Assessment of Atomic Interdiffusion of Mg and Nd in the Mg-Nd system

Ahmad Mostafa and Mamoun Medraj

Department of Mechanical & Industrial Engineering, Concordia University, Montreal, Canada, H3G 1M8
E-mail: ah_mosta@encs.concordia.ca

Introduction

The mechanical properties of the new designed alloys are greatly influenced by the microstructure and the resulting phase relationships. The alloys' microstructures can be enhanced by controlling the atomic interdiffusion process of a system species. Therefore, the mechanical properties can be predictable if the diffusion parameters are being known and controllable.

In order to understand the diffusion phenomena, diffusion couple technique with Boltzmann–Matano analysis are used to measure the interatomic diffusion coefficients of the system components.

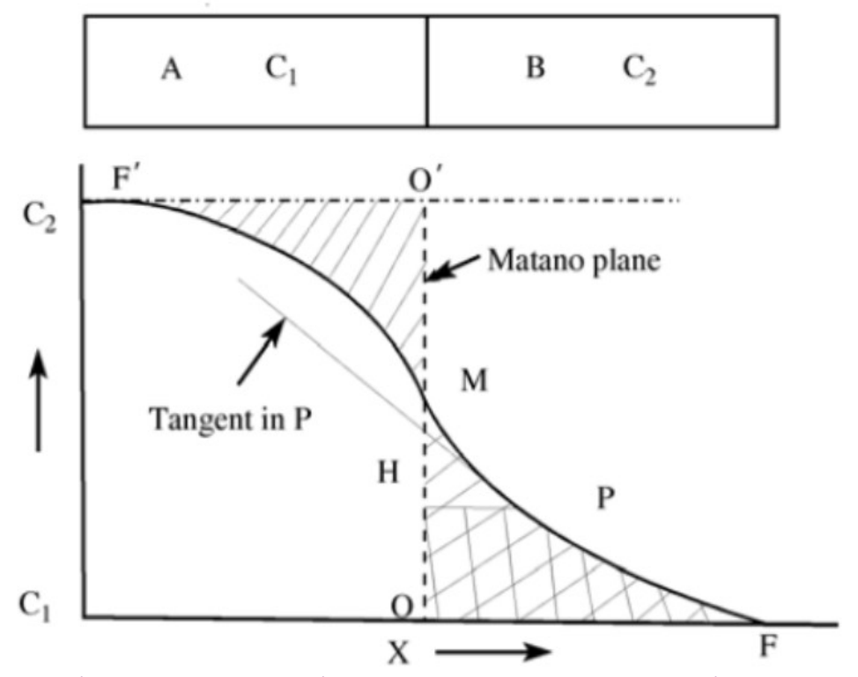

Figure 1: Boltzmann-Matano plane identification

$$\int_{c1}^{c2} x\,dc = 0$$

$$\check{D}(c^{\phi}) = -\left(\int_{c1}^{c^{\phi}} x\,dc\right)/(2t\partial c/\partial x)$$

Ď(c) is the interdiffusivity at the composition *C* (cm^2/sec), *t* is the annealing time (sec), *dc/dx* is the slope at the composition *C* (at.%/cm), and *x* is the layer thickness (cm)

Motivation

Very few attempts were carried out to measure the atomic interdiffusion coefficients of the Mg and Nd atoms in the Mg-Nd binary system.

The available data from the literature showed inaccurate results because one of the intermediate phases was missing from the obtained diffusion couple.

Objectives

The main objective of this work is to provide information on the interdiffusion coefficients of Mg and Nd atoms at Boltzmann-Matano interface between the existing binary compounds in the Mg-Nd system. Furthermore, this work will provide information on the temperature-independent diffusion coefficient (D_0) and the activation energy for diffusion (Q_d).

This information is necessary for practical applications such as solidification, precipitation, homogenization of alloys, recrystallization, grain boundary migration, creep-resistance enhancement, and joining processes.

Acknowledgments

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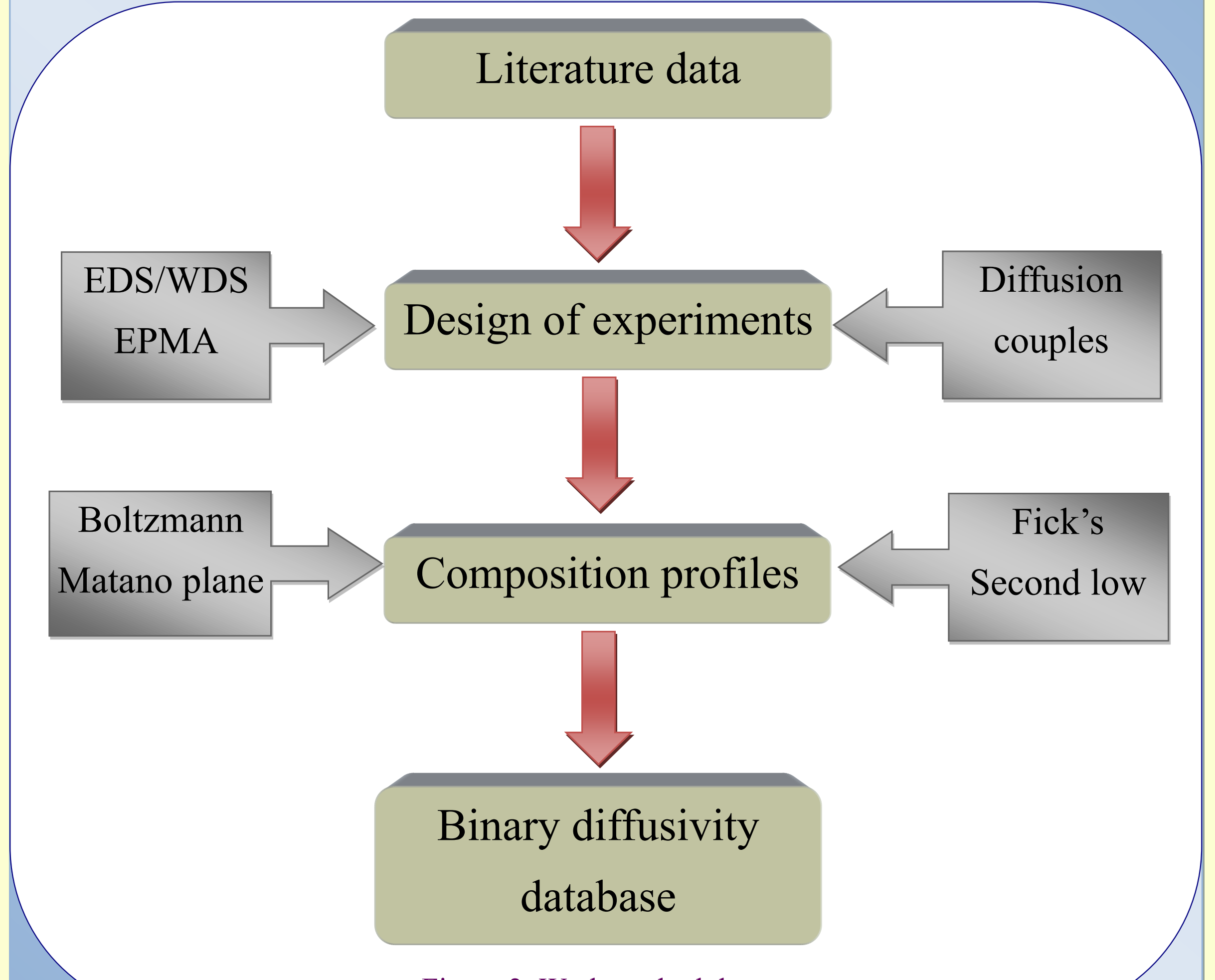
Methodology



Literature data

EDS/WDS EPMA

Design of experiments

Diffusion couples

Boltzmann Matano plane

Composition profiles

Fick's Second low

Binary diffusivity database

Figure 2: Work methodology

Experimental Procedure

- Diffusion couples were prepared initially from pure metals (99.98% Mg and 99.95%Nd).
- Metals used to make diffusion couples, were grinded down gradually up to 1200 grit size SiC sand papers. The ground members then polished up to 1µm using alcohol-based diamond suspension.
- Metallic ring-clamps were used to attach the polished end-members to make solid-solid diffusion couples.
- Diffusion couples, wrapped up with Ta foil, were inserted in a hermetically sealed quartz tube under vacuum to be annealed at certain temperature and time.
- EDS/WDS were used to measure the composition profile of the diffused species.
- Boltzmann-Matano plane analysis were performed on the obtained profiles to measure the interdiffusion coefficient of the diffused species.

Figure 3: Clamped end-members

Figure 4: Samples inside a sealed quartz tube

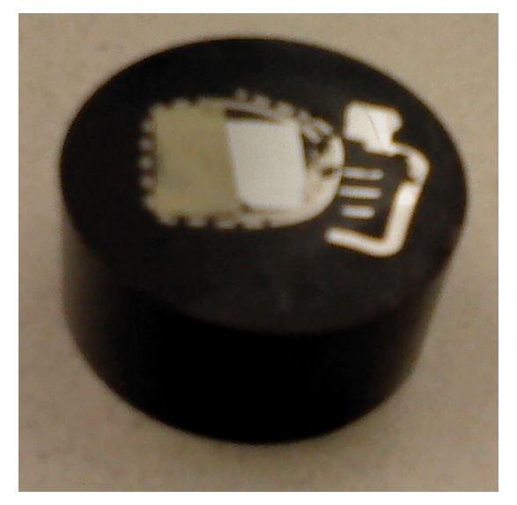


Figure 5: Mounted diffusion couple for WDS

Results and discussion

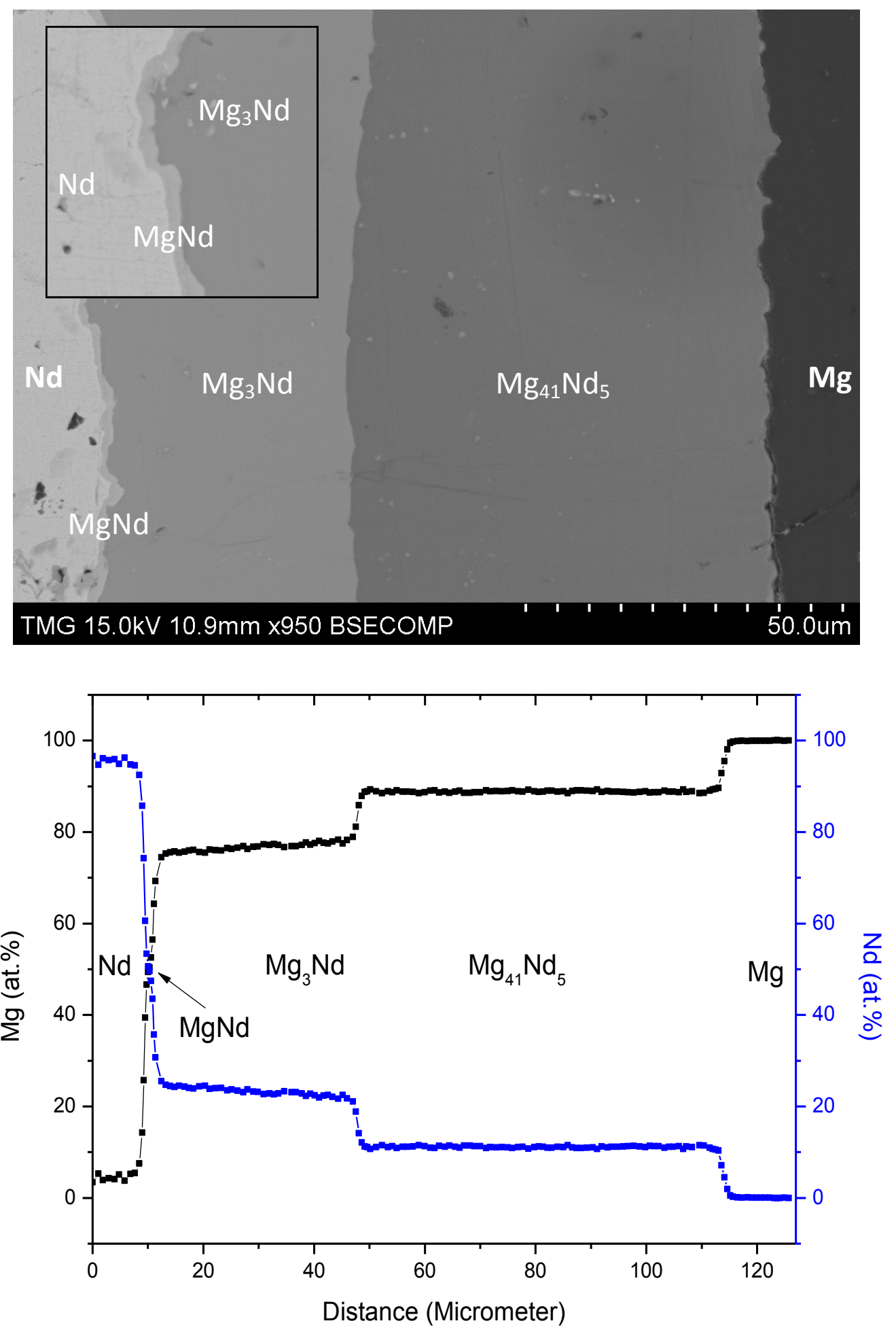


Figure 6: (a) SEM micrograph of Mg/Nd diffusion couple annealed at 450°C for 4 days; (b) composition profile

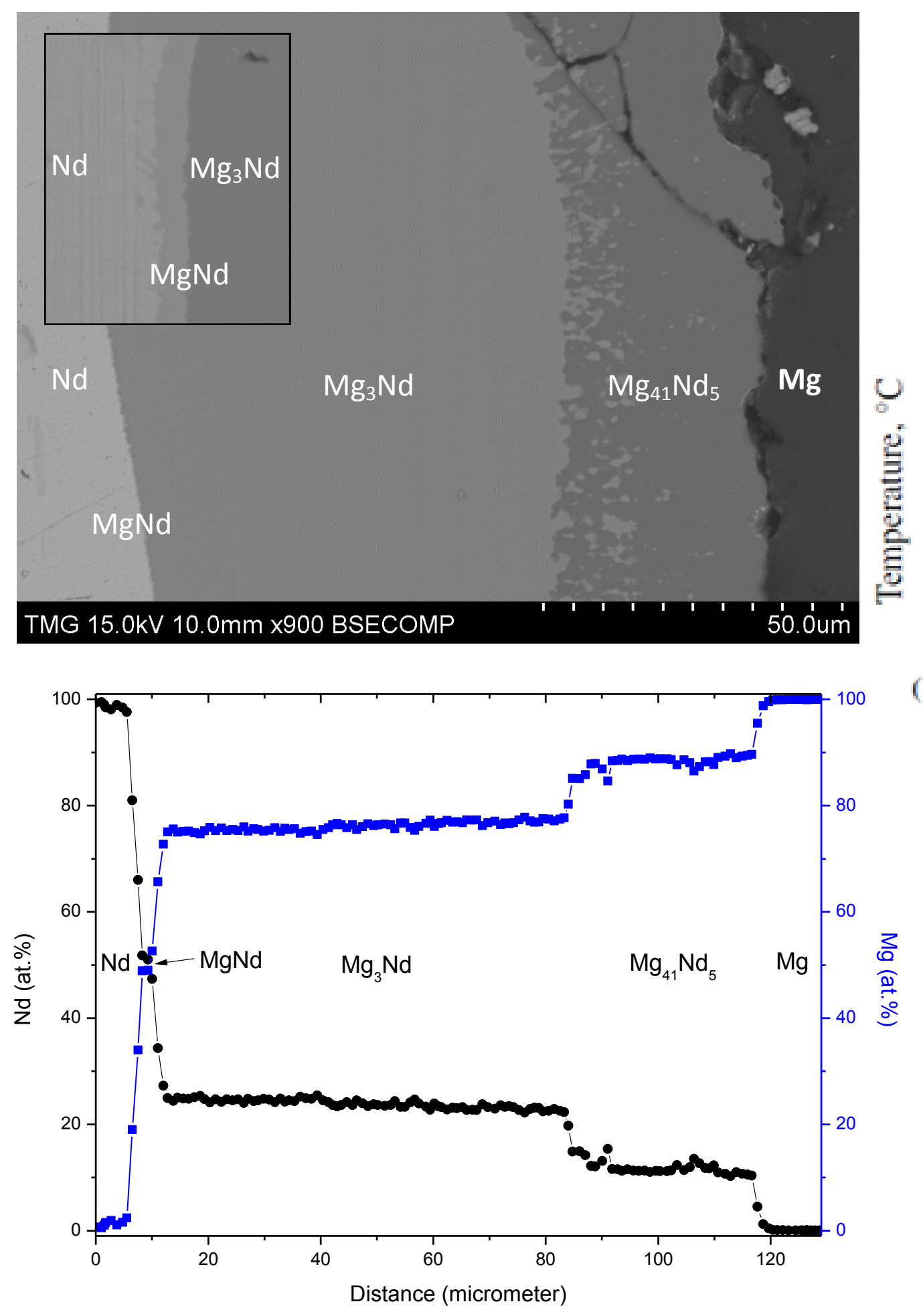


Figure 7: (a) SEM micrograph of Mg/Nd diffusion couple annealed at 400°C for 13 days; (b) composition profile

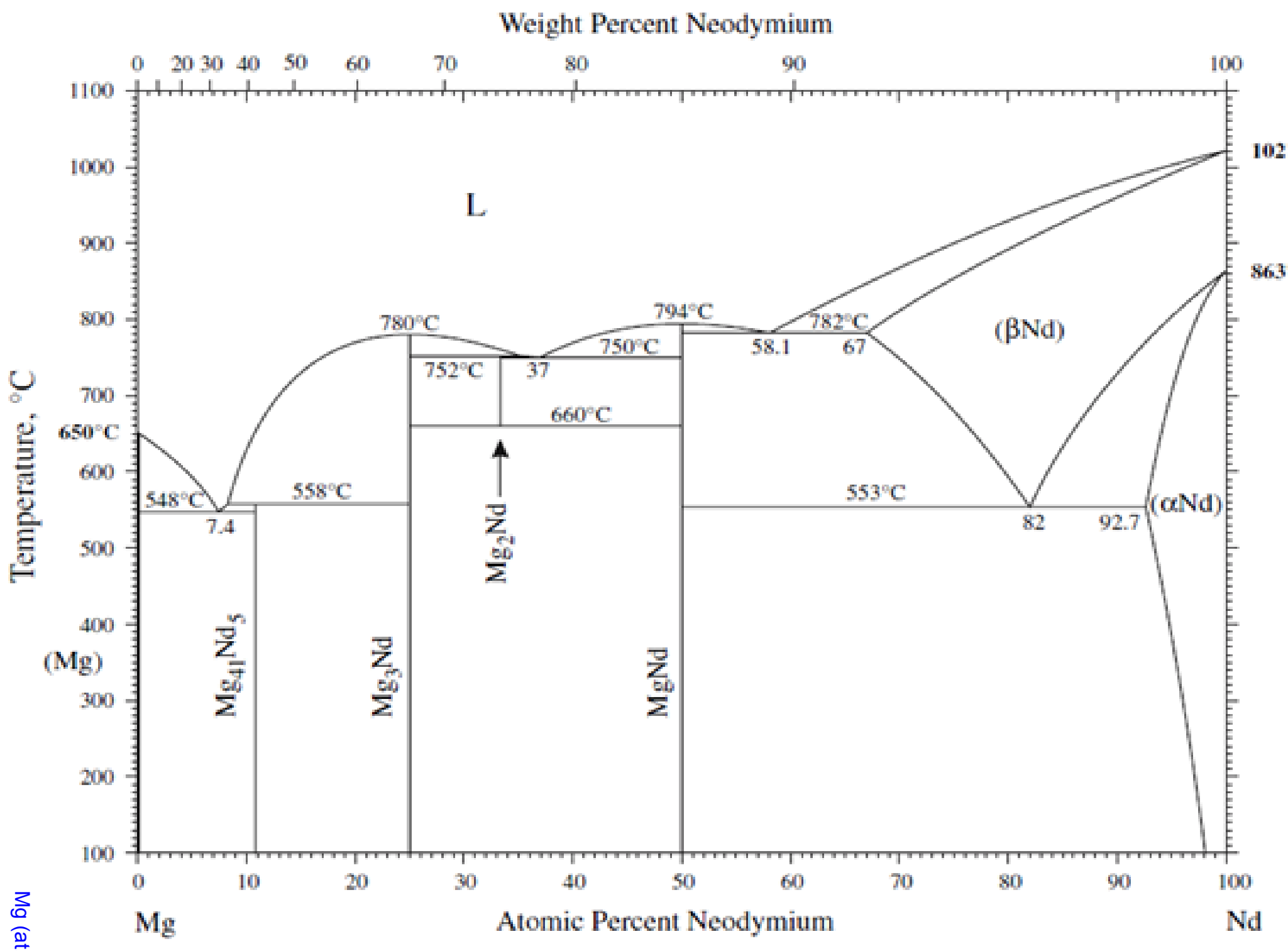


Figure 8: The Mg-Nd phase diagram

H. Okamoto, Mg-Nd, Journal of Phase Equilibria and Diffusion, 28 (2007) 405-405.

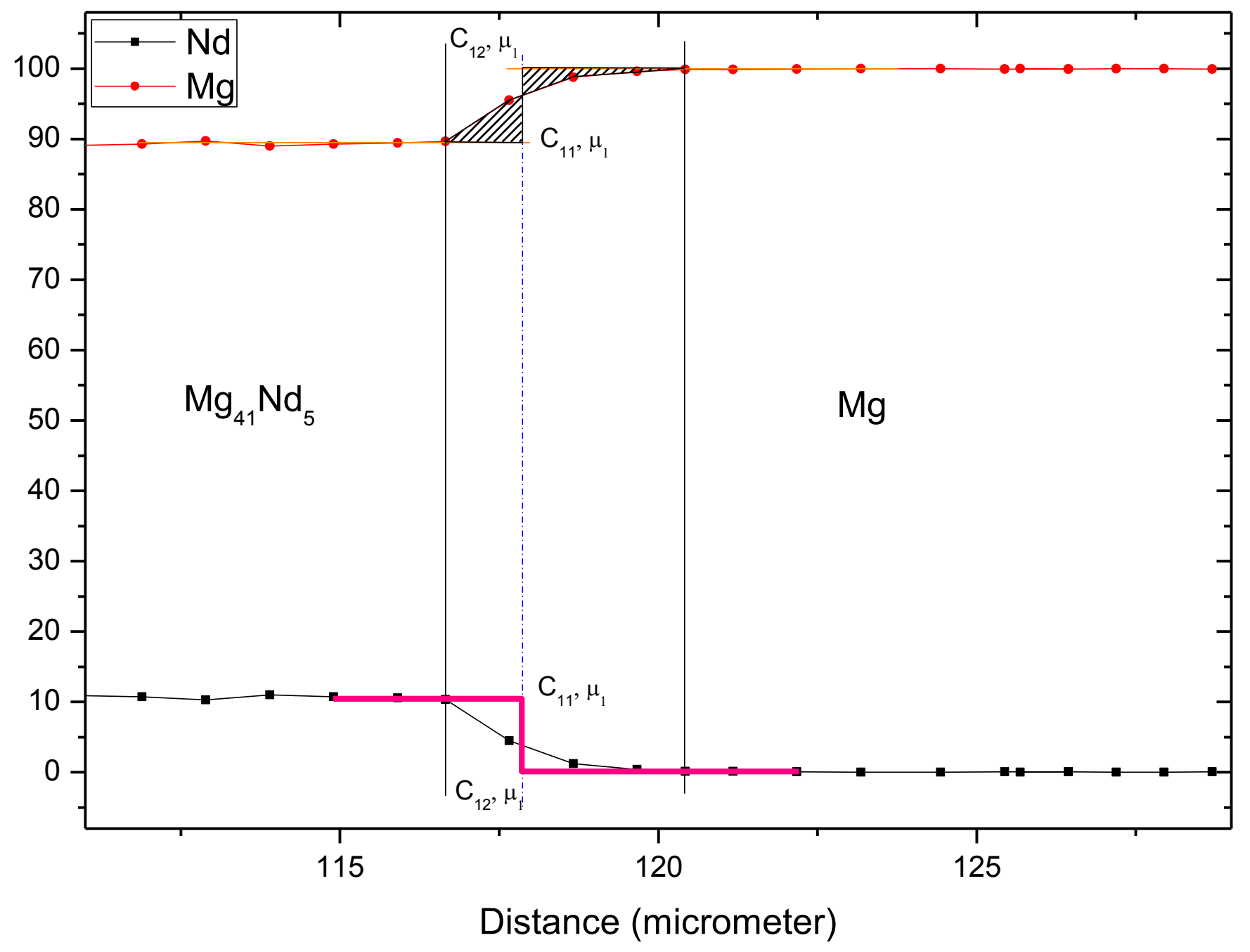


Figure 9: An example of the Boltzmann-Matano plane identification on the $Mg_{41}Nd_5$/Mg interface (400°C couple)

Table 1: comparison between the measured diffusion coefficients in the two diffusion couples

Interface	D(c) cm^2/sec (450°C diffusion couple)	D(c) cm^2/sec (400°C diffusion couple)
Nd/MgNd	2.0699×10^{-13}	1.1118×10^{-13}
MgNd/Mg_3Nd	3.7200×10^{-14}	2.0807×10^{-14}
Mg_3Nd/$Mg_{41}Nd_5$	2.9800×10^{-13}	2.3023×10^{-13}
$Mg_{41}Nd_5$/Mg	1.0610×10^{-13}	6.5394×10^{-14}

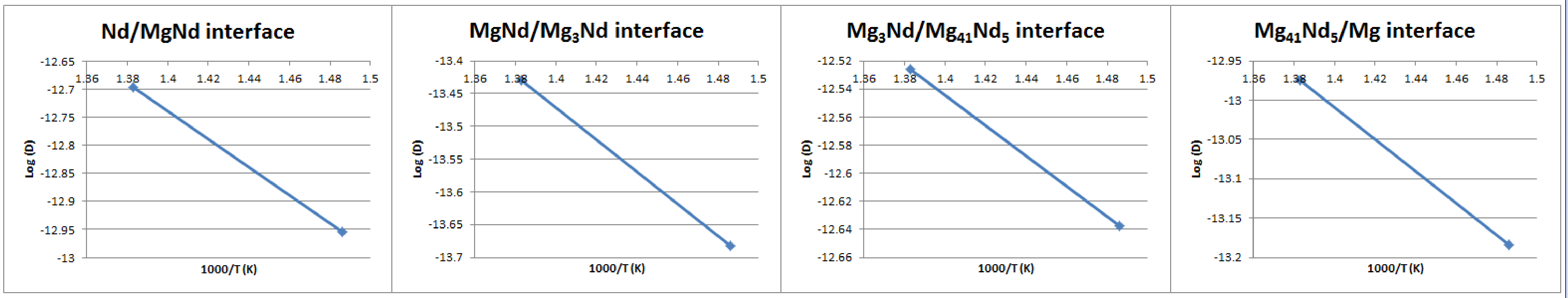


Figure 10: The log (D) Vs. 1000/T curves of the interfaces of the Mg/Nd diffusion couples

From the SEM micrographs of the two Mg/Nd diffusion couples, the MgNd diffusion zone appeared as very thin layer, far from the Mg end-member. However, the activation energy at the Nd/MgNd interface was the largest among those of other interfaces. This explains that the MgNd phase was forming across the Nd end-member and allowing other layers to form after.

Table 2: The measured D0 and Qd values at the Mg/Nd diffusion couples interfaces

Interface	D_0(c) cm^2/sec	Q_d kJ/mol $Q_d=2.3R\times\Delta\log(D)/\Delta(1/T)$
Nd/MgNd	5.84×10^{-10}	47.862
MgNd/Mg_3Nd	9.55×10^{-11}	47.111
Mg_3Nd/$Mg_{41}Nd_5$	1.89×10^{-09}	20.859
$Mg_{41}Nd_5$/Mg	7.16×10^{-11}	39.097

Conclusions

- According to the Mg-Nd phase diagram, three intermediate compounds were observed in the two Mg/Nd diffusion couples, annealed at 450°C for 4 days and 400°C for 13 days. These phases are: MgNd, Mg_3Nd and $Mg_{41}Nd_5$.
- The interdiffusion coefficients were measured experimentally using diffusion couples technique and Boltzmann-Matano analysis at all the diffusion couple's interfaces.
- The temperature-independent coefficient and the activation energy were concluded from the log (D) Vs. 1000/T charts.