

Study the Electronic, Magnetic and Magnetotransport Properties of SrRuO_3 (Strontium Ruthenate) Including their Crystal Structure

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Abstract: SrRuO_3 is endowed with three remarkable features. First, it is a moderately correlated material that exhibits several novel physical properties; second, it permits the epitaxial growth of essentially single-crystal films; and third, because it is a good conductor, it has attracted interest as a conducting layer in epitaxial heterostructures with a variety of functional oxides. In this paper we have discussed regarding the general properties, crystalline structure, electronic properties, magnetic properties and magnetotransport properties of the SrRuO_3 .

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Introduction

The interest in SrRuO_3 , a compound which is probably not found in nature, has originally arisen from the possibility of using this material as a metallic electrode or buffer layer in various heterostructure electronic devices which are based on materials with a perovskite-type crystal structure (such materials include high- T_c superconductors and ferroelectrics) [1, 2, 3]. The good thermal conductivity and the remarkable chemical and thermal stability of SrRuO_3 (stable up to 1200 K in oxidizing or inert-gas atmospheres [4]; unchanged in structure up to 685 K [5]) are a great advantage for many applications. In addition to the possible applications, SrRuO_3 has drawn much attention in the last few years due to its unusual properties, which in some cases were interesting in themselves, and in other cases provided a convenient playground for investigating general material properties. Some of these properties are described in the foregoing sections.

Crystalline structure

The unit cell of SrRuO_3 is shown in Fig. 1(a). SrRuO_3 belongs to the perovskite group of minerals, which is a group of oxides with a general formula of ABO_3 (in our case $A = \text{Sr}$, $B = \text{Ru}$), which have a common crystalline structure. The BO_3 ions form a framework of corner-sharing octahedra, with a B ion at the center of each octahedron and six O ions at the corners. The A ion is situated between eight such octahedra. In many perovskites the octahedra are tilted or rotated in order to accommodate the large A ions. The result is a variety of symmetries from isometric to tetragonal to orthorhombic to monoclinic depending on the degree of distortion. The unit cells of SrRuO_3 (containing 4 formula units) are arranged in an

orthorhombic lattice, shown in Fig. 1(b). Since the distortion of the octahedra positions in SrRuO_3 is not large, its structure can be also described as pseudocubic (the pseudocubic unit cell, with a lattice parameter of 3.93 \AA , is also shown in Fig. 1(a)).

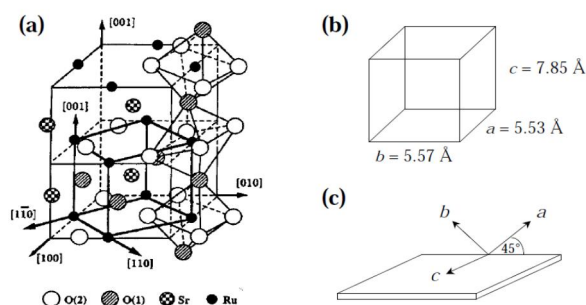


Figure 1: Structure of SrRuO_3 . (a) Unit cell, containing 4 formula units. (b) Lattice structure (orthorhombic), where a , b , and c correspond to $[100]$, $[010]$, and $[001]$, respectively. (c) Growth orientation on miscut SrTiO_3 substrate.

Electronic properties

SrRuO_3 is a metal. However, its electrical resistivity is relatively large ($\rho \sim 200 \text{ cm}^{-1}$ at room temperature, even for samples with a residual resistivity of $\sim \text{cm}^{-1}$), and it continues to grow with increasing temperature almost without saturation, and seems to cross the Ioffe-Regel limit [6] (where the mean free path becomes as small as the lattice constants). The exact reason for this behavior is not clear; possibly it is related to strong electronic interactions, which may be implied by the strong T^2 term in the electrical resistivity at low temperatures [7] and the mass enhancement (by a factor of 3:7 relative to band calculations) observed in

measurements of the specific heat [8]. Additional abnormal properties of SrRuO_3 include: non-Drude behavior of the infrared conductivity [9, 10, 11], violation of the Fisher-Langer relation for the temperature derivative of the resistivity near T_c [13], and deviations from Matthiessen's rule [12, 13] (the latter can be expected in a metal with a short mean free path due to the Pippard ineffectiveness condition [14]). Despite these irregularities, quantum oscillations in the electrical resistivity of SrRuO_3 at high magnetic fields (the Shubnikov-de Haas effect) show the existence of conventional fermion quasiparticles (at least at low temperatures, where the effect is observable) [15, 16].

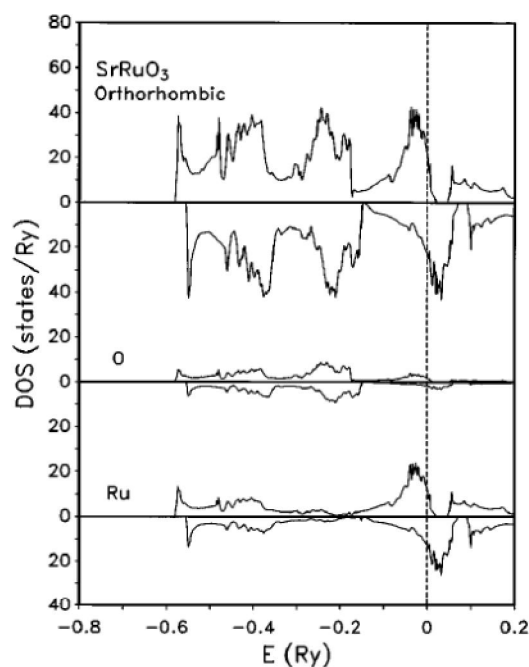


Figure 2: Density of states in SrRuO_3 . Majority (minority) spin is shown as positive (negative). The partial O (2p) and Ru (4d) contributions are also shown. The dashed vertical line denotes the Fermi energy.

Band calculations reveal a complicated band structure, and the results of the calculations are sensitive to the input parameters and depend on the method of calculation [19, 20, 21, 22]. A typical result for the density of states is shown in Fig. 2. The Fermi surface is dominated by the 4d electrons of Ru, which are also primarily responsible for the magnetic moment.

Magnetic properties

SrRuO_3 is a ferromagnet, with a transition temperature T_c of ~ 165 K in crystals, and ~ 150 K in thin films grown on SrTiO_3 substrates. The zero-temperature magnetic moment is about $1.4\mu_B$ per formula unit (or $M_0 = 210 \text{ emu/cm}^3$), and originates

from the 4d electrons of the Ru atoms (see Fig. 2). These are also the conduction electrons, so that SrRuO_3 is an itinerant ferromagnet. Consequently, significant spin polarization of the conduction electrons exists in SrRuO_3 [23]. The temperature dependence of the ferromagnetism of SrRuO_3 should be probably described in terms of the local-band model [24], since there is evidence from spectroscopic measurements that the ferromagnetic band splitting in SrRuO_3 , as in many other itinerant ferromagnets, does not disappear at T_c [25]. This means that as the temperature is increased to T_c , the magnetization disappears only on the long scale, but short-range order remains; the band splitting will disappear only at some temperature $T_S \gg T_c$. In the ferromagnetic state, SrRuO_3 films grown on miscut SrTiO_3 substrates possess a single easy axis of magnetization, roughly in the b orthorhombic direction [26, 27]. At T_c , the easy axis points strictly along the b direction (45° out of the film plane), and it slowly rotates as a function of temperature at a rate of $0.1^\circ/\text{K}$ toward the normal to the film (up to 30° relative to the normal at $T = 0$) [27]. The magnetic anisotropy in SrRuO_3 films is relatively large: the anisotropy constants are of the order of $K \sim 10^7 \text{ erg/cm}^3$ [28, 29], corresponding to an effective anisotropy field of about 10 T. The large anisotropy constant (compared to $5 \times 10^5 \text{ erg/cm}^3$ in iron [28], $8 \times 10^5 \text{ erg/cm}^3$ in nickel, and $4 \times 10^6 \text{ erg/cm}^3$ in hcp cobalt [29]) is probably a result of the reduced symmetry (see Fig. 1) and the large spin-orbit coupling, through which the spin direction is affected by the crystal structure. Shape anisotropy is negligible, since $2\pi M_0^2 \sim 3 \times 10^5 \text{ erg/cm}^3 \ll K$.

Magnetotransport properties

Throughout most of the temperature range (from $T \sim 10$ K up to at least room temperature) the electrical resistivity of SrRuO_3 decreases when a magnetic field H is applied, i.e., the magnetoresistance (MR) $\Delta\rho(H) = \rho(H) - \rho(0)$ is negative. The strongest MR ($\Delta\rho/\rho \sim 10\%$ for $H \sim 10$ T) is observed near T_c . This indicates that the MR is related mostly to diminishing of spin-dependent scattering (since the field-induced enhancement of magnetization is most significant near T_c). A comprehensive analysis of the relation of the MR to changes in magnetization is presented in Appendix A. The MR in SrRuO_3 is anisotropic; it depends on the directions of both the current and the magnetization relative to the crystalline directions. At low temperatures (below about 10 K) the MR becomes positive. This is expected due to shortening of the mean free path due to the Lorentz force. The positive MR is most significant in samples with low residual resistivity, and it becomes stronger as the temperature is lowered. These observations are in agreement with the expectation that the Lorentz MR is most significant when the mean free path is long.

Conclusion:

Here we have discussed regarding the general properties of SrRuO_3 including its crystal structure, electronic, magnetic and magnetotransport properties. In future we will be discussed the Extraordinary Hall effect in SrRuO_3

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