An X-ray determination of the thermal expansion of silver and copper-base alloys at high temperatures.

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X-ray measurements of the lattice parameters have been made in four Cu–Ga alloys in the solid-solution range using a Unicam 19 cm high-temperature camera in the temperature interval of 30–514°C. The measured lattice parameters have been found to increase non-linearly with the temperature and this variation has been expressed in an analytical form from a least-squares fitting. The linear thermal expansion coefficients have been found to decrease with increasing temperature in these alloys with a tendency to attain a nearly constant value at higher solute concentrations, and the decrease is rather slow compared to that observed earlier with Ag–Ga alloys over the same range of temperature.

X-ray measurements of lattice expansions in the temperature interval of 26–522°C have recently been reported by Halder & Sen Gupta (1974, hereafter referred to as I) for the four Ag–Ga alloys in the solid-solution range. The present investigation is concerned with the X-ray measurements of lattice expansion of four Cu–Ga alloys in the solid-solution range from the room temperature (30°C) to 514°C and forms a continuation of our previous work reported in I. These measurements have been undertaken in connexion with our present programme to study the thermal expansion behaviour of copper and silver-base alloys at high temperatures, the importance of which was emphasized earlier in I (Halder & Sen Gupta, 1974).

The preparation of four Cu–Ga alloys containing 3·40, 6·90, 10·85 and 15·00 at. % gallium was done by taking suitable amounts of spectroscopically pure copper and gallium obtained from Messrs. Johnson, Matthey & Co., Ltd, London, in evacuated and sealed quartz capsules and by melting the elements in an induction furnace. The homogenization treatment for all the alloys was made at 550°C for 10 days and the actual compositions of the prepared alloys were determined in the same way as described earlier in I after comparison of the data with those of Hume-Rothery, Lewin & Reynolds (1936). X-ray photographs at different temperatures were taken in the standard Unicam 19 cm high-temperature camera using Cu *Kα* radiation and the lattice parameters to an accuracy of ±0·0004 Å determined utilizing the same method of procedure as adopted in I. A voltage stabilizer was used with the control unit of the camera and the temperature stability was within ±2°C in the high-temperature range. However, the radiation heating as used in the 19 cm camera may lead to some uncertainty in specimen temperatures below 150°C.

Table 1 lists the mean values of the lattice parameters for the four Cu–Ga alloys in the temperature interval of 30 to 514°C obtained from the measurements of two sets of photographs. Fig. 1 shows the dependence of lattice parameter on temperature and this dependence may be analytically expressed by the following relations of the form $a_T = a_0 + a_1 T + a_2 T^2$ (*T* in °C) obtained from a least-squares fit of the experimental data:

(i) Cu–3·40 Ga:
$$a_T(\text{Å}) = 3{\cdot}6223 + 0{\cdot}7736 \times 10^{-4}T - 1{\cdot}6416 \times 10^{-8}T^2$$
(ii) Cu–6·90 Ga:
$$a_T(\text{Å}) = 3{\cdot}6320 + 0{\cdot}7988 \times 10^{-4}T - 1{\cdot}5189 \times 10^{-8}T^2$$
(iii) Cu–10·85 Ga:
$$a_T(\text{Å}) = 3{\cdot}6431 + 0{\cdot}7124 \times 10^{-4}T + 0{\cdot}4255 \times 10^{-8}T^2$$
(iv) Cu–15·00 Ga:
$$a_T(\text{Å}) = 3{\cdot}6545 + 0{\cdot}7830 \times 10^{-4}T - 0{\cdot}3209 \times 10^{-8}T^2.$$

As observed earlier in I, the best fit has been obtained with a polynomial of second degree and this may also be seen from the deviations computed for the calculated and the experimental values of lattice parameters in Table 1. The coefficients of linear thermal expansion $\alpha = 1/a_0 (\mathrm{d}a_T/\mathrm{d}T)_p$ which have been obtained from the above analytical expressions are also shown in Table 1 along with the average values. The lattice-parameter values for the initial and final room temperature (Table 1) signify that there is no appreciable loss of solute gallium during the repeated heat treatments.

From Fig. 1 and also from the above analytical expressions it is apparent that the lattice parameter increases in a more or less non-linear manner with the increase of temperature for the four alloys covering the solid-solution range. This non-linearity has also been observed earlier in I for the Ag–Ga alloys with a decrease in expansion coefficient α. However, the decrease in the expansion coefficient α for the Cu–Ga alloys is quite gradual from ~21 × 10^{-6} to ~17 × 10^{-6} as compared with that for the Ag–Ga alloys (I) where the decrease is quite rapid from ~33 × 10^{-6} to ~16 × 10^{-6}. In the Cu–Ga alloys, this decrease is small even at higher solute concentrations with a tendency to attain nearly a constant value as evident from the average values for the whole range concerned and the values of α at different temperatures obtained from the analytical forms for the Cu–10·85 Ga and Cu–15·00 Ga. The data
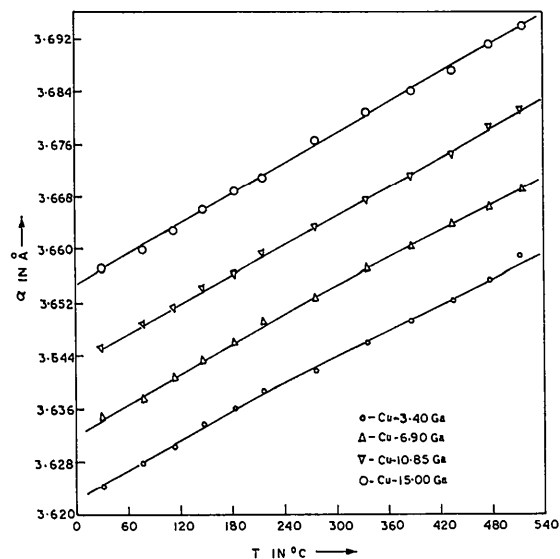

Fig. 1. Plot of lattice parameter *versus* temperature for the four Cu–Ga alloys.

Table 1. *Lattice parameters and linear expansion coefficients at different temperatures for the* Cu–Ga *alloys* (α-*phase*)

Temperature (°C)	Lattice parameter a (Å)	Lattice parameter calculated from least-squares analysis (Å)	Deviation from experimental value (Å)	Coefficient of linear thermal expansion $\alpha \times 10^6/°C$	$\alpha_{av} \times 10^6/°C$
Cu–3·40 at.% Ga					
30	3·6239	3·6246	0·0007	21·08	
77	3·6276	3·6282	0·0006	20·66	
113	3·6304	3·6308	0·0004	20·33	
148	3·6342	3·6334	−0·0008	20·01	
183	3·6362	3·6359	−0·0003	19·70	
215	3·6395	3·6382	−0·0013	19·40	18·94
277	3·6417	3·6425	0·0008	18·84	
335	3·6459	3·6464	0·0005	18·32	
387	3·6490	3·6498	0·0008	17·85	
434	3·6523	3·6528	0·0005	17·42	
477	3·6555	3·6555	0·0000	17·03	
514	3·6587	3·6577	−0·0009	16·70	
30	3·6239				
Cu–6·90 at.% Ga					
30	3·6348	3·6344	−0·0004	21·74	
77	3·6375	3·6381	0·0006	21·35	
113	3·6407	3·6408	0·0001	21·04	
148	3·6434	3·6435	0·0001	20·75	
183	3·6460	3·6461	0·0001	20·46	
215	3·6492	3·6485	−0·0007	20·19	19·76
277	3·6529	3·6529	0·0000	19·67	
335	3·6572	3·6571	−0·0001	19·19	
387	3·6604	3·6606	0·0002	18·75	
434	3·6639	3·6638	−0·0001	18·36	
477	3·6666	3·6666	0·0000	18·00	
514	3·6691	3·6690	−0·0001	17·69	
30	3·6344				
Cu–10·85 at.% Ga					
30	3·6451	3·6452	0·0001	19·62	
77	3·6486	3·6486	0·0000	19·73	
113	3·6510	3·6512	0·0002	19·82	
148	3·6542	3·6538	−0·0004	19·90	
183	3·6563	3·6563	0·0000	19·98	
215	3·6592	3·6586	−0·0006	20·05	20·17
277	3·6631	3·6632	0·0001	20·20	
335	3·6673	3·6674	0·0001	20·34	
387	3·6711	3·6713	0·0002	20·46	
434	3·6743	3·6748	0·0005	20·57	
477	3·6784	3·6781	−0·0003	20·67	
514	3·6810	3·6809	−0·0001	20·75	
30	3·6445				
Cu–15·00 at.% Ga					
30	3·6573	3·6569	−0·0004	21·37	
77	3·6600	3·6605	0·0005	21·29	
113	3·6631	3·6633	0·0002	21·22	
148	3·6661	3·6660	−0·0001	21·16	
183	3·6689	3·6687	−0·0002	21·10	
215	3·6711	3·6712	0·0001	21·04	20·95
277	3·6765	3·6760	−0·0005	20·93	
335	3·6808	3·6804	−0·0004	20·83	
387	3·6840	3·6843	0·0003	20·74	
434	3·6874	3·6879	0·0005	20·66	
477	3·6912	3·6911	−0·0001	20·58	
514	3·6941	3·6940	−0·0001	20·52	
30	3·6574				

for Cu–10·85 Ga, however show fluctuations in the trend. The dependence may be attributed to the nature of the interatomic forces and the variation of the Grüneisen parameter γ with temperature – the parameters which are involved in the lattice-dynamical effects.

References

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