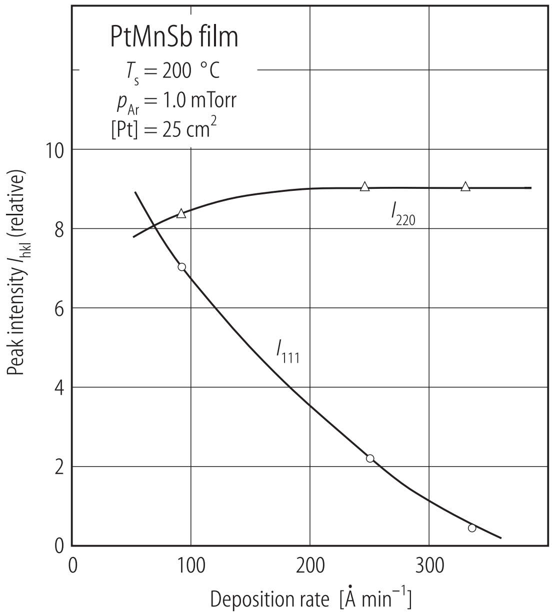

Fig. 60. Diffraction peak intensity as a function of deposition rate at argon pressure p_{Ar} = 1.0 mTorr (Pt: area of Pt chips) [88N3].

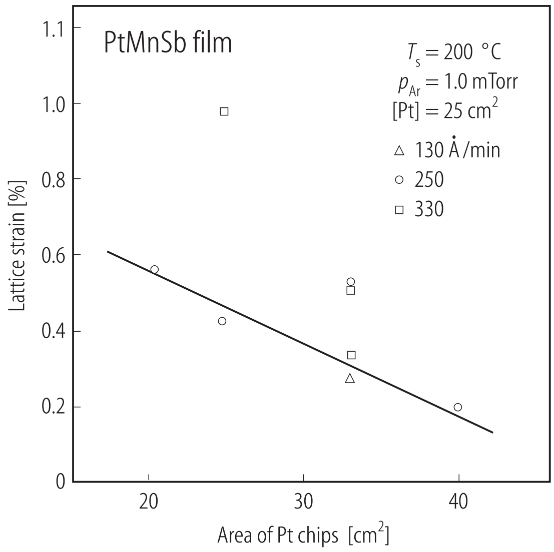

Fig. 61. Lattice strain (1 – c/a) vs. area of Pt chips in PtMnSb films for various deposition rates [88N3].

1.5.5.3 Bulk magnetic properties

1.5.5.3.1 Introduction

The investigation of the bulk magnetic properties of materials is an essential first step in obtaining an understanding at a microscopic level. Frequently analysis of these data is made, particularly for ferromagnetic materials, using Arrott plots in which the data is presented in the form of M^2 versus B/M isotherms. From these isotherms it is possible to ascertain whether a material has a spontaneous moment, the Curie temperature, the degree of magnetic homogeneity etc. However the application of Arrott plots is not restricted to ferromagnetic materials and in view of the information which may be obtained from such analysis and its importance to the present review a detailed account is given below.

1.5.5.3.2 Arrott plots

1.5.5.3.2.1 Introduction

The use of Arrott plots to analyse bulk magnetic properties arises from the application of Landau theory. It is the notion of an order parameter and the fact that the symmetry of the system can be treated exactly that makes this approach particularly attractive [90I1, 87T1]. By using an expansion of the free energy in powers of the order parameter (e.g. the ferromagnetic moment or the staggered magnetisation in an antiferromagnet) the magnetic behaviour may be described using a small number of (temperature dependent) coefficients. These coefficients may be extracted from experimental observations of the magnetic moment as a function of external field and temperature with the help of Arrott plots, namely M^2 vs. $\mu_0 H/M$. For a ferromagnetic system this can be readily obtained from measurements of the magnetisation.

To assist in the interpretation of magnetic data a Landau formulation is provided for ferromagnetic, antiferromagnetic and mixed magnetic systems. The functional dependence of the expansion coefficients is derived using a high temperature series expansion of the partition function as a function of the magnetic moment and temperature. The validity and range of applicability of this expansion is discussed.

In subsect. 1.5.5.3.2.2. the Landau free energy formulation is used for modelling magnetisation data of a ferromagnetic system. As a means of relating the field and temperature dependence of the magnetic moment to the coefficients of the free energy expansion of the Landau theory, Arrott plots are introduced in subsect. 1.5.5.3.2.3.

In subsects. 1.5.5.3.2.4 and 1.5.5.3.2.5, the analysis of magnetic data using Arrott plots is extended to systems with more complex forms of ferromagnetic or more complicated magnetic order. Arrott plots are shown to be a valuable means of analysis even for these cases. The physics and the resulting Arrott plots are illustrated by way of example using simple model systems.

1.5.5.3.2.2 Mean field description of magnetic phase transition and Landau form of the free energy

In this section a derivation is given for the form of the free energy of a ferromagnetic system as a function of the magnetic order parameter. Within the Landau theory of magnetic phase transitions the free energy is considered as a power series expansion in terms of the magnetic order parameter, and explicit expressions are derived for the coupling coefficients. For the magnetically ordered state and alternatively also in the limit of high temperature, these coupling coefficients are evaluated as a function of temperature and the quantum numbers which characterise the magnetic moment.

The Hamiltonian describing the short range interactions between magnetic moments is taken to be of the form

$$\mathrm{H} = -\sum_{\mathrm{i,j}} J_{\mathrm{i,j}}\, \boldsymbol{M}_{\mathrm{i}} \boldsymbol{M}_{\mathrm{j}} - \sum_{\mathrm{i}} \boldsymbol{M}_{\mathrm{i}} \boldsymbol{B}_0 \tag{3}$$

where the magnetic moment $\boldsymbol{M}_{\mathrm{i}}$ at lattice site i interacts with the magnetic moment at lattice site j and with the external magnetic field $\mu_0 \boldsymbol{H} = \boldsymbol{B}_0$. For simplicity the magnetic moment is taken to be of fixed magnitude.

In order to analyse the above Hamiltonian a mean field approximation is employed. First the Hamiltonian is written as the sum of two contributions:

$$\mathrm{H} = \mathrm{H}_0 + \mathrm{H}' \tag{4}$$

with

$$\mathrm{H}_0 = -(B_0 + b_0) \sum_{\mathrm{i}} M_{\mathrm{i}}^z \tag{5}$$

Here H_0 is the sum of single atom Hamiltonians. It consists of the sum of magnetic moments interacting with an effective magnetic field of magnitude (B_0+b_0). The internal field b_0 is added again in H'. The idea is to choose b_0 in such a way as to make H' as small as possible. The question of the magnitude and the optimal choice of b_0 will be discussed below.

Reformulating the Hamiltonian in (3) in the form of (5) is a simple re-writing with no approximations involved. In order to progress with the analysis of the properties of a system described by the Hamiltonian (5), a mean field approximation is employed combined with the assumption that the H' contribution is effectively small. The mean field approximation then consists of replacing all operators in H' by their expectation values which are evaluated using H_0. With