DIFFUSION MECHANISM IN Ce/Ni MULTILAYERS AS A FUNCTION OF THEIR PERIODS


To cite this version:

P. Guilmin, C. Brouder, G. Krill, W. Felsch, G. Marchal, et al.. DIFFUSION MECHANISM IN Ce/Ni MULTILAYERS AS A FUNCTION OF THEIR PERIODS. Journal de Physique Colloques, 1988, 49 (C8), pp.C8-1757-C8-1758. <10.1051/jphyscol:19888800>. <jpa-00229055>

HAL Id: jpa-00229055
https://hal.archives-ouvertes.fr/jpa-00229055
Submitted on 1 Jan 1988
DIFFUSION MECHANISM IN Ce/Ni MULTILAYERS AS A FUNCTION OF THEIR PERIODS

P. Guilmin (1), C. Brouder (1), G. Krill (1), W. Felsch (2), G. Marchal (1), E. Dartyge (3), A. Fontaine (3) and G. Tourillon (3)

(1) Laboratoire de Physique du Solide, Université de Nancy I, B.P. 239, F-54506 Vandœuvre-lès-Nancy cedex, France
(2) Physikalisches Institut, Universität Göttingen, F.R.G.
(3) Laboratoire d’Utilisation du Rayonnement Electromagnétique, Bât. 209 D., F-91405 Orsay Cedex, France

Abstract. – We have studied the diffusion in Ce/Ni multilayers with different periods (65 Å, 195 Å, 325 Å). We have observed that the final state of the diffusion process could vary as a function of the period, giving respectively a homogeneous amorphous alloy, a homogeneous crystalline compound and mixed phases.

1. Introduction

It was discovered recently that the diffusion in metallic multilayers could mix completely the constituent metals and result in an homogeneous amorphous alloy. This phenomenon, called the solid-state reaction, was thoroughly investigated but is not yet completely understood [1]. On the other hand, a knowledge of the diffusion mechanisms is very important for the epitaxial growth of superlattices.

In this paper, we report on a set of experiments (X-ray absorption, X-ray diffraction, electron diffraction, cross-sectional electron microscopy, magnetic measurement) that we carried out on Ce/Ni multilayers with various periods. All our results were compatible with the following interpretation: after the solid-state reaction, small periods form an amorphous alloy, intermediate periods lead to an homogeneous crystalline CeNi2, large periods form an alloyed interface that blocks the diffusion, leaving layers of pure cerium and nickel.

2. Sample preparation and experiment

Three Ce/Ni multilayers were prepared by alternate evaporation in an ultra-high vacuum chamber (3 \times 10^{-8} Torr) of cerium and nickel onto a polyimide substrate cooled by a copper plate in contact with a liquid nitrogen tank. The deposition rates were typically 2 Å/s, and the three samples were 130 bilayers of Ni(30 Å) and Ce(35 Å), 45 bilayers of Ni(90 Å) and Ce(105 Å) and 15 bilayers of Ni(150 Å) and Ce(175 Å). The average composition of the multilayers was Ce$_{0.27}$Ni$_{0.73}$. The samples were annealed at room temperature until no evolution could be detected.

The X-ray absorption experiments were carried out at the French synchrotron radiation facility, all the other measurements were performed in Nancy.

3. Experimental results and interpretation

X-ray absorption spectroscopy has become a standard measurement of the structural state of disordered materials [2] and of the valence of cerium in intermetallic alloys [3].

Figures 1 and 2 show, respectively, the K-edge spectra of nickel and the L_{III}-edge spectra of cerium in our samples.

Our results are fully described in [4] and can be summarized as follows:

(i) for our small period multilayer, the diffusion has been studied in detail in [5]. X-ray absorption, electron diffraction and magnetic measurements show that the final state of the diffusion process is an homogeneous amorphous alloy with some traces of nickel. A comparison of the Ni K-edge of the diffused sample with the

![Energy spectrum](http://dx.doi.org/10.1051/jphyscol:19888800)
Fig. 2. – From top to bottom, Ce LIII-edge spectra of the multilayers with periods 325 Å, 195 Å, 65 Å.

Ni K-edge of CeNi2 shows that the amorphous alloy formed has a disordered CeNi2 structure;

(ii) for our intermediate period multilayer, X-ray diffraction proves that the main phase of the diffused sample is crystalline CeNi2. Cross-sectional electron microscopy shows that the diffused sample is homogeneous. Since the nominal atomic concentration of cerium in the sample is 0.27, there must be some nickel left. Moreover, the average valence of cerium in our sample is 3.28 instead of 3.23 (the cerium valence in CeNi2 [6]), this means that there are also some cerium atoms which have a nickel rich disordered environment. This is confirmed by the fact that the magnetic measurements exhibit a ferromagnetic component which does not exist in ordered Ce-Ni alloys [7];

(iii) for our large period multilayers, cross-sectional TEM proves that a layer-structure is conserved in the final state of diffusion. A comparison of the Ni K-edge in our sample and in pure nickel shows that the nickel is mainly in a pure crystalline phase. From the magnetic measurements, we know that 27% of the nickel has lost its ferromagnetic character. The valence measured from the Ce LIII-edge is 3.10. All this information, combined with the valence of cerium as a function of cerium concentration in Ce-Ni amorphous alloys [8, 9], enables us to deduce that a Ce-Ni interlayer has formed with thickness 30-100 Å. Our cross-sectional TEM is not accurate enough to measure the thickness of interlayer. In any case, our results show that for large periods, the diffusion is stopped at a certain stage.

All these results are compatible with the idea, put forward by Newcomb and Tu [10], of a competition between amorphization and crystallization. According to these authors, an amorphous alloy forms during the solid-state reaction because the diffusion is too fast for the crystalline compounds to nucleate. When the amorphous interlayer has reached a critical thickness, the diffusion front is so slow that crystallization becomes possible. In our samples with large periods, this crystalline interlayer stops the diffusion.