Albedo Numbers of $Ag_{72}Cu_{28}$ Alloy Etched by Hydrofluoric Acid

Sedanur Kalecik, Abdul Fatah Pathman, Demet Yılmaz, Yakup Kurucu

Abstract— In this work we studied the albedo numbers change of $Ag_{72}Cu_{28}$ alloy after etching in hydrofluoric acid (HF). As samples four groups of $Ag_{72}Cu_{28}$ alloy were prepared the first group is control group, second group was immersed at 25ºC in 10% HF for 1, 2, 3, 6 and 14 h, third was immersed at 25ºC in 40% HF for 1, 2, 3, 6 and 14 h and the fourth group was immersed at 80ºC in 40% HF for 15, 30, 45 and 60 min. All the HF-etched $Ag_{72}Cu_{28}$ alloy samples were evaluated under EDXRF system with HPGe detector. The albedo numbers (A_N) are determined using 59.54 keV energy emitted from ^{241}Am radioactive source. It was observed that the surface scattering and albedo numbers change with increasing the time of immersion and with high temperature of etching solution.

Index Terms— $Ag_{72}Cu_{28}$ alloy, Albedo number, HF etching, Surface scattering.

1 Introduction

Bimetallic alloys such as Ag-Cu, Cu-Zn and Ag-Au attracts a growing interest in scientific studies. Bimetallic alloys have different physical, optical, magnetic and chemical properties and interesting scientific results can be obtained in materials containing two types of atoms. Zinc, silver and copper are the most popular member elements of the bimetallic alloy studies [1].

Gamma radiations are known as an uncharged flows of photons. The photons would be absorbed or scattered during the interaction of gamma radiation with material [2]. Scattering is one of the phenomena of interaction of electromagnetic radiation with matter. According to the energy of scattered photons there are two groups of scattering they are elastic and inelastic scattering. These scattering actions are also known as coherent and incoherent scattering. Coherent scattering is typically utilized in the equivalent sense of elastic or Rayleigh scattering. It is more observable in low radiation energies and elements which have high atomic number. If there is a difference between the incident and scattered photons that come from the scattering, this kind of scattering is called incoherent scattering [3].

The backward scattering of gamma radiation from the surface of material is called backscattering (or reflection) of gamma radiation. Understanding the physical process of gamma ray transmission and reflection in material is of fundamental importance in calculation of the dose of gamma radiation, shielding of gamma radiation, designation of gamma ray detector and the nondestructive analysis of materials with gamma radiation [4]. To investigate the reflection at the interfaces one of the useful methods is the determination of the albedo factors. Reflectivity or reflecting power of a surface is called albedo. Albedo depends on the structure of a surface (roughness, flatness, etc.) color, area and thickness of material the spectral distribution ofincident radiation (intensity, energy) and atomic properties.

The materials which reflect more electromagnetic radiation in various part of electromagnetic spectrum have a high albedo. Some materials reflect a very small part of electromagnetic radiation falling on it, but absorb more radiation, the albedo of such materials are low. Albedo has no specific unit, but we can define it in two ways. First way to express the value of albedo is percentage, second way, the range of albedo value is from 0 to 1. With respect to the first definition, the albedo of the materials which reflect all light falling on it is defined as 100% the albedo of the material that does not reflects is 0% and the albedo of material that reflects half of light is 50%. According to the second definition 0, 50 and 100 numbers can be replaced by 0, 0.5 and 1 respectively. Albedo factors are described as number albedo, dose albedo and energy albedo [5]. The ratio of the total number of backscattered photons to the total number of photons falling on the material is number albedo. Energy albedo is defined as the fraction of incident energy that escapes the target. Also, energy and albedo number can be used for calculating the dose albedo [6]. As far as the importance of albedo factors is concerned, it can be widely used in different studies, for instance, albedo factors can be used for environmental research [7], nuclear reactor [8], astronomy [9] and radiation protection dosimetry [10].

A lot of studies have been done about reflection of photons and albedo factors. Dependence of albedo factors on mean atomic number was studied by T. Akkuş and D. Yılmaz [6], in their study, dependence of albedo factors on mean atomic number determined by using 662 keV gamma rays emitted from ^{137}Cs radioactive source for 180° scattering angle. Albedo factors of 279, 320, 511 and 662 keV backscattered gamma photons was studied by A. D. Sabharwal et al. [4], they obtained that the number and energy albedos increase with an increase in the target thickness and saturate at the saturation thickness of multiply-backscattered photons. They also obtained that the energy albedos are decrease with the increase in the incident gamma-ray energy. Albedo factors of rare-earth oxides were studied by T. Ahmet [3], in this study 59.54 keV energy was used in 160° scattering angle. This work shows that the albedo factors change with the increasing atomic

- *Sedanur Kalecik is currently pursuing doctorate degree program in physics department in Atatürk University, Turkey. E-mail: sedanurkalecik@atauni.edu.tr*

number of target. With same incoming radiation energy and scattering angle, the reverse Compton scattering effect and changing of scattering centers cause the decrease in albedo factors. The effect of sample thickness on albedo factors were studied by D. Yılmaz et al. [11], the investigation of albedo factor was for 59.54 keV and 662 keV energy. Albedo factors measurement was done by using Germanium (HPGe) detector which operated at a 180° scattering angle.

Intermetallic compounds have complex and rigid structures, they can be used for the improvement of new substance systems. Bimetallic alloys of Ag and Cu are of extreme technological significance [12]. They can be used for different purposes. Bimetallic alloys have dissimilar catalytic, optical, surface, electricand magnetic properties [13].

In this study were determined the roughness created by hydrofluoric acid on the alloy surface by photon scattering. Albedo numbers change of $Ag_{72}Cu_{28}$ alloy were studied depend on immersion times and etching solution temperatures.

2 APPROACHES FOR CALCULATING THE ALBEDO FACTORS

2.1 Theoretical approach

In experiments the albedo is often described with a thin beam of gamma radiation, without considering build-up factors as they are insignificant in a narrow beam geometry. The albedo number is given as follow [4].

$$A_N = 2\pi \int_0^{\pi/2} \int_0^E N(\theta, E') sin\theta \, d\theta dE' \quad (1)$$

In above equation $N(\theta, E')$ being the number of scattered photons at an angle θ relative to the incident beam direction. Albedo energy can be calculated by the following equation.

$$A_E = \frac{2\pi}{E} \int_0^{\pi/2} \int_0^E N(\theta, E') E' \, sin\theta \, d\theta dE' \quad (2)$$

The numbers of reflected photons are always smaller than the number of incoming photons at a specific reflected angle due to the absorption of gamma radiation; therefore, the values of albedo number and energy albedo are always smaller than unity [4].

2.2 Experimental approach

A precise measurement of albedo can be determined by using a well-designed geometry. For a scattering medium where gamma photons are not absorbed, the sum of number and energy albedos will be unity. The source activity will provide the amount of radiation released by the source in unit time. The number albedo (A_N) is the simplest of these albedos which is the ratio of the total number of backscattered photons to the total number of photons falling on the target [4]. Number albedo is given by the following equation [14].

$$A_N = \left[\frac{N_{Comp}/N_{\varepsilon(E_{Comp})}}{N_{Coh}/N_{\varepsilon(E_{Coh})}(1/d\Omega)(1/2)} \right] \quad (3)$$

In this equation N_{Comp} and N_{Coh} show the number of events recorded under the Compton and Coherent peaks, respectively. $\varepsilon(E_{Comp})$ and $\varepsilon(E_{Coh})$ factors are photo peak efficiencies of HPGe detector for Compton and coherent peaks, respectively. HPGe photo peak efficiency was described by determining the K X-ray yields from spectroscopically some pure targets. $d\Omega$ in above equation is the solid angle. $1/2$ in the above equation indicates that half of the gamma radiation emitted by the source are incident on the target [6].

3 EXPERIMENTAL SETUP AND MEASUREMENT

3.1 Acquisition system

This study was done in Prof. Dr. Wolf Weyrich High Energy Spectroscopy laboratory at Atatürk University, Erzurum, Turkey. The experimental setup of this study is shown in Figure 1.

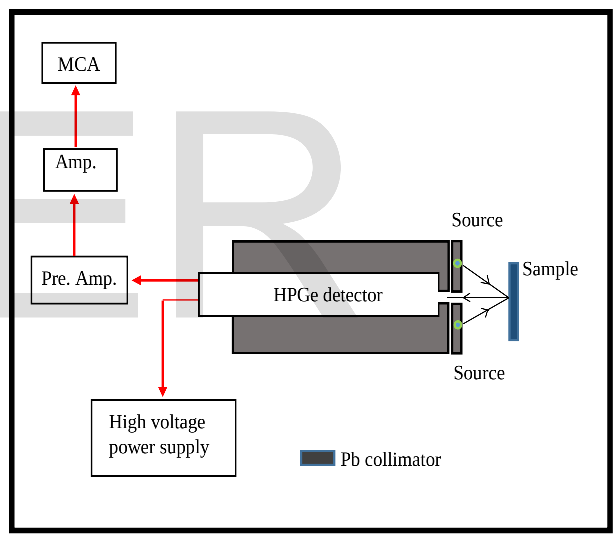

Fig. 1. Experimental geometry.

A lead collimator with circular aperture having a diameter of 0.5 cm, a length of 6.6 cm and a wall thickness of 1.8 cm was used for protecting the detector from being directly exposed to radiation from the radioactive source and environment. Samples were excited by 59.54 keV gamma radiation emitted from ^{241}Am (intensity of 5 Ci) radioactive source. HPGe detector with 182 eV at 5.9 keV resolution was used to detect the scattered gamma radiation from all the samples. The radiations were scattered under 168° angle. The XRF spectra of the alloy samples were recorded for 7200 s. Also, background spectra for the same period of time were subtracted from each measurement. MAESTRO program was used for data analyze.

The thickness of $Ag_{72}Cu_{28}$ foil alloy (Sigma Aldrich) was 0.25 mm. The sample with radius of 0.65 cm were cut from the foil alloy. Four groups of $Ag_{72}Cu_{28}$ alloy were prepared the first group is control group, second group was immersed at 25°C in

10% HF for 1, 2, 3, 6 and 14 h third was immersed at 25^{o}C in 40% HF for 1, 2, 3, 6 and 14 h and the fourth group was immersed at 80^{o}C in 40% HF for 15, 30, 45 and 60 min. The experimental obtained XRF spectra of $Ag_{72}Cu_{28}$ are shown in Figure 2.

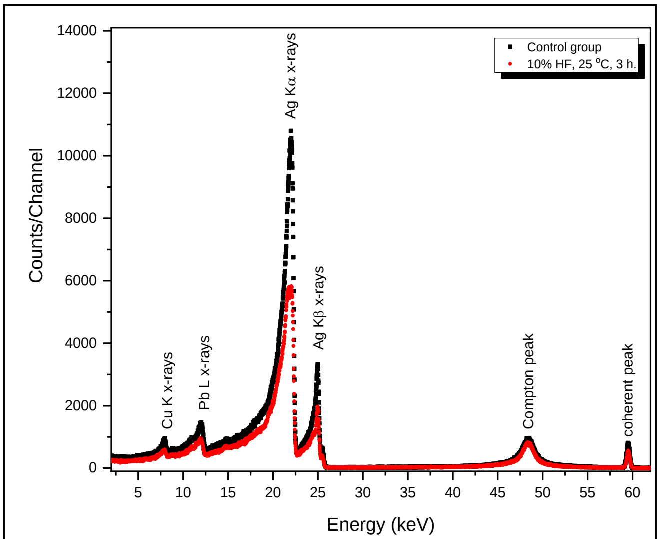

Fig. 2. EDXRF spectrum of $Ag_{72}Cu_{28}$.

4 RESULT AND DISCUSSIONS

In this study, the albedo number of the unetched $Ag_{72}Cu_{28}$ alloy surface was found to be 0.1524. The mass attenuation coefficient $(\mu/\rho_{Theo.})$ and effective atomic number (Z_{eff}) of $Ag_{72}Cu_{28}$ alloy are 5.093 cm^2/g and 45.33, respectively. Albedo numbers were given in Table 1 and Table 2, respectively, for each immersion times in 10% HF at 25^{o}C and 40% HF at 25^{o}C.

TABLE 1
ALBEDO NUMBERS OF $Ag_{72}Cu_{28}$ ALLOY FOR DIFFERENT IMMERSION TIMES IN 10% HF AT 25^{O}C AND 40% HF AT 25^{O}C

	Albedo numbers	
Time (h)	10% HF at 25^{o}C	40% HF at 25^{o}C
1	0.1485	0.1362
2	0.1412	0.1322
3	0.1386	0.1274
6	0.1354	0.1225
14	0.1218	0.1179

TABLE 2
ALBEDO NUMBERS OF $Ag_{72}Cu_{28}$ ALLOY FOR DIFFERENT IMMERSION TIMES IN 40% HF AT 80^{O}C

	Albedo numbers
Time (min)	40% HF at 80^{o}C
15	0.1278
30	0.1166
45	0.1114
60	0.1084

After times of treatment, surface porosity (roughness) increase compared with the control group. In addition, with longer treatment times, the $Ag_{72}Cu_{28}$ alloy HF-treated reveal a further increase in the development of large holes on the alloy surfaces. The albedo number value varies inversely with the surface porosity of the alloy. Albedo numbers decrease with increasing immersion time and higher concentration of the etching solution. This is due to the surface irregularities observed on the alloy sample surfaces. It is found that albedo numbers decreased at higher etching solution temperatures. In this study, it was also concluded that levels of concentration, immersion times and temperature of the acid solution affected the rate of reaction leading to micro-morphological changes.

5 CONCLUSION

Albedo is used to describe the reflective capability of electromagnetic radiation from the surface of materials. Albedo factors plays an essential role in different parts of science and research, for example, astrophysics, radiation protection and dosimetry, environmental science, etc. In this study the purpose was to determine the roughness created by hydrofluoric acid on the alloy surface by photon scattering. Albedo numbers change of $Ag_{72}Cu_{28}$ alloy was studied depend on immersion times and etching solution temperatures. It was found that the albedo number changes with the increasing of the etching time, temperature as well as it changes with high percentage of hydrofluoric acid. It can be concluded that albedo numbers decreased at higher etching solution temperatures with extension of involving time and greater concentration of the etching solution.

REFERENCES

[1] O.M. Ozkendir, E. Cengiz, E. Yalaz, Ö. Söğüt, D.H. Ayas, and B.N. Thammajak, "Crystal and electronic structure study of AgAu and AgCu bimetallic alloy thin films by X-ray techniques," *J. Electron Spectros. Relat. Phenomena*, vol. 209, pp. 53–61, 2016, doi: 10.1016/j.elspec.2016.04.002.

[2] Y.H. Zuo, J.H. Zhu, and P. Shang, "Monte Carlo simulation of reflection effects of multi-element materials on gamma rays," *Nucl. Sci. Tech.*, vol. 32, no. 1, pp. 1–10, 2021, doi: 10.1007/s41365-020-00837-z.

[3] T. Ahmet, "Albedo factor determination of rare-earth oxides," *Radiat. Eff. Defects Solids*, vol. 173, no. 11–12, pp. 1037–1044, 2018, doi: 10.1080/10420150.2018.1531412.

[4] A.D. Sabharwal, S. Singh, B. Singh, and B.S. Sandhu, "Albedo factors of 279, 320, 511 and 662keV backscattered gamma photons," *Radiat. Eff. Defects Solids*, vol. 166, no. 6, pp. 451–458, 2011, doi: 10.1080/10420150.2010.544039.

[5] T. Akkuş, "Determination of number, energy and dose albedos of samples with various mean atomic number for 59.54 keV gamma-rays," *Radiat. Phys. Chem.*, vol. 170, no. April 2019, 2020, doi: 10.1016/j.radphyschem.2019.108579.

[6] T. Akkuş and D. Yılmaz, "Dependence of albedo factors on mean atomic number for 662 keV gamma photons," *Appl. Radiat. Isot.*, vol. 154, no. July, 2019, doi: 10.1016/j.apradiso.2019.108870.

[7] F. Cappucci and N. Gobron, "Benchmarking of essential climate variables: Gamma index theory and results for surface albedo and aerosol optical depth," *Remote Sens. Environ.*, vol. 203, pp. 90–100, 2017, doi: 10.1016/j.rse.2017.06.004.

[8] C. Papastefanou, "Measurement of neutron flux and albedo of water for thermal neutrons with foils of indium in a subcritical nuclear reactor," *J. Radioanal. Nucl. Chem.*, vol. 261, no. 3, pp. 671–678, 2004, doi: 10.1023/B:JRNC.0000037112.08894.21.

[9] S.S. Sheppard, Y.R. Fernandez, and A. Moullet, "The Albedos, Sizes, Colors, and Satellites of Dwarf Planets Compared with Newly Measured Dwarf Planet 2013 FY27," *Astron. J.*, vol. 156, no. 6, p. 270, 2018, doi: 10.3847/1538-3881/aae92a.

[10] F. Fernández, M. Bakali, K. Amgarou, A. Nourreddine, and D. Mouhssine, "Personal neutron dosimetry in nuclear power plants using etched track and albedo thermoluminescence dosemeters," *Radiat. Prot. Dosimetry*, vol. 110, no. 1–4, pp. 701–704, 2004, doi: 10.1093/rpd/nch231.

[11] D. Yılmaz, T. Akkuş, and S. Kalecik, "Influence of the sample thickness upon the albedo factors using 59.54 and 662 keV photon energies," *Instrum. Sci. Technol.*, vol. 50, no. 4, pp. 447–455, 2022, doi: 10.1080/10739149.2021.2023175.

[12] L.U. Rahman *et al.*, "Monitoring of 2-butanone using a Ag-Cu bimetallic alloy nanoscale electrochemical sensor," *RSC Adv.*, vol. 5, no. 55, pp. 44427–44434, 2015, doi: 10.1039/c5ra03633j.

[13] M. Valodkar, S. Modi, A. Pal, and S. Thakore, "Synthesis and anti-bacterial activity of Cu, Ag and Cu-Ag alloy nanoparticles: A green approach," *Mater. Res. Bull.*, vol. 46, no. 3, pp. 384–389, 2011, doi: 10.1016/j.materresbull.2010.12.001.

[14] D. Yılmaz, A.B. Yurtcan, T.Ö. Özer, and F. Memioğlu, "Albedo parameters and effective atomic numbers of PEDOT/Carbon black composites," *Radiat. Phys. Chem.*, vol. 182, no. January, 2021, doi: 10.1016/j.radphyschem.2021.109378.