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The Co-Ge-Mo (Cobalt-Germanium-Molybdenum) System

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Introduction

Only very limited information is available on the Co-rich side of the $(Co,Ge)_2$ Mo composition region of the Co-Ge-Mo system and is reported here.

Binary Systems

The Co-Ge system [Massalski2] (Fig. 1) shows the presence of six intermediate phases: Co_3Ge, Co_5Ge_2, Co_5Ge_3, CoGe, Co_5Ge_7, and $CoGe_2$, of which the Co_5Ge_3 phase exists in two polymorphic forms, the high-temperature βCo_5Ge_3 and the low-temperature (T < 382 °C) αCo_5Ge_3 phases. The βCo_5Ge_3 phase melts congruently at 1210 °C. Alloying Co with Ge stabilizes the hexagonal close packed (hcp) (ϵCo) phase to quite high temperatures. The (ϵCo), CoGe, and $CoGe_2$ phases form through peritectic reactions: L + (αCo) ↔ (ϵCo), L + βCo_5Ge_3 ↔ CoGe, and L + CoGe ↔ $CoGe_2$ at 1123, 985, and 832 °C, respectively. The Co_3Ge, Co_5Ge_2, and Co_5Ge_7 phases form through peritectoid reactions: (ϵCo) + βCo_5Ge_3 ↔ Co_3Ge at ~770 °C; (ϵCo) + βCo_5Ge_3 ↔ Co_5Ge_2 at 636 °C; and CoGe + $CoGe_2$ ↔ Co_5Ge_7 at 806 °C. The Co_3Ge and Co_5Ge_2 phases exist only at the higher temperatures and transform through eutectoid reactions: Co_3Ge ↔ (ϵCo) + βCo_5Ge_3 at temperatures above 836 °C and Co_5Ge_2 ↔ (ϵCo) + βCo_5Ge_3 at temperatures 382 °C. Two eutectic reactions, L ↔ (ϵCo) + βCo_5Ge_3 and L ↔ $CoGe_2$ + (Ge), occur at 1108 and 817 °C, respectively.

The Co-Mo system [Massalski2] (Fig. 2) shows the presence of four intermediate phases: Co_9Mo_2, Co_3Mo, Co_7Mo_6 (μ); and σ. The σ and μ phases form through the peritectic reactions L + (Mo) ↔ σ at 1620 °C and L + σ ↔ μ at ~1510 °C. A eutectic reaction, L ↔ μ + (αCo), occurs at 1335 °C. Three peritectoid reactions, μ + (αCo) ↔ Co_9Mo_2, Co_9Mo_2 + μ ↔ Co_3Mo, and probably (αCo) + Co_3Mo ↔ (ϵCo), occur at 1200, 1025, and ~700 °C, respectively. The Co_9Mo_2 and σ phases transform through eutectoid reactions Co_9Mo_2 ↔ (αCo) + Co_3Mo and σ ↔ (Mo) + μ at 1018 and ~1000 °C, respectively.

The Ge-Mo system [1987Ole, Massalski2] (Fig. 3) has four intermediate phases: αGe_2Mo; $Ge_{23}Mo_{13}$; Ge_3Mo; and $GeMo_3$. A metastable βGe_2Mo phase forms on rapid quenching of alloys containing <40 at.% Mo from 1350 °C. The βGe_2Mo phase, however, is a stable phase above 20 kbar pressure, and only after annealing in a vacuum at 1000 °C for 5 h does the βGe_2Mo phase transform into the αGe_2Mo phase. All of the intermediate phases form through peritectic reactions: L + (Mo) ↔ $GeMo_3$ at 1800 °C;

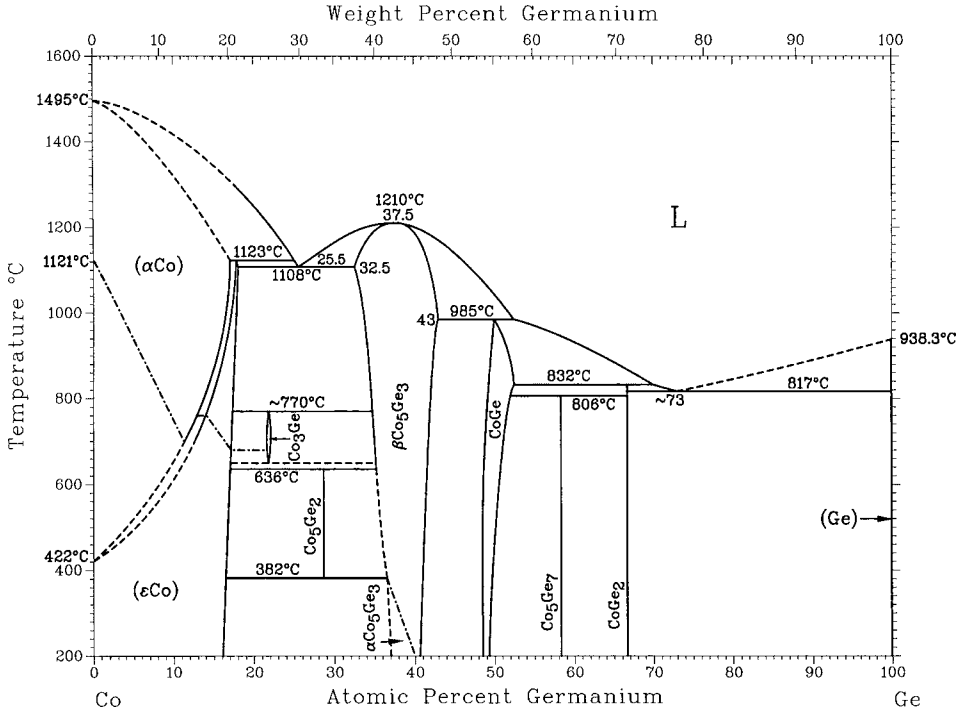

Fig. 1 The binary Co-Ge diagram [Massalski2]

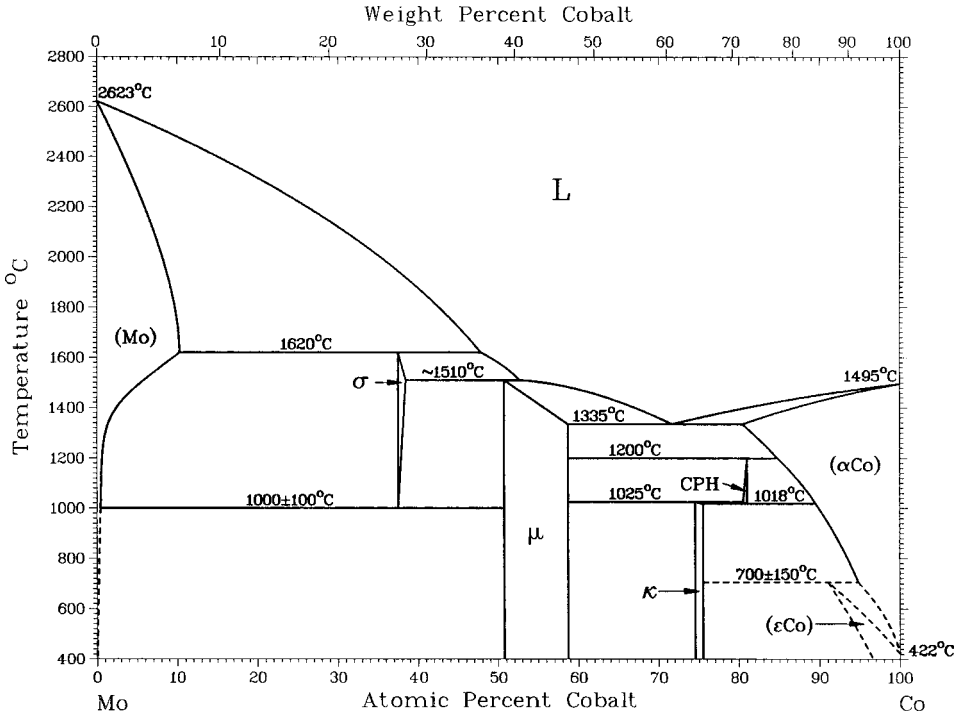

Fig. 2 The binary Co-Mo diagram [Massalski2]

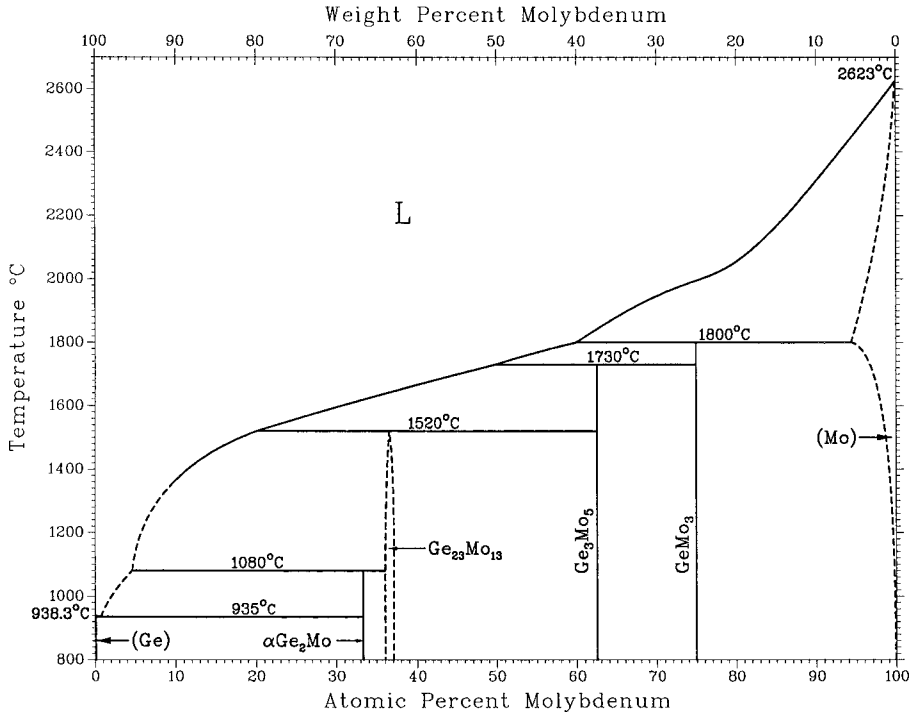

Fig. 3 The binary Ge-Mo diagram [Massalski2]

L + $GeMo_3$ ↔ Ge_3Mo_5 at 1730 °C; L + Ge_3Mo_5 ↔ $Ge_{23}Mo_{13}$ at 1520 °C; and L + $Ge_{23}Mo_{13}$ ↔ αGe_2Mo at 1080 °C. A eutectic reaction, L ↔ (Ge) + αGe_2Mo, occurs at 935 °C.

Binary and Ternary Phases

In the three binary systems of the Co-Ge-Mo system, 14 intermediate phases form. In the Co-Ge-Mo system, the

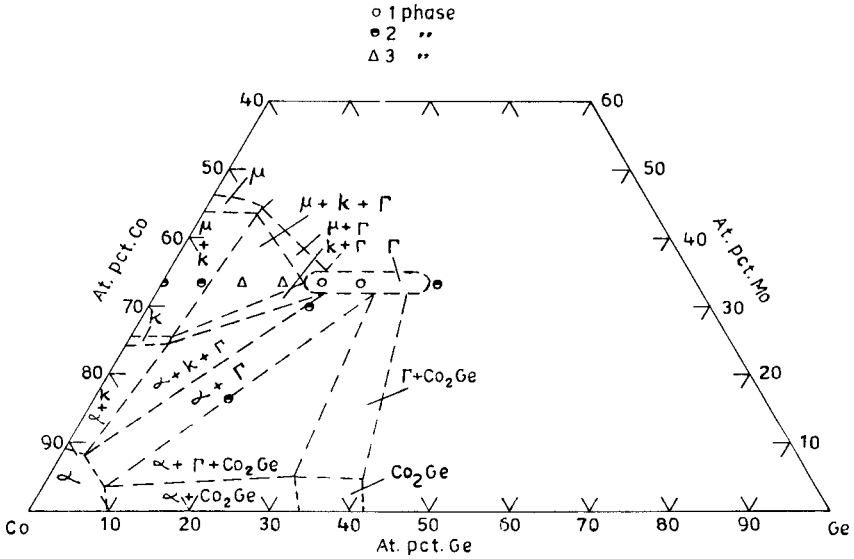

Fig. 4 A partial isothermal section of Co-Ge-Mo system at 600 °C [1964Bor]

Table 1 Binary and ternary phases in the Co-Ge-Mo system

Phase designation	Composition	Pearson symbol	Space group	Type	Lattice parameter, nm		
					a	*b*	*c*
(αCo)	(αCo)	*cF*4	$Fm\bar{3}m$	Cu	…	…	…
(εCo)	(εCo)	*hP*2	$P6_3/mmc$	Mg	…	…	…
(Mo)	(Mo)	*cI*2	$Im\bar{3}m$	W	…	…	…
(Ge)	(Ge)	*cF*8	$Fd\bar{3}m$	C(diamond)	…	…	…
δ_1	Co_3Ge	*cP*8(?)	$Pm\bar{3}n$(?)	Cr_3Si(?)	…	…	…
θ	Co_5Ge_2	…	…	…	…	…	…
α_1	αCo_5Ge_3	*oP*12	*Pnma*	Co_2Si	0.502	0.382	0.726
β_1	βCo_5Ge_3	*hP*6	$P6_3/mmc$	$InNi_2$	0.3876	…	0.4995
η	CoGe	*mC*16	*c*2*m*	…	1.1648	0.3807	0.4945
		*cP*8	$P2_13$	FeSi	…	…	…
ρ	Co_5Ge_7	*tI*24	*I*4*mm*	…	0.764	…	0.581
τ	$CoGe_2$	*oC*24	*Aba*2	…	0.5681	0.5681	1.0818
α^1	αGe_2Mo	*oP*12	*Pnma*	$PbC1_2$	0.6343	0.3451	0.8582
β^1	βGe_2Mo(HP)(a)	*tI*8	*I*4/*mmm*	$MoSi_2$	0.3322	…	0.8219
ι	$Ge_{23}Mo_{13}$	*tP*144	$P\bar{4}n2$	$Ge_{23}Mo_{13}$	0.599	…	6.354
υ	Ge_3Mo_5	*hP*16	$P6_3/mcm$	Mn_5Si_3	0.9837	…	0.4973
δ_2	$GeMo_3$	*cP*8	$Pm\bar{3}n$	Cr_3Si	0.49330	…	…
π	Co_9Mo_2	*h*	…	…	0.25973	…	0.42123
κ	Co_3Mo	*hP*8	$P6_3/mcm$	Ni_3Sn	0.51245	…	0.41125
μ	Co_7Mo_6	*hR*13	$R\bar{3}m$	Fe_7W_6	0.4726	…	2.5015
σ	Co_9Mo_{15}	*tP*30	$P4_2/mnm$	σ(CrFe)	0.92287	…	0.48269
Γ	$Co_{1.4}Ge_{0.6}Mo$	*hP*12	$P6_3/mmc$	$MgZn_2$	0.4790	…	0.7688

(a) Lattice parameters for the Co-Ge and Co-Mo systems are from [Pearson3]; lattice parameters for the Ge-Mo system are from [1987Ole]. (b) βGe_2Mo is metastable at ordinary pressures but is stable above 20 kbar pressure

existence of a ternary intermediate phase has been reported. The phases and their structural data are given in Table 1.

Ternary System

The Co-Ge-Mo system was investigated at the Co end by [1964Bor] around the $(Co,Ge)_2Mo$ composition up to ~34 at.% Ge. Nine alloys were melted, using pure metals Mo (99.93 mass%), Co (99.98 mass%), and Ge (99.99 mass%), in corundum crucibles under an argon atmosphere. Samples were annealed in sealed quartz capsules (time of annealing and annealing temperature were not mentioned) and water-quenched. The characterization of the annealed alloys was done by metallography and x-ray diffraction. The

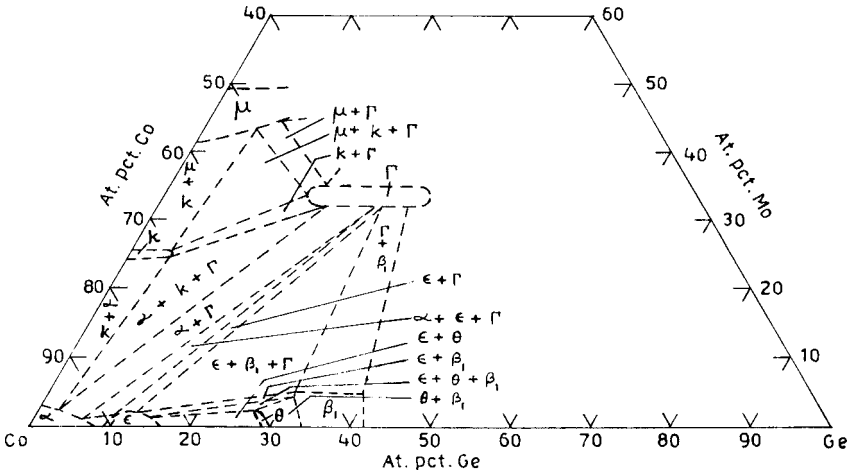

Fig. 5 A probable isothermal section (schematic) of Co-Ge-Mo system at 600 °C

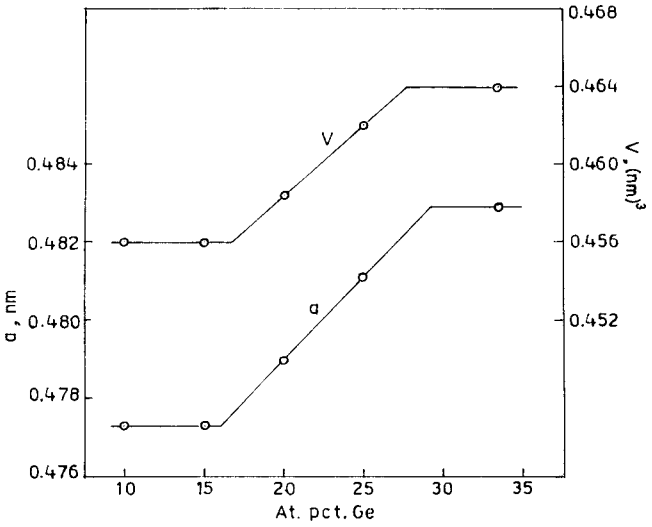

Fig. 6 Variation of lattice parameter *a* and lattice volume *V* of the phase as a function of Ge content [1964Bor]

existence of a ternary phase, Γ, was established along the $(Co,Ge)_2Mo$ composition line. The Γ phase region was shown to be very narrow and was reported to be in equilibrium with the (αCo), Co_3Mo, Co_7Mo_6 (μ), and Co_2Ge phases. Among the alloys along the $(Co_x,Ge_{1-x})Mo$ line, the alloy with 5 at.% Ge had two phases (μ + κ), the alloy with 15 at.% Ge had three phases (μ + κ + Γ), and the alloy with 20 at.% Ge had a single phase Γ, whereas the alloy with 33.4 at.% Ge was found to have two phases, the Γ phase and a second phase that was not identified. Two alloys containing 16.7 at.% Ge and 16.7 at.% Mo and 20 at.% Ge and 30 at.% Mo were found to have two phases, (αCo) and Γ; the latter alloy contained only traces of the (αCo) phase.

On the basis of these data, the possible phase equilibria for the Co corner of the Co-Ge-Mo system was drawn and is given in Fig. 4. Because only a few alloys were used and for most of the two-phase and three phase regions no experimental data are available, the phase equilibria given in Fig. 4 should be treated as a schematic representation of phase equilibria of the Co-Ge-Mo system at 600 °C. The phase equilibria given in Fig. 4 also does not agree with the binary data of Co-Ge and Co-Mo systems. According to the accepted Co-Mo binary diagram, the μ phase region is much wider than that given in Fig. 4. In the accepted Co-Ge binary system, the sequence of phases at 600 °C is (αCo), (ϵCo), Co_5Ge_2, and βCo_5Ge_3 as Ge content increases. There is no Co_2Ge phase in the Co-Ge system, but the composition region of the Co_2Ge phase in Fig. 4 agrees well with the βCo_5Ge_3 phase in the Co-Ge system. The solubility of Mo in αCo at 600 °C is ~3 at.% Mo and that of Ge in αCo in the Co-Ge system is ~8 at.% Ge. Thus, the (αCo) phase region will be smaller than that given in Fig. 4. Moreover, the presence of the (ϵCo) and Co_5Ge_2 phases in the Co-Ge system should show additional phase boundaries related to the equilibrium of the Γ phase with the (ϵCo) phase, and the equilibrium of the Co_5Ge_2 phase with the (ϵCo) and βCo_5Ge_3 phases. The probable phase equilibria at the Co corner of the Co-Ge-Mo system is schematically shown in Fig. 5.

The Γ phase was identified as an $MgZn_2$-type Laves phase. For the alloy with composition $Co_{1.4}Ge_{0.6}Mo$, the lattice parameter was reported to be $a = 0.4790 \pm 0.0003$ nm and $c = 0.7665 \pm 0.0004$ nm. With the increase in Ge content the variation of lattice parameter *a* and lattice volume *V* (Fig. 6) indicates that the Γ phase region extends from ~16 at.% Ge to ~28 at.% Ge.

References

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1987Ole: R.W. Olesinski and G.J. Abbaschian, *Bull. Alloy Phase Diagram,* 1978, **8,** p 53-56 (Evaluation)

# Indicates presence of phase diagram.

Co-Ge-Mo evaluation contributed by **K.P. Gupta,** The Indian Institute of Metals, Metal House, Plot 13/4, Block AQ, Sector V, Calcutta, India. Literature searched through 1996. Dr. Gupta is the Alloy Phase Diagram Co-Category Program Editor for ternary nickel alloys.