We report the magnetotransport properties of thin polycrystalline films of the recently discovered nonoxide perovskite superconductor MgCNi$_3$. CNi$_3$ precursor films were deposited onto sapphire substrates and subsequently exposed to Mg vapor at 700 °C. We report transition temperatures ($T_c$) and critical field values ($H_c$) of MgCNi$_3$ films ranging in thickness from 7.5 nm to 100 nm. Films thicker than ~40 nm have a $T_c$~8 K, and an upper critical field $H_c$(T=0)=14 T, which are both comparable to that of polycrystalline powders. Hall measurements in the normal state give a carrier density, $n = -4.2 \times 10^{22}$ cm$^{-3}$, that is approximately 4 times that reported for bulk samples.

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resistivity $\rho_{10K} = 20 \mu\Omega\text{cm}$, is a factor of 2–6 lower than polycrystalline powder values. The midpoint of the resistive transitions in Fig. 1 are 8.2 and 3.9 K for the 60 and 7.5 nm films, respectively. In Fig. 2 we plot the resistive transitions for a variety of film thicknesses $d$. Note that the transition temperature $T_c$ is relatively insensitive to $d$ down to about $d = 15$ nm, below which $T_c$ is suppressed and broadened.

The perpendicular critical field behavior of a 60 nm film is shown in Fig. 3. As is the case with pressed pellets of MgCNi$_3$ powder, the resistive critical field transition width is only weakly temperature dependent. We defined the critical field, $H_{c2}$, as the midpoint of the transitions in Fig. 3, and in Fig. 4 we plot critical values as a function of temperature.

The solid symbols represent a 60 nm film, and the open symbols are for a polycrystalline sample from Ref. 12. Clearly the 60 nm critical field behavior is comparable to that of sintered MgCNi$_3$ powders, which are known to have an anomalously high critical field and excellent flux pinning properties. The zero temperature critical field can be estimated using the relation $H_{c2}(0) = -0.693(dH_{c2}/dT)_{T_c}T_c$. From the data in Fig. 4 we obtain $(dH_{c2}/dT)_{T_c} = -2.3$ T/K, $H_{c2}(0) = 12.8$ T and a zero temperature coherence length $\xi(0) \approx 5$ nm.

We have also made Hall measurements of the films in the normal state between 10 K and room temperature. In the inset of Fig. 4 we show the Hall voltage as a function of

![FIG. 1. Resistivity of a 60 nm and a 7.5 nm MgCNi$_3$ film as a function of temperature in zero magnetic field. The midpoint transition temperatures of the 60 nm and 7.5 nm films were $T_c = 8.2$ K and $T_c = 3.9$ K, respectively. Inset: X-ray powder diffraction pattern of a 90 nm MgCNi$_3$ film on sapphire.](image1)

![FIG. 2. Resistive transitions for varying film thickness. The curves correspond from left to right to MgCNi$_3$ layer thicknesses of 7.5, 15, 30, 45, and 60 nm.](image2)

![FIG. 3. Resistive critical field transitions of a 60 nm film at different temperatures. The magnetic field was applied perpendicular to the film surface.](image3)
magnetic field at 10 and 200 K. The solid lines are linear fits to the data. The slopes of the lines are proportional to the Hall coefficient $R_H = 1/n$, where $n$ is the effective carrier density. Clearly the MgCNi$_3$ films have electronlike carriers as is the case in the bulk material. However, the calculated carrier density at 10 K, $n = -4.2 \times 10^{22} \text{cm}^{-3}$, is about 4 times larger than that reported in Ref. 12 for sintered powder samples. It is somewhat surprising that the superconducting properties of the films are so similar to that of the bulk systems given the large enhancement in the density of states suggested by the Hall data.

Interestingly, recent studies of Ni-site substitution with Co, which in principle hole dopes the system, show a rapid quenching of the superconducting phase with increasing Co concentration, even for concentrations as little as a few percent. Two possible explanations for this sensitivity to Co doping immediately come to mind. One is that Co behaves as a localized magnetic impurity and consequently produces pair breaking. However, susceptibility measurements of MgCNi$_{3-x}$Co$_x$ powders are not consistent with what would be expected for free Co moments. Furthermore, even at doping levels up to $x=0.75$ no long range magnetic order is seen. A second possibility is that superconductivity in MgCNi$_3$ is very sensitive to a narrow spectral feature in the electronic structure, and that at even small Co doping levels the optimum band filling is compromised. Our Hall data, however, would suggest that this is not case and that $T_c$ is not extraordinarily sensitive to the density of states. Presumably, the enhancement we observe in the Hall carrier density reflects a significant modification of bands near the Fermi surface that is a result of disorder or perhaps substrate-induced strain.

In conclusion, we report the first synthesis of MgCNi$_3$ films and find that their transition temperatures and critical field behavior are very similar to that of bulk powder samples. The films are smooth, adherent, and show no significant air sensitivity. A thin film geometry lends itself quite well to planar counter-electrode tunnelling measurements of the electronic density states, thus providing a compelling alternative to scanning electron microscopy tunneling. Such a study in MgCNi$_3$ films should prove invaluable in resolving the nature of the superconducting condensate. The film geometry will also allow access to the spin paramagnetic limit in parallel magnetic field studies, as well as possible electric field modulation of the carrier density via gating and critical current studies.

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