Comment on "Localization and Size Effects in Single-Crystal Au Films"

In an interesting recent Letter,[1] Chaudhari, Habermeier, and Maekawa (CHM) present resistance measurements as a function of temperature and magnetic field for epitaxially grown single-crystal gold films. These results were interpreted as being due to a significant enhancement of the electron localization effect in the presence of the quantum size effect. We argue here that their data can be equally well explained by the presence of a small concentration of magnetic impurities in the gold films.

The resistance per square $R_\square$ of the films ranges between 8.0 $\Omega/\square$ and 32 $\Omega/\square$ and the nominal thickness is $t=10$ nm. This implies a resistivity $\rho=8\times10^{-8}$ Ω m which is rather high for a single-crystal film. Indeed, van Attekum *et al.*[2] report for an as-deposited polycrystalline Au film with the same thickness a value for $\rho\approx10\times10^{-8}$ Ω m and for a heat-treated film $\rho\approx3\times10^{-8}$ Ω m.

The temperature dependence of $R_\square$ (see Fig. 1 of Ref. 1) shows a negative logarithmic slope which is much too large to be explained by localization and electron-electron interaction effects. The variation over one decade of temperature $\Delta R_\square/R_\square^2=1.6\times10^{-4}$ $(\Omega/\square)^{-1}$ for a Au film with $R_\square=8.0$ $\Omega/\square$, while for a disordered film[3] one expects that $\Delta R_\square/R_\square^2=7\times10^{-6}$ $(\Omega/\square)^{-1}$. For the Kondo system AuCr[4] the logarithmic variation of the resistivity over one decade of temperature due to the magnetic Cr impurities is given by $\Delta\rho=1\times10^{-12}$ Ω m/ppm; for AuFe[5] the variation is $\Delta\rho=1.8\times10^{-12}$ Ω m/ppm. The Kondo temperature for these systems is only a few millikelvins. Hence an impurity concentration $n_i=100$ ppm Cr or $n_i=55$ ppm Fe can explain the large value for $\Delta R_\square/R_\square^2=\Delta\rho[1/\rho R_\square]$ reported by CHM.

These magnetic impurities also give rise to a negative contribution to the magnetoresistance (MR). From the MR data of dilute AuCr alloys reported by Shiozaki and Kawarazaki[6] one obtains at $T=0.5$ K, a resistivity correction which is nearly independent of the impurity concentration up to a field $B=2$ T and which is given by $\Delta\rho(2\text{ T})=\rho(B=2\text{ T})-\rho(0)=-6\times10^{-11}$ Ωm. At higher fields this correction becomes even more important with increasing impurity concentration and one finds at $B=3$ T a correction $\Delta\rho(3\text{ T})=-1\times10^{-12}$ Ω m/ppm. For the single-crystal Au film with $R_\square=8$ $\Omega/\square$ as reported by CHM, this would result in a magnetoresistance variation of, respectively, $\Delta R_\square/R_\square$ (2 T) $=7.5\times10^{-4}$ or $\Delta R_\square/R_\square$ (3 T) $=1.2\times10^{-3}$, for an impurity concentration of 100 ppm Cr in the film. This important negative MR correction is, however, masked in the experimental data (see Fig. 2 of Ref. 1) by the much stronger positive bulk MR combined with the MR due to the perpendicular and longitudinal size effect.[7] In a magnetic field perpendicular to the plane of the film the size effect results in an increase in amplitude of the normal bulk MR, while in the longitudinal field direction the positive bulk MR is reduced at higher fields. The magnitude of these corrections is larger than the MR due to magnetic impurities and hinders the interpretation of the MR contribution due to weak localization at low fields.

It therefore seems to us that the temperature dependence of $R_\square$ (see Fig. 1 in Ref. 1) gives the only experimental information for discussing the localization and interaction effects in the Au films. It has, however, been clearly demonstrated that the $R_\square(T)$ data are very sensitive to the presence of magnetic impurities. Therefore, no clear evidence for an enhancement of the localization effect due to the size effect is present. This would require a detailed study of the 2D epitaxial layers as a function of the film structure and film purity.

This work was supported in part through a Research Assistantship for one of us (M.G.) from the Belgian Interuniversitair Instituut voor Kernwetenschappen.

M. Gijs and Y. Bruynseraede
Laboratorium voor Vaste Stof-Fysika en Magnetisme
Katholieke Universiteit Leuven
B-3030 Leuven, Belgium

Received 24 December 1985
PACS numbers: 71.50.+t, 72.15.Eb, 72.15.Gd

[1]P. Chaudhari, H.-U. Habermeier, and S. Maekawa, Phys. Rev. Lett. **55**, 430 (1985).

[2]P. M. Th. M. van Attekum, P. H. Woerlee, G. C. Verkade, and A. A. M. Hoeben, Phys. Rev. B **29**, 645 (1984).

[3]T. Kawaguti and Y. Fujimori, J. Phys. Soc. Jpn. **51**, 703 (1982).

[4]J. Teixeira, Ph.D. thesis, Université Scientifique et Medicale de Grenoble, 1974 (unpublished).

[5]O. Laborde, Ph.D. thesis, Université Scientifique et Medicale de Grenoble, 1977 (unpublished).

[6]Y. Shiozaki and S. Kawarazaki, Solid State Commun. **38**, 1227 (1981).

[7]K. L. Chopra, *Thin Film Phenomena* (McGraw-Hill, New York, 1969), p. 345ff.