chi_P \) is \( \approx -9 \times 10^{-5} \text{ cm}^3/\text{mol} \) for both compounds. This value is somewhat more negative than the intrinsic values in Fig. 5 suggesting that the Van Vleck paramagnetic orbital susceptibility \( \chi_{VV} \) and/or Stoner enhancement of \( \chi_P \) are not negligible in these compounds. This value is also of the same order of magnitude as has been estimated for BaRh\(_2\)As\(_2\).

In the following discussion we relate the properties of the (Sr,Ba)Ru\(_2\)As\(_2\) compounds with those of other ThCr\(_2\)Si\(_2\)-type and ZrCuSiAs-type pnictides and consider their superconducting transition temperature \( T_c \) or lack thereof. Lee and coworkers and Zhao and coworkers found an interesting correlation for a wide range of parent compounds Ba(Fe,Ni)\(_2\)(P,As)\(_2\) and Ln(Fe,Ni)(P,As)O where \( Ln \) is a rare earth element: the highest \( T_c \) occurred for the doped materials in which the respective FeAs\(_4\) tetrahedra were least distorted. Within a \( MPn_4 \) tetrahedron where \( M \) is the transition metal and \( Pn = P \) or As, there is a two-fold \( Pn-M-Pn \) bond angle where the two \( Pn \) atoms are on the same side of the \( M \) atom layer along the \( c \) axis, and there is a four-fold \( Pn-M-Pn \) bond angle where the two \( Pn \) atoms are on opposite sides of the \( M \) layer (see Fig. 1). The angle plotted in Refs. 32 and 33 is the two-fold \( Pn-M-Pn \) bond angle.

We have calculated the two-fold As-Ru-As bond angles from our structural data for the (Sr,Ba)Ru\(_2\)As\(_2\) compounds and also for the As-Rh-As bond angle for BaRu\(_2\)As\(_2\). For the body-centered-tetragonal BaFeAs\(_2\)-type and the primitive tetragonal LaFeAsO-type structures, the two-fold and four-fold As-Fe-As bond angles are given by

\[
\theta_2 = \arccos \left[ \frac{-a^2 + (z-\alpha)^2 c^2}{r^2} \right] \quad (2 - \text{fold})
\]

\[
\theta_4 = \arccos \left[ \frac{-(z-\alpha)^2 c^2}{r^2} \right] \quad (4 - \text{fold})
\]

where

\[
r^2 = \frac{a^2}{4} + (z-\alpha)^2 c^2
\]

and \( \alpha = 1/4 \) for the BaFeAs\(_2\)-type structure and \( \alpha = 1/2 \) for the LaFeAsO-type structure. Here \( a \) and \( c \) are the lattice parameters, \( z \) is the \( z \)-axis position parameter of the \( As \) atom in the respective structure (\( z \approx 0.35 \) in BaFeAs\(_2\) and \( z \approx 0.65 \) in LaFeAsO), and \( r \) is the nearest-neighbor Fe-As distance within an Fe-centered FeAs\(_4\) tetrahedron (all four Fe-As nearest-neighbor distances are the same in each of the two structures). The Fe atoms in both structures form a square lattice where the 4-fold nearest-neighbor Fe-Fe distance in both structures is \( d_{\text{Fe-Fe}} = a/\sqrt{2} \).

Using Eqs. 5, we find \( \theta_2 = 117.6^\circ \), 118.4°, and 112.2° for BaRu\(_2\)As\(_2\), SrRu\(_2\)As\(_2\) and BaRh\(_2\)As\(_2\), respectively. These bond angles for the (Ba,Sr)Ru\(_2\)As\(_2\) compounds are significantly larger than the above optimum value of \( \approx 110^\circ \) for the (P,As)\(_4\)-based materials and therefore the low \( T_c \)’s < 1.8 K for the (Ba,Sr)Ru\(_2\)As\(_2\) compounds are consistent with this overall behavior. On the other hand, BaRh\(_2\)As\(_2\) stands out as an exception: it has the same \( \theta_2 \) as the high temperature superconducting LaFeAsO-based and CeFeAsO-based compounds with \( T_c = 28-40 \text{ K} \) (Refs. 32 and 33) but is not superconducting. Therefore, at least one additional characteristic
of the materials must be controlling $T_c$. As will be discussed in detail elsewhere \cite{7}, the bare nonmagnetic band structure density of states at the Fermi energy $N(E_F)$ is not correlated with $T_c$. For example, the calculated $N(E_F)$ for nonsuperconducting BaRh$_2$As$_2$ and that of superconducting LaFeAsO$_{0.9}$F$_{0.1}$ with $T_c = 27$ K are the same. The values are 1.76 \cite{27} and 1.28–2.01 states/(eV-M atom) \cite{39} and \cite{37}, respectively, for both spin directions.

On the other hand, $\chi(300 \text{ K})$ is large for all FeAs-based compounds with high $T_c$, suggesting that Stoner enhancement of the susceptibility may be relevant to the superconducting mechanism. Again using the same examples as above, for BaRh$_2$As$_2$ one finds a powder averaged $\chi(300 \text{ K}) = 0.18 \times 10^{-4}$ cm$^3$/mol Rh \cite{22} whereas for LaFeAsO$_{0.9}$F$_{0.1}$ one obtains $\chi(300 \text{ K}) = 3.3 \times 10^{-4}$ cm$^3$/mol Fe \cite{22} which is a factor of 18 larger. For LaFeAsO$_{0.9}$F$_{0.1}$, the above $N(E_F)$ range predicts a bare Pauli conduction electron spin susceptibility of 0.41–0.65 \times 10^{-4} \text{ cm}^3/(\text{mol Fe})$, suggesting a Stoner enhancement by a factor of 5 to 8. However, accurate estimates of the enhancement factor require that orbital contributions to $\chi$ must be corrected for \cite{22}. \cite{23}

V. CONCLUSION

We have synthesized and investigated the physical properties of ThCr$_2$Si$_2$-type polycrystalline BaRu$_2$As$_2$ and SrRu$_2$As$_2$ compounds. Both compounds were found to be metallic in character. Unlike other similar isoelctronic compounds (Ca,Sr,Ba)Fe$_2$As$_2$, BaRu$_2$As$_2$ shows no signature of a spin density wave or a structural transition from $\rho(T)$, $\chi(T)$ or $C_p(T)$ measurements down to 1.8 K. However, a clear cusp in $\chi(T)$ and a hint of one in $C_p(T)$ was found at $\sim 200$ K for SrRu$_2$As$_2$, which may be indicative of a structural and/or magnetic transition.

From analysis of our $C_p(T)$ data, the density of states at the Fermi energy $N(E_F)$ for (Ba,Sr)Ru$_2$As$_2$ was estimated to be $\sim 1$ state/(eV Ru atom) for both spin directions and is comparable to that per Rh atom in BaRh$_2$As$_2$. The small and negative values of $\chi(T)$ for both BaRu$_2$As$_2$ and SrRu$_2$As$_2$ indicate small or negligible Stoner enhancement of the conduction electron spin susceptibility. A comparison of $N(E_F)$ with that of BaRh$_2$As$_2$ suggests that the maximum contribution to $N(E_F)$ comes from the Ru $4d$ states. It would be interesting to study the effect of doping of SrRu$_2$As$_2$ in view of the occurrence of superconductivity in Ba$_{1-x}$K$_x$Fe$_2$As$_2$, Sr$_{1-x}$K$_x$Fe$_2$As$_2$ and BaFe$_{2-x}$Ru$_x$As$_2$. \cite{7,19,39} Finally, a comparison of the properties of (Ba,Sr)Ru$_2$As$_2$ and BaRh$_2$As$_2$ with those of the FeAs-based materials indicates that $N(E_F)$ for these nonsuperconducting Ru and Rh arsenides is about the same as for FeAs-based compounds with high $T_c$. \cite{35} A distinguishing feature of the high $T_c$ FeAs-based materials is their large $\chi$ values that evidently reflect significant Stoner enhancement of the conduction electron spin susceptibility\cite{32} as has been pointed out before. \cite{40,41,42} Thus it seems possible that the mechanisms for the Stoner enhancement and for the high $T_c$ in the FeAs-based materials may be closely related.

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