A CONTRIBUTION TO THE INVESTIGATION OF THE PROPERTIES OF THE Au—Fe SYSTEM

MARIÁN VAŇO,* JOZEF SITEK,** JÚLIUS CIRÁK,** Bratislava

The Mössbauer spectroscopy, an electronic microanalyzer and X-ray diffractometry were used to study the properties of an Au—Fe solid solution during its preparation via installing Fe atoms into the Au matrix by diffusion heating at a temperature from 550 °C to 850 °C. On the basis of such measurements, the convenient heating temperature was determined to be 850 °C as well as the Debye-Waller factor for Au—Fe $f = 0.604 \pm 0.040$ and the existence of two vicinities of Fe atoms in the Au crystal lattice were described.

I. INTRODUCTION

The properties of an Au—Fe solid solution with ^{57}Fe impurity atoms were studied by means of the Mössbauer spectroscopy and other methods in several works [1—6]. These studies were mostly oriented to investigate the dependences of parameters of the Mössbauer spectra on the ^{57}Fe concentration and the influence of temperature on the magnitude of the Debye-Waller factor. Further, a way in which ^{57}Fe is installed into the Au matrix and the magnetic properties of an Au—Fe solid solution in the low temperature region were studied.

The present work is an attempt to determine the diffusion coefficients and to find their relation to the parameters of the Mössbauer spectra. In order to determine the concentration of ^{57}Fe in Au and in order to find the influence of the ^{57}Fe atoms on the Au matrix further supplementary measurements were performed on the electron microanalyzer and X-ray diffractometer.

II. METHODS OF MEASUREMENTS AND RESULTS

II. 1. Sample preparation

Iron powder enriched by ^{57}Fe up to 80 % and gold foils with the thickness of 9×10^{-6} m were used for the preparation of Au—Fe absorbers. The sample

* Fyzikálny ústav SAV, Dúbravská cesta, 899 30 BRATISLAVA, Czechoslovakia
** Katedra jadrovej fyziky a techniky EF SVŠT, Vazovova 5, 880 19 BRATISLAVA, Czecho-slovakia

preparation technology consists of the electrolytical deposition of Fe on the gold foil and the installation of Fe atoms into the Au matrix by means of diffusion heating [7]. Calculations of the diffusion heating time were based on the works [8, 9]. Diffusion annealing was carried out for temperatures of $T_n = 550, 650, 750$ and 850 °C during one hour.

II. 2. Measurements on the electronic microanalyzer JXA-5A

For the calculation of the Debye–Waller factor and the determination of the diffusion coefficients it is necessary to determine the Fe concentration and, eventually, to find the diffusion profiles. This was made on the microanalyzer JXA-5A [10]. The method of the characteristic X-ray radiation was used for the measurements. The linear qualitative analysis performed on the microanalyzer makes it possible to obtain data concerning the relative Au-Fe concentration by elaborating signals from two independent X-ray spectrometers. For the Fe measurements were performed in the central part of the section plane. The beam of electrons was incident perpendicularly to the plane of the cut section. The sample was placed into a vacuum tube of the microanalyzer in such a position that the homogeneous displacement of Fe was expected. The sample prepared in this way sample was prepared for the measurement by cutting it in that part where the the resolution of Au we used the LiF crystal and the L_α line was recorded. Each resolution the analysing SiO_2 crystal was used and the K_α line was recorded. For elaborating signals from two independent X-ray spectrometers. For the Fe measurements were performed in the central part of the section plane. The get the percentage of the concentration c adjusting by standards was done. The measurements were performed in the central part of the section plane. In order to

Fig. 1. The dependence of concentration distribution Fe atoms $c = f(x)$ for different temperature of diffusion, where c_n and c are boundary concentrations.

dependence $c = f(x)$ is shown in Fig. 1, where x is the distance from the sample surface. Displayed dependences $c = f(x)$ show that the Fe atoms in the Au matrix are quite homogenously diffused at $T_n = 850$ °C. The concentration of Fe determined from $c = f(x)$ for this sample is $c_{Fe} = 11.0 \% \pm 0.5 \%$. In order to determine the diffusion coefficients (Table 1), Göhler's nomogram [11] was used. No correction was considered for so called diffusion reflections in final thickness of sample.

II. 3. Measurements on a Philips X-ray diffractometer

Measurements on the X-ray diffractometer were carried out in order to test the concentration of the Fe atoms in Au and to find the effect of all the diffused Fe atoms into the Au matrix. First, diffractograms were measured for the Au foil and then for Au—Fe made at the temperature $T_n = 850$ °C with relatively homogeneously diffused Fe atoms. In the measurements the method of monochromatic X-ray radiation was used. Lines from $Cu_{K\alpha}$, having the wave length $\lambda = 1.54051 \times 10^{-10}$ m were recorded. From the analysis of the diffractograms and from the X-ray wave length the interatomic distance $a = 4.047 \times 10^{-10}$ m was determined by means of the least square method. For this value according to [12] the concentration of Fe atoms is $c = 11.4 \%$. When comparing the diffractograms for the Au and for the Au—Fe system, no characteristic reflections corresponding to any known crystalline phases of iron were found. Thus iron forms no separate structure in the solid solution of Au—Fe prepared for the purposes of this work. Only a change of the interatomic distance occurs. Thus iron either substitutes Au atoms in a crystalline lattice or occupies vacancies.

II. 4. Measurements of the Mössbauer spectra

The spectra were measured on the KFKI Mössbauer spectrometer NP — 255. The spectrometer has a driving unit with a constant acceleration to move the source. The source of the gamma rays with the energy of 14.4 keV was a ^{57}Fe isotope, a product of decay of ^{57}Co, which was installed in the matrix Pd with the activity of 50 mCi. A scintillation detector with the crystal NaI (Tl) of the thickness of 1 mm was used. The spectra were measured into 256 channels at the velocity of $v_{max} = 3.41251$ mm s^{-1}. The measurements were performed at room temperature. The measured spectra (Fig. 2) were evaluated by means of the program [13] by the Minsk 22 computer. Spectra drawings and calculations of areas by the integration method were carried out by the Hewlet-Packard calculator. The spectra were interpreted to be a doublet superimposed on a single line. This indicates that the Fe ions, despite their random distribution in these alloys, have only two kinds of electronic configurations. The doublet is associated with the Fe ions by one or more

of the nearest neighbours of Fe, while the single line is associated with the Fe ions by no nearest neighbours of Fe. The doublet is created by quadrupole splitting of the line, which is due to an electric field gradient in a Fe atom surroundings and its non-zero electric quadrupole moment. Non-homogeneity of the internal electric field is caused by an asymmetric arrangement and a non-homogeneous diffusion of Fe atoms in the Au crystalline lattice.
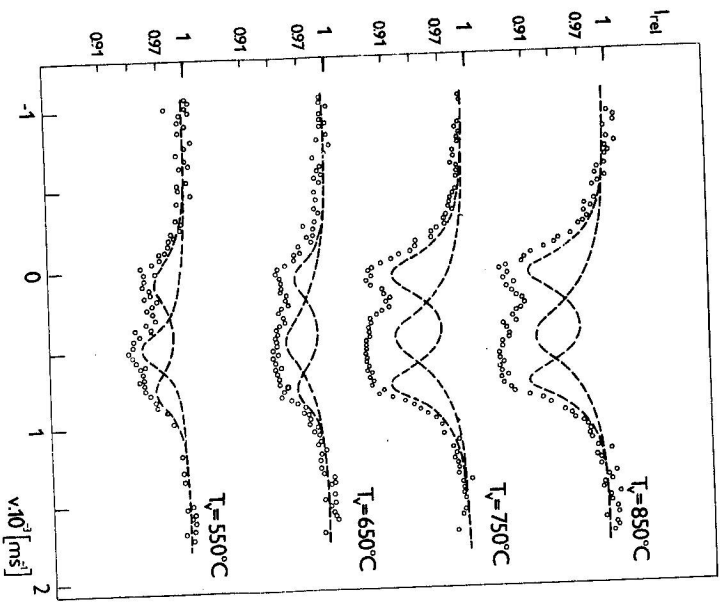

Fig. 2. The Mössbauer spectra of solid solution Au–Fe, made at different temperature of diffusion.

The observed line width Γ_a of a doublet as well as Γ_b for a single line are equal within experimental errors (Table 1). The line width of a doublet is smaller than the width of a single line for each sample. That would confirm the assumption of [5] that a single line can be also an unresolved quadrupole doublet.

The isomeric shift of the doublet δ_a and of the single line δ_b are changed only within the experimental errors for different components of the spectra (Table 1) and are independent of the concentration of Fe atoms, which is in agreement with the experimental results given in Ref. [4]. It was found that in the case where the nearest neighbours of Fe are only Au atoms, the isomeric shift is higher for each sample than the isomeric shift in the case where the nearest neighbours of Fe are

one or more Fe atoms. Thus a conclusion can be drawn that the density of the s-electrons in a nucleus environment is smaller in the former case than in the latter.

The quadrupole splitting ΔE shows a slightly decreasing tendency with increasing temperature T_t (Table 1). As this decrease is within the range of experimental errors, such phenomenon cannot be unambiguously attributed to the fact that with an increasing temperature T_t there is a decrease of the nonhomogeneity of internal electric field resulting from a more regular arrangement of the Fe atoms in the Au matrix.

Table 1

The values of the heating temperature, the diffusion coefficients and the parameters of the Mössbauer spectra. The isomer shifts are given relative to sodium nitroprusside.

T_t °C	Γ_a [mms⁻¹]	Γ_b [mms⁻¹]	D [cm²s⁻¹]	δ_a [mms⁻¹]	δ_b [mms⁻¹]	ΔE [mms⁻¹]	A_a	A_b [mms⁻¹]	A
550	0.319±0.010	0.430±0.011	1.1×10⁻¹⁰	0.841±0.012	0.871±0.010	0.360±0.010	0.032	0.030	0.062
650	0.332±0.010	0.510±0.015	3.7×10⁻¹⁰	0.811±0.010	0.883±0.011	0.350±0.010	0.043	0.041	0.083
750	0.341±0.015	0.490±0.012	5.7×10⁻⁹	0.843±0.011	0.883±0.011	0.340±0.012	0.081	0.059	0.139
850	0.333±0.012	0.530±0.015	2.7×10⁻⁸	0.831±0.010	0.887±0.013	0.330±0.015	0.083	0.064	0.146

The effect magnitude, the total area A under the spectrum as well as the areas A_a and A_b, under the individual components of the spectrum grow with the temperature T_t. The area of the doublet increases faster than the area corresponding to a single line. The sample produced at $T_t = 850$ °C has quite homogeneously diffused Fe atoms in the Au matrix. For this sample there was determined the Debye-Waller factor $f = 0.604 \pm 0.040$ using the area method [14]. This value is in good agreement with values given by other authors [2, 3, 6].

III. CONCLUSION

Measurements made on the X-ray diffractometer and the Mössbauer spectrometer confirmed that the Au–Fe system forms a substitute solid solution whereby Fe

atoms substitute Au atoms or occupy vacancies. The existence of the doublet and a single line indicates that the Fe atoms in our Au—Fe system have only two kinds of configurations in the Au matrix. At the heating temperature $T_z = 850\ °C$, only slight changes in the area of the spectrum and in the distribution of the relative Fe concentration were observed. Thus it can be said that the convenient temperature of diffusion heating is about 850 °C. In this region no marked changes occur in the parameters of the Mössbauer spectra and in the distribution of the concentration of the Fe atoms.

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