

O.I. Kushnerov¹, V.F. Bashev², S.I. Ryabtsev¹, T.V. Kalinina², P.O. Galagan¹

The Effect of Quenching from the Melt and Vapor States on the Formation of Supersaturated Solid Solutions in Co–Cu Alloys

¹Oles Honchar Dnipro National University, Dnipro, Ukraine, kushnrv@gmail.com;

²Dnipro State Technical University, Dnipropetrovsk Region, Kamianske, Ukraine

Co–Cu alloys were prepared by splat quenching from the melt and modified three-electrode ion-plasma deposition. The X-ray diffraction results were consistent with the predominant formation of metastable supersaturated fcc solid solutions in the investigated samples. The fcc lattice parameter increased continuously with Cu content and showed a slight systematic negative deviation from Vegard's law. Ion-plasma deposition enabled the fcc phase to be retained in films containing 57–70 at.% Cu, thereby extending the metastable solid-solution range compared with splat quenching. No separately resolved diffraction reflections attributable to Co-rich or Cu-rich crystalline phases were detected within the resolution and sensitivity of the employed methods. The extended solid-solution range is attributed primarily to kinetic stabilization resulting from atomic-scale intermixing and suppression of the compositional redistribution required for phase separation. Temperature-dependent sheet-resistance measurements revealed irreversible changes near 430°C and 650–660°C, which were interpreted as reflecting structural relaxation and stepwise decomposition of the supersaturated state. The results demonstrate the effectiveness of ion-plasma deposition for producing metastable Co–Cu solid solutions over an extended composition range.

Keywords: Co–Cu alloys, supersaturated solid solutions, splat quenching, ion-plasma deposition, rapid solidification, phase composition, metastable states.

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Introduction

The formation of solid solutions is commonly accompanied by changes in the mechanical and physical properties of metallic materials, as illustrated by Cu-based alloys such as bronzes and brasses. The factors governing solid-solution formation include the well-known Hume–Rothery criteria [1], particularly crystal-structure compatibility and atomic-size mismatch. According to the atomic-size criterion, extensive substitutional solid solutions are favoured when the difference between the atomic radii of the solvent and solute elements does not exceed approximately 15%. Larger atomic-size differences generally restrict the equilibrium solid-solubility range.

However, the equilibrium criteria do not fully determine phase formation under strongly nonequilibrium conditions. Rapid solidification from the melt can

substantially extend the solid-solubility range because increasing the velocity of the solidification front suppresses compositional partitioning between the solid and liquid phases. Under these conditions, the velocity-dependent partition coefficient approaches unity owing to solute trapping, allowing the composition of the rapidly growing solid to approach that of the parent melt.

Recently, increasing attention has been paid to materials composed of elements exhibiting severely limited mutual solubility under equilibrium conditions [2–4]. Such systems are often characterized by a positive enthalpy of mixing, considerable differences in the physical properties of the components, and a thermodynamic tendency toward phase separation. In some systems, these features may be accompanied by liquid-phase immiscibility over a wide temperature–composition interval. These thermodynamic factors complicate the preparation of chemically homogeneous

alloys by conventional equilibrium processing.

Strongly nonequilibrium preparation methods can kinetically suppress compositional redistribution and phase separation, thereby retaining metastable chemically mixed states in systems with a positive enthalpy of mixing. A variety of single-phase crystalline, nanocrystalline, and amorphous alloys have been produced in nominally immiscible systems using rapid solidification, ion implantation, vapor deposition, and other nonequilibrium methods [2–10].

The equilibrium Co–Cu phase diagram [11–16] is characterized by very limited mutual solid solubility and the presence of a metastable liquid miscibility gap in the undercooled state. The thermodynamic tendency toward separation is associated with the positive enthalpy of mixing and the nearly flat liquidus over a substantial composition interval. On the Co-rich side, the maximum solubility of Cu reaches approximately 12 at.% at 1100°C, whereas on the Cu-rich side, the solubility of Co decreases from approximately 5.5 at.% at 1100°C to 0.1 at.% at 500°C [11–16]. Previous investigations have shown that rapid quenching from the melt can extend the metastable fcc solid-solution range to approximately 25 at.% Cu on the Co-rich side and to approximately 10 at.% Co on the Cu-rich side [17].

Nevertheless, a wide intermediate composition range remains in which predominant single-phase metastable Co–Cu solid solutions have not been reported for alloys produced by conventional melt-quenching techniques. Modified ion-plasma deposition is characterized by short atomic-accommodation and incorporation times, limited diffusion lengths, and rapid local energy relaxation. These conditions may suppress the compositional redistribution required for the formation of separate Co-rich and Cu-rich phases.

The aim of the present work was to compare the formation and thermal stability of highly supersaturated fcc Co–Cu solid solutions produced by two strongly nonequilibrium routes: splat quenching from the melt and quenching during condensation from the vapor state by modified three-electrode ion-plasma deposition. We examined the composition dependence of the fcc lattice parameter, the extension of the metastable solid-solution range, and the irreversible resistance changes during heating.

I. Materials and methods

Two series of Co–Cu alloys containing 12, 24, 57, 61, 70, and 90 at.% Cu were investigated.

The first series of Co–Cu alloys was prepared by the splat-quenching technique [18]. A drop of the molten alloy was propelled by a high-pressure argon jet onto the inner surface of a hollow, highly thermally conductive copper cylinder rotating at approximately 8000 rpm. The resulting splat-quenched samples were approximately 30 μm thick. The estimated cooling rate was at least 10^6 K/s [18].

The second series consisted of Co–Cu films approximately 200 nm thick, prepared by a modified three-electrode ion-plasma sputtering method using an argon ion accelerator [19]. In the following, these samples

are referred to as vapor-deposited films. Before sputtering, the vacuum chamber was evacuated to an initial pressure of approximately 10^{-4} Pa, whereas the working argon pressure during deposition was approximately 10^{-2} Pa. The composite target consisted of 16 independent sputtering sources formed by parallelepipeds ($20 \times 20 \times 5$ mm) of pure Cu and Co, statistically uniformly distributed over the sputtering surface. The walls of the sources acted as electrostatic lenses. Consequently, compared with conventional three-electrode ion-plasma sputtering, the energy of the sputtered species before their interaction with the substrate was increased by a factor of approximately 5–7. Owing to the differences in the velocities and angular distributions of the sputtered Co and Cu species, the atomic fluxes from the individual target elements strongly overlapped during transport toward the substrate, promoting extensive intermixing of the Co and Cu species before deposition. Variation of the relative sputtering areas occupied by Cu and Co made it possible to produce alloy films over a wide composition range.

For vapor and sputter condensation, in [20,21] were reported effective atomic-scale quenching rates of approximately 10^{12} K/s, based on the picosecond-scale thermal accommodation of condensing atoms. In [22] was reported a characteristic quenching rate exceeding 10^{16} K/s for sputter deposition (Table 6.49, p. 494). These literature values are used here as order-of-magnitude characteristics of the local accommodation and energy relaxation of the deposited species rather than as macroscopic cooling rates of the complete films.

The films were deposited on glass-ceramic substrates and freshly cleaved NaCl single crystals. The target geometry, working argon pressure, substrate arrangement, and deposition configuration were kept unchanged for all samples to ensure reproducibility. Films deposited on glass-ceramic substrates were used for electrical measurements. Films deposited on freshly cleaved NaCl single crystals were separated from the substrates by dissolving the NaCl. The resulting free-standing films were subsequently used for X-ray diffraction measurements.

The two sample series were investigated using different X-ray diffraction procedures because of the substantial difference in their thicknesses and diffracting volumes.

The splat-quenched samples were examined using a DRON-2.0 X-ray diffractometer with monochromatized Cu K_α radiation. The phase composition was evaluated using the complete set of recorded diffraction reflections. The fcc lattice parameter was determined from the angular positions of all fcc reflections suitable for quantitative analysis, using the Nelson–Riley extrapolation method. The lattice-parameter values calculated from the individual reflections were extrapolated to $\theta = 90^\circ$ to reduce systematic errors. The diffraction patterns were processed using the QualX2 software for qualitative phase analysis [23].

The vapor-deposited films were approximately 200 nm thick and had a very small diffracting mass. Under the available experimental conditions, their diffraction signal could not be reliably detected using the DRON-2.0 diffractometer, and the contribution from the substrates

complicated conventional diffractometric measurements. Therefore, the free-standing films separated from the NaCl substrates were examined using a URS-2.0 X-ray apparatus equipped with an RKD Debye–Scherrer camera and Cu K_α radiation. The original Debye–Scherrer diffraction photographs were scanned, and the resulting distributions of photographic optical density were converted into densitometric profiles. The phase composition was evaluated using the complete set of observable diffraction reflections. The fcc lattice parameter was determined from the angular positions of all reliably recorded fcc reflections using the Nelson–Riley extrapolation method.

The electrical resistance of the rapidly quenched samples was measured by the four-probe method during continuous heating under vacuum. The temperature dependent resistance measurements were used to characterize irreversible structural changes and the thermal stability of the metastable states formed by quenching from the liquid and vapor phases.

II. Results and discussion

The X-ray diffraction data for the investigated Co–Cu alloys are shown in Fig. 1.

All observed reflections were indexed using a fcc structural model. No additional resolved reflections attributable to separate Co-rich or Cu-rich crystalline phases were detected within the angular resolution and sensitivity of the employed X-ray diffraction methods. However, the absence of additional resolved reflections does not exclude minor secondary phases, strongly overlapping fcc components, or nanoscale compositional heterogeneity below the detection limit. With increasing Cu content, the reflections shift toward smaller 2θ angles, indicating an increase in the lattice parameter a . The experimentally determined lattice parameters are shown as a function of composition in Fig. 2.

The solid line in Fig. 2 represents the dependence predicted by Vegard's law and was calculated using the lattice parameters of the pure fcc Co and Cu reference

samples. The dashed curve is included only to visualize the trend in the experimental data with composition. The experimentally determined lattice parameters vary continuously with composition and follow the general trend predicted by Vegard's law but exhibit a small systematic negative deviation from the ideal linear dependence.

The continuous shift of the diffraction reflections and the corresponding monotonic change in the lattice parameter are consistent with the formation of metastable supersaturated fcc Co–Cu solid solutions. Among the splat-quenched samples, the alloys containing 12 and 24 at.% Cu are located within the previously reported Co-rich range of supersaturated solid solutions [17], whereas the sample containing 90 at.% Cu corresponds to Cu–10 at.% Co and belongs to the Cu-rich range.

The vapor-deposited films containing 57, 61, and 70 at.% Cu lie outside the single-phase ranges previously reported for melt-quenched Co–Cu alloys. Their lattice parameters follow the common trend with composition without a detectable discontinuity. This finding indicates that modified ion-plasma deposition considerably extends the composition range over which a predominant metastable fcc Co–Cu solid solution can be retained.

The absence of discontinuities in the variation of the lattice parameter with composition provides evidence against macroscopic separation into two equilibrium phases with different lattice parameters. However, this continuous variation cannot completely exclude minor secondary phases, coherently related nanoscale regions, or unresolved fluctuations in composition. In this work, the term “single-phase fcc solid solution” refers to an fcc phase for which no separate Co-rich or Cu-rich crystalline components were detected within the angular resolution and sensitivity of the X-ray diffraction measurements.

Previous studies have established the existence of a metastable liquid miscibility gap in undercooled Co–Cu melts [24–27]. Above the binodal temperature, the melt is homogeneous, whereas undercooling below the binodal results in liquid–liquid phase separation into a Co-rich liquid L_1 and a Cu-rich liquid L_2 . The experimentally determined miscibility gap is approximately symmetric

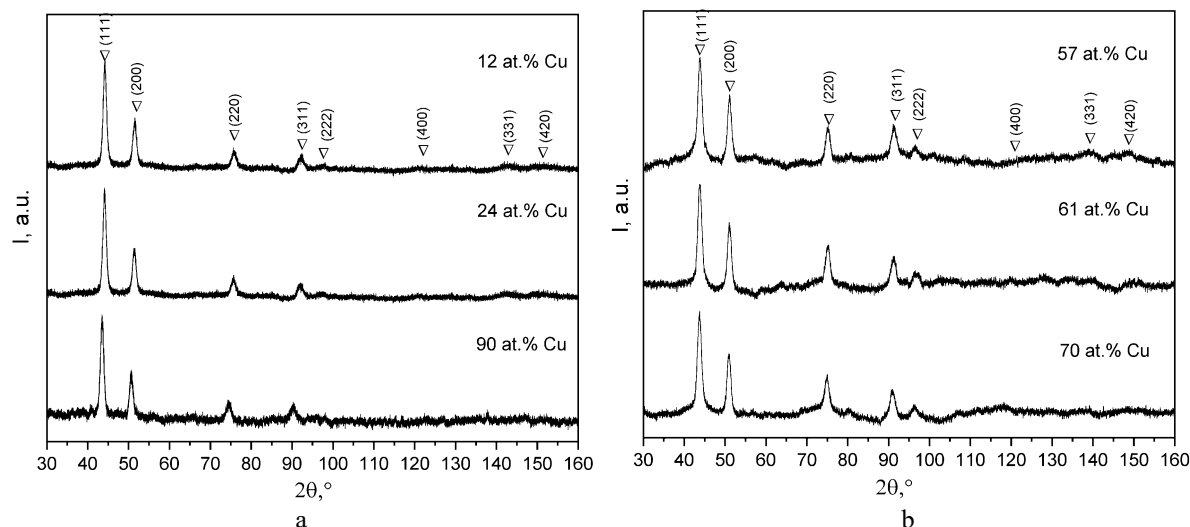


Fig.1. X-ray diffraction data for the investigated Co–Cu alloys: a- splat-quenched samples, b- vapor-deposited films.

about 53 at.% Cu, and its critical temperature is 1547 ± 1.5 K ($\sim 1274^\circ\text{C}$) [26, 27]. The closed binodal defines a single homogeneous liquid phase above this critical temperature.

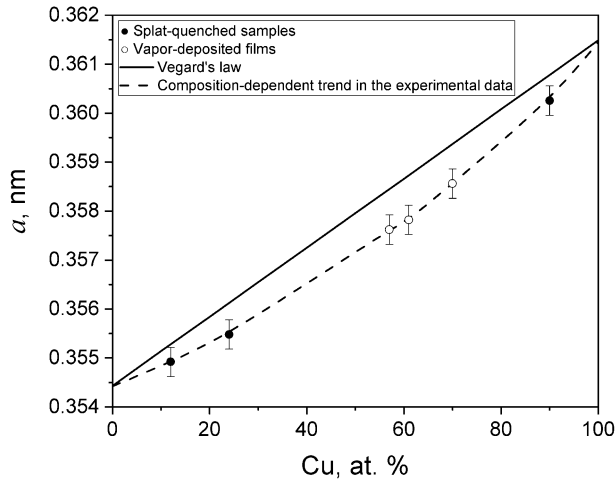


Fig. 2. Composition dependence of the experimentally determined fcc lattice parameter of Co–Cu alloys. Error bars represent the estimated uncertainties in the lattice parameter determination.

For the $\text{Co}_{16}\text{Cu}_{84}$ alloy, the liquidus temperature is 1583 K (1310°C), whereas the binodal temperature is approximately 1467 K (1194°C). At relatively small undercooling, primary α -Co crystallization occurs, resulting in the $L + \alpha$ -Co state. If primary crystallization is kinetically delayed, the initially homogeneous melt can be undercooled below the metastable binodal and undergo the alternative transformation $L \rightarrow L_1 + L_2$. The maximum reported undercooling of 193 K corresponds to approximately 1390 K (1117°C), i.e., approximately 77 K below the binodal, with liquid-phase separation occurring before solidification [24, 25].

Primary α -Co crystallization and liquid–liquid phase separation thus represent competing transformation pathways. The path followed by the alloy depends on whether crystal nucleation or liquid-phase separation develops first during undercooling. The subsequent evolution of the $L_1 + L_2$ state involves nucleation, diffusional growth, collision, and coalescence of the separated liquid regions [24, 25, 28].

At still shorter characteristic times, liquid–liquid phase separation may itself be kinetically suppressed. The system may then pass through the temperature range corresponding to the metastable miscibility gap without developing macroscopically resolved Co-rich and Cu-rich liquid regions. If crystallization occurs sufficiently rapidly, the chemically mixed state can be retained as a metastable supersaturated solid solution.

The formation of substitutional solid solutions in the Co–Cu system is facilitated by the close atomic radii of cobalt and copper, approximately 0.126 and 0.128 nm, respectively. Thus, the system satisfies the atomic size criterion of the Hume–Rothery rules [1]. Nevertheless, Co and Cu exhibit very limited mutual solubility under equilibrium conditions. This demonstrates that similarity in atomic size alone is insufficient to determine the thermodynamic stability of a solid solution. Phase stability

also depends on the enthalpic and entropic contributions to the Gibbs free energy of mixing, electronic and magnetic interactions, crystal structure, and temperature.

The Cu–Ni system, which is similar to Co–Cu in some of its crystallographic parameters and atomic sizes, forms a continuous series of substitutional solid solutions. The different equilibrium behaviour of the Cu–Ni and Co–Cu systems confirms that the atomic size criterion of the Hume–Rothery rules is useful but insufficient for predicting mutual solubility. The thermodynamic driving force for mixing in Cu–Ni differs substantially from that in Co–Cu.

In Co–Cu alloys rapidly solidified from the melt, the formation of highly supersaturated solid solutions can be related to solute trapping at the moving solid–liquid interface. As the interface velocity increases, compositional partitioning between the solid and liquid phases decreases, and the velocity dependent partition coefficient $k(V)$ approaches unity. The composition of the growing solid therefore approaches that of the parent melt, promoting the retention of a supersaturated solid solution. Near-complete solute trapping is attained only within an appropriate range of interface velocities and undercooling conditions [29].

To compare empirically the tendency of related binary systems to form substitutional solid solutions, we consider the ratio of the sums of successive ionization potentials of the alloy components:

$$R_{AB} = \frac{\sum_{i=1}^n V_i^{(A)}}{\sum_{i=1}^n V_i^{(B)}} \approx 1. \quad (1)$$

Here, $V_i^{(A)}$ and $V_i^{(B)}$ are the successive ionization potentials associated with the i -th outer electron of components A and B, respectively, and n is the number of ionization stages included in the comparison. This ratio provides a qualitative comparison of the energy scales associated with the outer electrons of the constituent atoms.

For example, the ratios calculated using the first three successive ionization potentials are approximately 1.05 for Cu–Ni, 1.11 for Co–Cu, and 1.19 for Cu–Fe [30]. The progression of these values correlates qualitatively with the increasing tendency toward limited equilibrium mutual solubility in the considered Cu-based binary systems.

The equilibrium formation and stability of metallic solid solutions are governed by the Gibbs free energy of mixing, $\Delta G_{\text{mix}} = \Delta H_{\text{mix}} - T\Delta S_{\text{mix}}$, as well as by other thermodynamic and structural factors. In the Co–Cu system, the positive enthalpic contribution favours compositional separation, whereas the configurational entropy contribution increasingly favours mixing with increasing temperature. Their competition qualitatively accounts for the existence of a closed metastable liquid miscibility gap, above which the homogeneous liquid becomes thermodynamically stable. In the solid state, phase stability additionally depends on differences in atomic size, compatibility of the crystal structures, electronic and magnetic interactions, interfacial energy, and contributions from defects.

The calculated ratios of the sums of ionization

potentials may therefore be used only as empirical parameters for comparing the electronic dissimilarity of the components. These ratios should not be regarded as independent thermodynamic criteria for the formation of solid solutions and cannot by themselves explain either the restricted equilibrium solubility of Co and Cu or the formation of highly supersaturated metastable solid solutions.

Rapid quenching does not change the atomic ionization potentials and therefore cannot overcome an unfavourable ratio of their sums in a direct physical sense. Instead, rapid quenching changes the kinetics of phase formation. As discussed above, the extension of solid solubility during splat quenching is associated with solute trapping and with the approach of the velocity dependent partition coefficient to unity.

During modified three-electrode ion-plasma deposition, a macroscopically defined moving solid-liquid interface is not necessarily present. The retention of a compositionally mixed state is therefore more appropriately described in terms of local atomic intermixing at the growth front, rapid overgrowth and incorporation of the deposited species into the growing film, and kinetic suppression of surface and bulk diffusion. Rapid incorporation limits the time available for surface segregation, whereas suppressed long-range diffusion restricts the subsequent development of Co-rich and Cu-rich regions.

According to literature estimates, the characteristic local energy-relaxation rate under such deposition conditions is of the order of 10^{12} K/s or higher [20-22]. Such rapid local energy relaxation further restricts the time available for compositional redistribution during film growth.

The energy delivered by the arriving atoms and ions, together with the heat released upon condensation, may enhance atomic mobility in the near-surface region of the growing condensate. The earliest stage of film growth may therefore involve a transient highly mobile and structurally disordered liquid-like state localized within a nanoscale near-surface region rather than the formation of a continuous macroscopic liquid film. The physical plausibility of such a state is consistent with studies of liquid phase formation, deep supercooling, and the stability of liquid phases in nanoscale thin-film systems [31, 32]. This possible liquid-like state is considered a working hypothesis rather than an experimentally established intermediate.

The existence of a homogeneous liquid above the critical temperature of the metastable miscibility gap provides a thermodynamic context for considering atomic mixing in the liquid state. However, the possible liquid-like state during ion-plasma deposition need not correspond to a macroscopically homogeneous equilibrium liquid above this temperature. It may instead represent a short-lived and highly disordered nanoscale state at the growth front. Enhanced surface diffusion may also contribute to local atomic rearrangement during the early stages of film growth [33].

Additional indirect evidence of substantial atomic mobility under strongly nonequilibrium preparation conditions is provided by the formation of chemically ordered B2-type phases in rapidly quenched Al-Ni and

vapor-deposited Al-Co alloys [34, 35]. Although these observations do not prove the existence of a liquid intermediate, they indicate that the corresponding preparation conditions can provide sufficient atomic mobility for intermixing and subsequent chemical ordering during crystallization.

In the present Co-Cu films, a transient highly mobile near-surface state could facilitate the initial atomic mixing of Co and Cu. Rapid local energy dissipation, incorporation of the deposited species into the growing film, and suppression of long-range diffusion could prevent the subsequent development of Co-rich and Cu-rich regions and stabilize highly supersaturated metastable fcc solid solutions. Ionized species generated during modified ion-plasma sputtering may additionally contribute to energy transfer and impact-induced atomic rearrangement at the growth front. The observed extension of the metastable fcc solid-solution range is attributed primarily to kinetic stabilization rather than to any change in the ionization potentials of the constituent elements.

Analysis of the temperature dependence of the sheet (ohm/square) resistance of the Co-Cu films prepared under identical deposition conditions shows that, as the Cu content increases from 57 to 61 at.%, the initial sheet resistance decreases by a factor of 1.77. At the same time, the degree of metastability, defined here as the ratio of the initial sheet resistance to that measured after heat treatment, increases from 1.48 for the Co-57 at.% Cu film to 1.66 for the Co-61 at.% Cu film. The temperature coefficient of resistance also increases from 1.3×10^{-4} to $3.0 \times 10^{-4} \text{ K}^{-1}$ (Fig. 3).

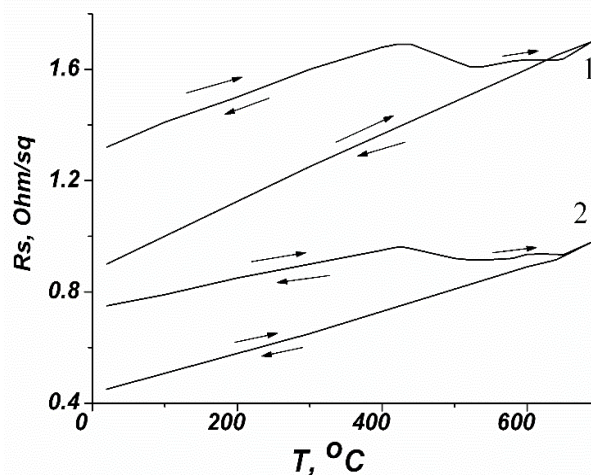


Fig. 3. Temperature dependence of the sheet resistance of vapor-deposited Co-Cu alloys: 1- Co- 57 at.% Cu; 2- Co-61 at.% Cu.

The decrease in sheet resistance with increasing Cu content is consistent with the higher electrical conductivity of Cu and the increasing contribution of Cu-rich local environments to electron transport. The resistance of the metastable films is determined not only by their chemical composition but also by structural disorder, lattice distortions, defects, interfaces, and the characteristic dimensions of the structural regions.

Up to approximately 425–430°C, the $R_s(T)$ dependences are nearly linear and reversible. This behaviour indicates that no pronounced irreversible

structural transformation occurs in this temperature interval within the sensitivity of the resistance measurements.

The first irreversible deviation from linearity at approximately 430°C is accompanied by an average decrease in sheet resistance of approximately 15%. This feature is interpreted as the onset of structural relaxation and possible decomposition of the highly supersaturated fcc solid solution. Within this interpretation, the initial homogeneous metastable state may evolve toward Co-rich and Cu-rich fcc regions that remain supersaturated with the second component.

The decrease in resistance may result from several concurrent processes, including redistribution of Co and Cu, reduction of static lattice distortions and microstrain, annihilation of defects introduced during deposition, and an increase in structural order. The resistance anomaly alone cannot distinguish the individual contributions of these processes. Its interpretation as the onset of decomposition is based on the irreversible character of the change and the expected evolution of the metastable Co–Cu system toward phase separation.

The second irreversible feature in the temperature dependence of the sheet resistance occurs in the range of 650–660°C. This feature is interpreted as reflecting further evolution of the compositionally redistributed state and a decrease in the supersaturation of the Co-rich and Cu-rich fcc phases. At this stage, their lattice parameters are expected to approach the corresponding equilibrium values.

The resistance changes become substantially less pronounced near 700°C, suggesting that the principal irreversible transformation processes are approaching completion. Thus, the two irreversible resistance anomalies indicate a stepwise transformation of the initially supersaturated fcc solid solution: the first stage is associated with the onset of chemical decomposition and structural relaxation, whereas the second stage corresponds to further compositional redistribution and an approach toward the equilibrium Co-rich and Cu-rich phases.

Such multistage behaviour is consistent with the general tendency of strongly nonequilibrium systems to approach equilibrium through intermediate metastable states rather than by a single direct transformation.

The formation of metastable supersaturated fcc Co–Cu solid solutions by ion-plasma deposition provides a means of controlling the electrical resistance and its evolution during thermal treatment. This behaviour may be relevant to applications requiring composition dependent electrical properties and controlled thermal stability. Practical applications of these films must, however, take into account the irreversible resistance changes associated with decomposition of the supersaturated state at elevated temperatures.

Conclusions

1. Co–Cu alloys prepared by splat quenching from the melt and modified three-electrode ion-plasma deposition were investigated over a wide composition range. Within the resolution and sensitivity of the employed X-ray diffraction methods, the studied alloys exhibited a single set of fcc reflections. Their systematic shift with composition and the corresponding continuous change in the lattice parameter are consistent with the formation of highly supersaturated metastable fcc solid solutions.

2. Splat quenching from the melt enabled metastable fcc solid solutions to be retained in the Co-rich and Cu-rich composition ranges. Modified ion-plasma deposition also enabled a predominant metastable fcc phase to be retained at the intermediate compositions containing 57, 61, and 70 at.% Cu, thereby extending the solid-solution range achieved under strongly nonequilibrium conditions.

3. During rapid solidification from the melt, the supersaturated state is retained through solute trapping at the moving solid–liquid interface. During ion-plasma deposition, the compositionally mixed state is retained through atomic intermixing at the growth front, rapid incorporation of the deposited species into the growing film, local energy relaxation, and kinetic suppression of surface and bulk diffusion.

4. The close atomic radii of Co and Cu facilitate substitutional mixing but are insufficient to explain the observed extension of the solid-solution range. The calculated ratios of the sums of ionization potentials may be used only as empirical parameters for comparing the electronic dissimilarity of the components and should not be regarded as independent thermodynamic criteria for the formation of solid solutions. The formation of highly supersaturated metastable fcc solid solutions is attributed primarily to kinetic stabilization rather than to any change in the ionization potentials of the constituent elements.

5. The temperature dependence of the sheet resistance confirms the metastable character and limited thermal stability of the vapor-deposited Co–Cu solid solutions. The irreversible changes observed during heating are consistent with structural relaxation and stepwise decomposition of the supersaturated state.

Kushnerev O.I. – Candidate of Physical and Mathematical Sciences, Associate Professor, Associate Professor of the Department of Experimental and Theoretical Physics;

Bashev V.F. – Doctor of Sciences in Physics and Mathematics, Professor, Professor of the Department of Condensed State Physics;

Ryabtsev S.I. – Doctor of Sciences in Physics and Mathematics, Professor, Head of the Department of Experimental and Theoretical Physics;

Kalinina T.V. – Candidate of Physical and Mathematical Sciences, Associate Professor, Head of the Department of Condensed State Physics;

Galagan P.O. – Postgraduate student of the Department of Experimental and Theoretical Physics.

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О.І. Кушнеров¹, В.Ф. Башев², С.І. Рябцев¹, Т.В. Калініна², П.О. Галаган¹

Вплив швидкісного гартування з розплаву та іонно-плазмового осадження на формування пересичених твердих розчинів у сплавах Co–Cu

¹Дніпровський національний університет імені Олеся Гончара, м. Дніпро, Україна, kushnrv@gmail.com;

²Дніпровський державний технічний університет, Дніпропетровська обл., м. Кам'янське, Україна

Сплави Co–Cu отримували методом швидкісного гартування краплі розплаву та модифікованого триелектродного іонно-плазмового осадження. Рентгеноструктурний аналіз виявив у досліджених зразках переважно метастабільні пересичені тверді розчини з ГЦК-структурою. Параметр ГЦК-гратки безперервно збільшувався зі зростанням вмісту Cu та демонстрував незначне систематичне від'ємне відхилення від закону Вегарда. Іонно-плазмове напилення забезпечило збереження ГЦК-фази у плівках із вмістом 57–70 ат.% Cu, розширюючи таким чином концентраційний діапазон існування метастабільного твердого розчину порівняно зі швидкісним гартуванням краплі розплаву. У межах роздільної здатності та чутливості застосованих методів не виявлено окремо розділених дифракційних рефлексів, які можна було б віднести до кристалічних фаз, збагачених Co або Cu. Розширення діапазону твердого розчину пояснюється насамперед кінетичною стабілізацією, зумовленою перемішуванням компонентів на атомному рівні та пригніченням концентраційного перерозподілу, необхідного для фазового розділення. Температурні залежності питомого поверхневого електричного опору виявили незворотні зміни поблизу 430°C та в інтервалі 650–660°C, пов'язані зі структурною релаксацією і поетапним розпадом пересиченого стану. Одержані результати засвідчують ефективність іонно-плазмового напилення для формування метастабільних твердих розчинів Co–Cu у розширеному концентраційному діапазоні.

Ключові слова: сплави Co–Cu, пересичені тверді розчини, швидкісне гартування краплі розплаву, іонно-плазмове осадження, швидкісна кристалізація, фазовий склад, метастабільні стани.