Optical properties of Al-8 at.% Ce alloy in liquid, amorphous and crystal states

L A Akashev¹, V I Kononenko¹, V E Sidorov¹, P Svec², D Janickovic²

¹Institute of Solid State Chemistry UB RAS, 91 Pervomayskay Str., 620219 Ekaterinburg, Russia
²Insitute of Physics SAV, Bratislava, Slovakia

E-mail: kononenko@ihim.uran.ru

Abstract. The optical constants of liquid, amorphous and polycrystalline Al-8 at.% Ce alloy were measured by spectroscopic ellipsometry method in the 0.52-2.7 eV spectral range. For that purpose the special installation was created. It allows one to carry out experiments up to 1600 K in vacuum 10⁻⁵ Pa or in the controllable atmosphere. Using the results obtained, disperse dependences of optical conductivity, reflective ability and functions of characteristic losses of electrons energy in this alloy were calculated. It was found, that optical properties in amorphous and polycrystalline states are determined by interband transitions. On the other hand, the essential differences in properties caused by the difference in the structure of the alloys were fixed. Two peaks of absorption in the spectra of optical conductivity of these alloys are observed. For the amorphous alloy these peaks have maxima at 1.72 eV and 0.69 eV. As for polycrystalline state, the optical conductivity curve lies higher in near IR-spectral range than for amorphous one, and the peaks of absorption are located at 1.55 eV and 1.03 eV. It is necessary to note, that for pure polycrystalline aluminum the maximum on the spectrum is at 1.5 eV. Reflective ability for liquid and amorphous states is higher, than for polycrystalline.

1. Introduction

Amorphous aluminum-rare-earth (Al-REM) alloys are widely used nowadays in different fields of technique [1,2], however their optical properties are practically unknown. It is rather interesting to compare the results for amorphous samples with liquid and crystalline ones, because their difference in atomic and electronic structures can provide different optical properties.

According to Inoe [3], amorphous samples in Al-REM systems can be obtained in limited concentration ranges. For Al-Ce alloys, the cerium content should be in the interval 7-11 at. % only. That is why in this work we investigated optical properties of Al-8 at.% Ce alloy in crystal, liquid and amorphous states.

2. Experimental

Amorphous ribbons (width - 4 mm, thickness – 30-35 μm) of Al-8at.%Ce composition were produced by standard planar flow method in the controlled atmosphere of inert gas (the chamber was preliminary de-gazed). These ribbons were produced in the Institute of Physics, Slovak Academy of Sciences (Bratislava).

Optical constants of the alloys and the oxide films, and the thickness of these films on the surface of polycrystalline and amorphous samples also, have been determined using the immersion ellipsometric method [4]. The thickness of the oxide film of the surface of amorphous alloy was found to be equal 5.5
nm, and on the surface of polycrystalline - 4 nm. The distilled water (refractive index \(n=1.33\)), benzene (\(n=1.50\)) and the liquid with the high refractive index - monobromnaftalin (\(n=1.66\)) at \(\lambda=0.6328\) microns have been used as immersion liquids. For determination of optical constants of the alloys and the oxide films, the immersion method of Lukes F., Knausenberger W.H. and Vedam K. was modified with application to metals and alloys [5]. The essential fact of modification was as follows: at the incidence angle of \(\varphi=50^\circ\), the ellipsometric parameter \(\psi\) remains practically the constants at reflection from the surface, covered with the thin film, and from the clean surface, within the thickness of film up to 20-30 nm.

The optical constants for the oxidized surfaces in amorphous and polycrystalline alloys have been determined by Beatty's method in the spectral range 0.46-2.5 mcm, with the step of 0.02 mcm. The optical constants for the pure (non-oxidized) surfaces in amorphous and polycrystalline Al-8 at. % Ce alloys were determined using Drude P.-Archer R.J. approximation in the same range of a spectrum [6].

3. Results and discussion
The optical constants (refraction index \(n\) and absorption coefficient \(k\)) for Al-8 at. % Ce alloy in amorphous, polycrystalline (oxidized and non-oxidized) and liquid states are obtained. It was found that in amorphous state \(n\) and \(k\) increase from 0.36 to 3.15 and 4.45 to 7.22 respectively for oxidized sample with the increase of wavelength from 0.46 to 2.5 mcm. For non-oxidized amorphous sample \(n\) and \(k\) increase from 0.59 to 3.62 and 5.85 to 7.66. For polycrystalline sample \(n\) and \(k\) change from 1.02 to 5.96 and from 3.35 to 8.01 (oxidized) and from 1.29 to 6.67 and from 3.82 to 8.21 (non-oxidized), whereas for liquid state \(n\) and \(k\) change from 0.21 to 7.98 and from 5.12 to 10.88 respectively (the oxide film disappeared with overheating for 50-70 K above melting point).

From the measured values of \(n\) and \(k\), the dispersion dependences of optical conductivity \(\sigma\), reflectivity \(R\), absorption \(A\) and the function of characteristic energy losses of electrons \(\text{Im}(\varepsilon)^{-1}\) were calculated (figures 1-4).

![Figure 1. Optical conductivity \(\sigma\) vs the energy of photons \(E\) for Al-8 at.% Ce alloy (1-amorphous, 2-crystal, 3-liquid states).](image1)

![Figure 2. The dispersion dependence of reflectivity for Al-8 at.% Ce alloy (1-amorphous, 2-crystal, 3-liquid states).](image2)

It was found that optical conductivity of amorphous and polycrystalline alloys has two peaks of absorption (see figures 1, curves 1 and 2). For non-oxidized amorphous alloy these peaks of absorption are located at 1.72 eV and 0.69 eV. The presence of oxide film on the surface of the alloy results in decreasing of optical conductivity, especially in the field of high energies of photons, and to insignificant displacement of absorption peaks to the smaller energies. For polycrystalline alloy the influence of oxide film is similar, but peaks of absorption are shifted to 1.55 eV and 1.03 eV. Let us
mention, that the spectrum of optical conductivity for polycrystalline aluminum has a maximum at 1.5 eV. From figure 1 it comes that optical conductivity for polycrystalline alloy (2) in near IR region lays much above, than for amorphous (1), but the spectrum for liquid alloy (3) is the highest one in this IR region. However, in the visual region of the spectrum, curves (1) and (2) are located close enough and curve 3 is essentially low. Besides on the spectrum of optical conductivity for liquid alloy (3) insignificant peaks of absorption are observed at 1.24 eV and 0.6 eV.

![Figure 3](image1.png)  ![Figure 4](image2.png)

**Figure 3.** Absorption ability A vs the energy of photons E for Al-8 at.% Ce alloy (1- amorphous, 2-crystal, 3-liquid states).

**Figure 4.** The functions of characteristic losses in electrons energy (1-amorphous, 2-crystal, 3-liquid states).

It is known, that character of spectrum of optical conductivity for metals and alloys is determined by their electrons energy spectrum, hence from figure 1 it follows, that the electronic structures of amorphous, polycrystalline and liquid alloys are essentially different. Figure 2 gives the dependences of reflective ability for amorphous (1), polycrystalline (2) and liquid (3) states of Al-8 at.% Ce alloy. The spectrums of reflection coincide for amorphous (1) and liquid (3) states, whereas for polycrystalline alloy (2) it lies much below (figure 2). The reflective ability for amorphous (1) and the liquid (3) alloys changes in the specified range of spectrum from 78 % up to 94 %, and from 71 % up to 80 % for polycrystalline (2) one. At the same time the influences of oxide film on a spectrum of reflection for amorphous and polycrystalline alloys was found to be rather small. Thus, the reflective ability is a structure - sensitive property, one can say that atomic structures of investigated amorphous and liquid alloys are very similar and differ from polycrystalline structure.

The absorption abilities for amorphous and liquid states are rather close in all investigated range and differ from the curve for polycrystalline sample (figure 3). Functions of the characteristic losses in electrons energy for amorphous (1) and polycrystalline (2) alloys coincide in near IR region of the spectrum (figure 4), and are identical in the whole interval of energies.

The existence of two peaks in optical conductivity spectrum is an evidence of the fact that optical properties of Al-8 at.% Ce are determined by interbands transitions of electrons mainly in the investigated energy range.

4. Conclusions

Optical properties of Al-8 at. % Ce alloy in liquid, amorphous and crystal states are measured. The tables for optical constants (refraction index $n$ and absorption coefficient $k$) are obtained in the interval of wavelengths 0.46 to 2.5 mcm. It is shown, that optical properties of amorphous, polycrystalline and liquid Al-8 at. % Ce alloys are determined by interband transitions in the region of spectrum 0.5-2.8 eV. The spectra of reflection coincide for amorphous and liquid states, whereas for polycrystalline
state it is located much below. Thus, the reflective ability is a structure-sensitive property, one can say that atomic structures of investigated amorphous and liquid alloys are very similar and differ from polycrystalline structure. The absorption abilities for amorphous and liquid states are rather close in all investigated range and differ from the curve for polycrystalline sample. Functions of the characteristic losses in electrons energy for amorphous and polycrystalline alloys coincide in near IR region of the spectrum and are identical in the whole interval of energies.

Thus the character of spectrum of optical conductivity for metals and alloys is determined by their electrons energy spectrum, the electronic structures of amorphous, polycrystalline and liquid alloys are essentially different.

Acknowledgment
This work has been supported by RFBR (project N 07-02-01049).

References

[1] Nemoshkalenko V V, Romanova A V, Iljinsky A G, etc. 1987 Amorphous metal alloys (Kiev: Naukova dumka) 246 p
[2] Guntherodt H J and Beck H 1983 Glassy metals (Moscow: Mir) 376 p
[3] Inoui A 1998 Progress in materials science. 10 365-520
[4] Tjagaj V A, Shirshov J M, Rastrenenko N A 1978 Ukrainian physical magazine 23 1683
[5] Lukes F, Knausenberger W H, Vedam K 1969 Surface science 16 112
[6] Azzam P, Bashara H 1981 Ellipsometry and polarized light (Moscow: Mir) 583 p.