Silver - Copper - Tin

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Introduction

[59Geb] investigated the ternary system, mainly in the Ag-Cu region containing up to 25 mass% Sn, by thermal, metallographic and X-ray analyses. For the Sn-rich region, data by [59Wag] (thermal analysis) and by [54Cro] (metallography) were incorporated. 16 four-phase equilibria exist in the ternary system, see the Reaction Scheme, Fig. 1, and Table 2. The phase denominations in Figs. 2-7 were adopted from [77Cha], who reviewed the ternary system.

Binary Systems

The binary systems are taken from [E-S] (Ag-Sn); [80Joh] (Cu-Sn); and a slightly modified system of that published by [H] and [80Gie] (Ag-Cu). The room temperature phase boundaries (37°C) of all three systems are extrapolated.

Solid Phases

No ternary compounds have been found. The intermediate phases of the Ag-Sn and Cu-Sn binary systems are listed in Table 1.

Invariant Equilibria

16 invariant reactions were found to occur in the ternary system; see Fig. 1 and Table 2. The transition equilibria U_1-U_7 in Fig. 2 correspond to the liquid composition. There are 9 additional four-phase equilibria in the solid state, marked with asterisks in Fig. 1 and Table 2; the compositions of these phases are estimated from line drawings given in [59Geb].

Isothermal Sections

Figures 3 and 4 show the phase equilibria at 500 and 600°C [59Geb]. The homogeneous phases are rather dependent on the temperature and show only a small ternary expansion. The isotherm at 37°C exhied in Fig. 5 in based on microscopic and X-ray determinations of alloys tempered for at least 6 weeks at 37°C; for experimental details see [80Kra]. The results confirm investigations by [72Jen] and an independent study by [73Wir].

Miscellaneous

Isopleths of the ternary Ag-Cu-Sn system were published by two teams, [59Geb] and [81Fed]. The cross sections at constant Sn content, namely 5, 10, 15, 20 and 25 mass% are based on thermal, microscopic and X-ray studies by [59Geb]. Figures 6 and 7 represent Ag-Cu-10Sn and Ag-Cu-25Sn, respectively. Three cross sections were constructed by [81Fed]: one parallel to the Ag-Sn system containing 10 mass% Cu, one cross section from 100 Ag to (80Sn, 17.8Cu) and one from 100Cu to (50Ag, 50Sn). The results of both teams agree fairly well [81Fed], thus supporting the proposed ternary equilibrium diagram given by [59Geb]. Ag-Cu-Sn alloys form the basis of dental amalgams. A knowledge of the phase relationships in the ternary and quaternary (Ag-Cu-Sn-Hg) systems is essential for the understanding and

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development of new dental amalgams. Ag_3Sn is known as "dental alloy". If mixed with an equal amount of Hg, the undesirable phase $Sn_{7.8}Hg$ (γ_2) is formed during the hardening process. The addition of Cu to the basic Ag-Sn alloys suppresses the (γ_2)phase formation during the amalgamation [80Kra].

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Table 1: Solid Phases

Phase / Temperature Range (°C)	Pearson Symbol/ Prototype	Lattice Parameters (pm)	Comments
(Ag)	cF4 Cu	a = 408.53 to a = 414.7	pure 14 at.% Sn [V-C]
(Cu)	cF4 Cu	a = 361.52 to a = 368.93	pure 12 at.% Sn [80Joh]
β-Sn(r)	tI4 β-Sn	a = 583.15 c = 318.14	pure [80Joh]
α-Sn(l)	cF8 C	a = 648.92	pure [80Joh]
ε_2, Ag_5Sn	hP2 Mg	a = 292.84 c = 478.44 a = 297.60 c = 478.24	12.9 at.% Sn 22 at.% Sn [E-S]
θ, Ag_3Sn	oP8 Cu_3Ti	a = 596.80 b = 478.02 a = 518.43	300°C [V-C]
β, $Cu_{17}Sn_3$(h) 799-586	cI2 W	a = 298.12	13-16 at.% Sn [80Joh]
γ, Cu_3Sn(h) 756-520	cF16 BiF_3	a = 611.66	[V-C]
δ, $Cu_{41}Sn_{11}$(h) 590-350	cF416 $Cu_{41}Sn_{11}$	a = 1798	[V-C]
ζ, Cu_7Sn_2(h) 640-582	hP8 Na_3As	a = 428.1 c = 784.2	[V-C]
ε_1, $Cu_{10}Sn_3$	hP26 $Cu_{10}Sn_3$	a = 733.1 c = 787.0	[V-C]
η, Cu_6Sn_5(h)	hP4 NiAs	a = 419.0 c = 508.6	[V-C]
η', Cu_6Sn_5(r)	hR22	a = 864.8 c = 1067.5	[V-C]

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Table 2: Invariant Equilibria

T(°C)	Type	Phase	Composition (at.%)		
Reaction			**Ag**	**Cu**	**Sn**
605	U_1	L	39.45	46.73	13.82
L+(Cu) O		(Cu)	4.20	88.18	7.62
(Ag)+β		(Ag)	85.32	6.66	8.02
		β	9.87	75.39	14.74
560	U_2	L	37.65	42.36	19.99
L+β O		β	9.93	74.61	15.46
(Ag)+γ		(Ag)	84.75	5.85	9.40
		γ	9.33	73.07	17.60
550	U_3	L	41.19	37.53	21.27
L+(Ag) O		(Ag)	84.49	4.22	11.29
ε_2+γ		ε_2	79.72	5.88	14.40
		γ	8.67	72.31	19.03
540	U_4	L	40.35	35.73	33.91
L+γ O ε_2+ε_1		γ	7.99	71.54	20.47
		ε_2	77.12	6.71	16.17
		ε_1	8.23	67.30	24.47
440	U_5	L	41.71	19.53	38.77
L+ε_2 O θ+ε_1		ε_2	72.50	6.74	20.76
		θ	71.96	4.27	23.77
		ε_1	7.53	66.47	26.00
350	U_6	L	20.53	10.45	69.02
L+ε_1 O θ+η		ε_1	5.96	68.31	25.73
		θ	71.77	3.43	24.80
		η	3.30	53.22	43.48
225	U_7	L	4.37	0.93	94.71
L+η O		η	2.07	52.75	45.18
θ+(Sn)		θ	72.06	2.58	25.36
		(Sn)	0.55	1.85	97.60
570	E_1^*	ζ	2.11	77.47	20.42
ζ O δ+γ+ε_1		δ	1.39	79.03	19.58
		γ	2.78	78.93	18.29
		ε_1	2.85	75.10	22.05

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545,	E_2^*	β	9.87	75.39	14.74
β O		(Cu)	4.51	88.48	7.02
(Cu)+(Ag)+γ		(Ag)	86.90	5.03	8.07
		γ	14.82	74.72	10.90
525	U_8^*	γ	6.40	74.85	18.74
$\gamma+\varepsilon_1$ O $\delta+\varepsilon_2$		ε_1	6.59	70.80	22.61
		δ	3.59	74.26	22.16
		ε_2	76.52	8.33	15.15
515	U_9^*	(Cu)	3.19	89.86	6.95
(Cu)+γ O		γ	10.10	72.21	17.69
(Ag)+δ		(Ag)	84.67	8.26	7.07
		δ	4.18	78.08	17.73
505	E_3^*	γ	13.25	68.70	18.05
γ O		(Ag)	82.60	6.68	10.72
(Ag)+ε_2+δ		ε_2	81.41	5.06	13.53
		δ	4.93	76.51	18.53
450	U_{10}^*	(Ag)	86.90	5.03	8.07
(Ag)+δ O		δ	5.66	75.69	18.65
(Cu)+ε_2		(Cu)	2.55	89.91	7.54
		ε_2	80.78	6.67	12.53
300	E_4^*	δ	4.96	75.74	19.31
δ O		(Cu)	1.25	92.49	6.26
(Cu)+ε_2+ε_1		ε_2	81.41	5.06	13.53
		ε_1	2.14	75.15	22.71
170	U_{11}^*	ε_1	5.96	68.31	25.73
$\varepsilon_1+\eta$ O $\theta+\eta'$		η	2.48	53.26	44.27
		η'	1.63	55.38	42.99
		θ	71.20	5.11	23.69
150	E_5^*	η	2.49	52.19	45.31
η O		θ	70.26	5.11	24.62
$\theta+\eta'$+(Sn)		η'	1.64	54.35	44.01
		(Sn)	0.00	0.00	100.00

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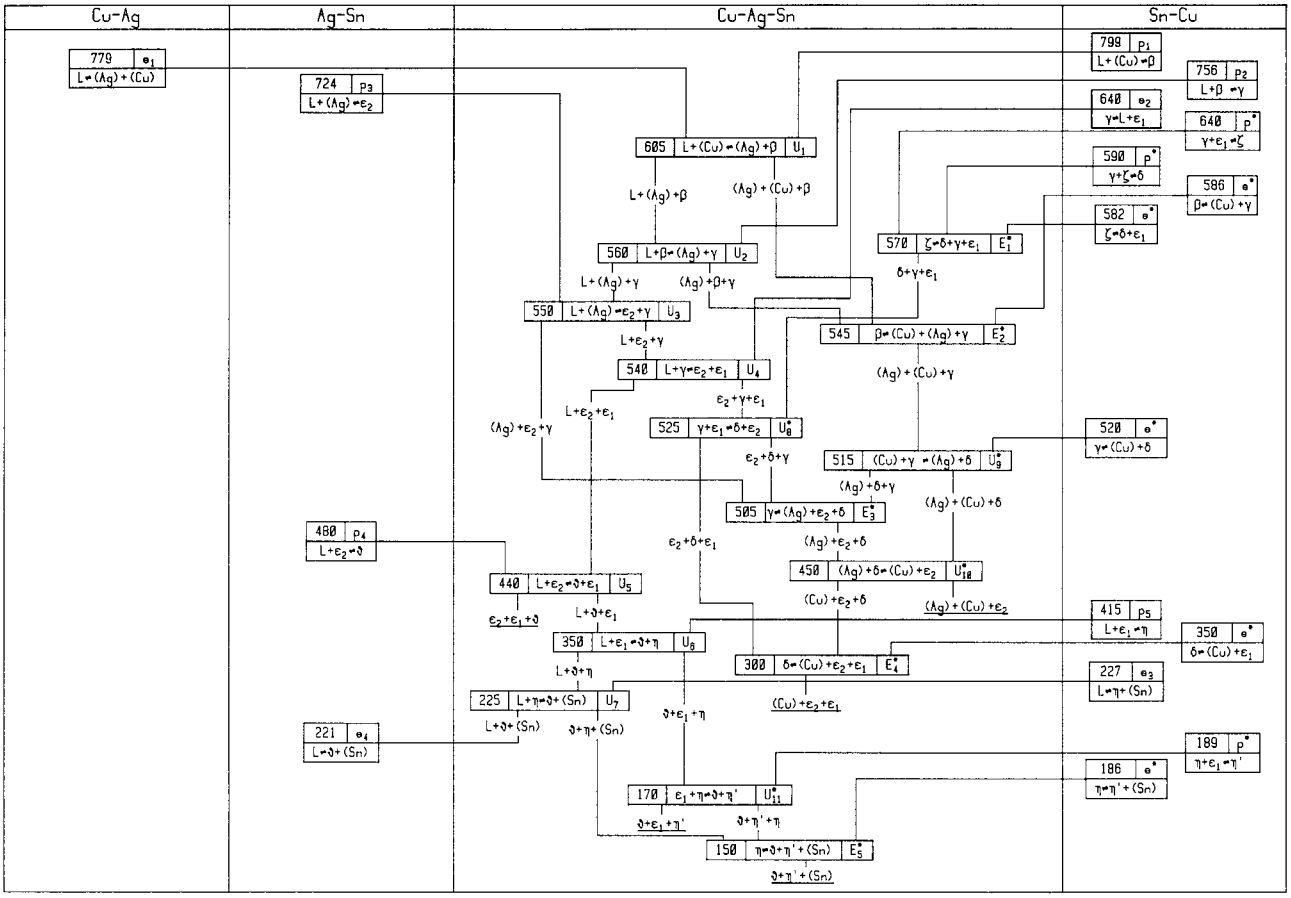

Fig. 1: Reaction scheme

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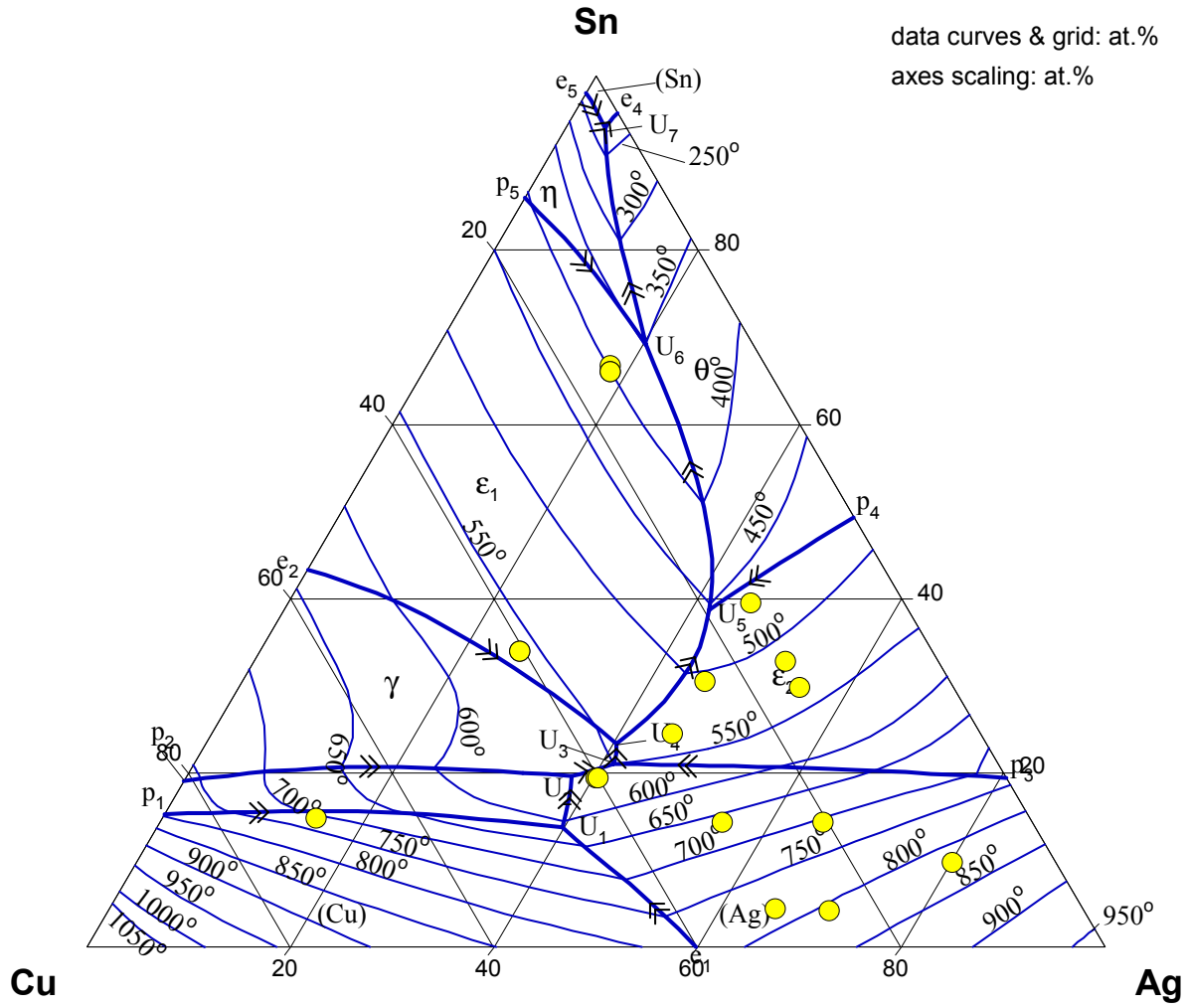

Fig.2: Liquidus surface [59 Geb]

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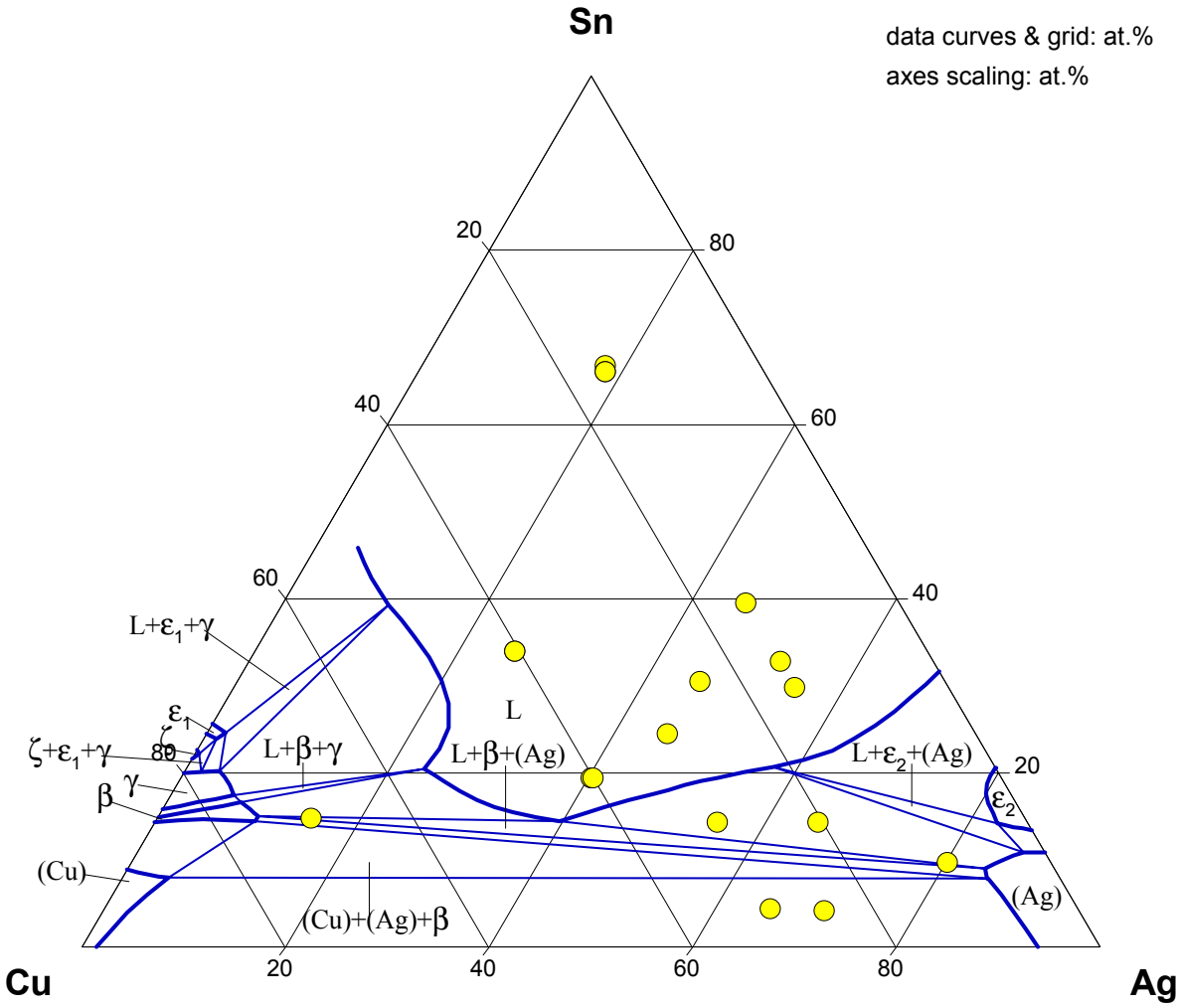

Fig.3: Partial isothermal section at 600° C [59 Geb]

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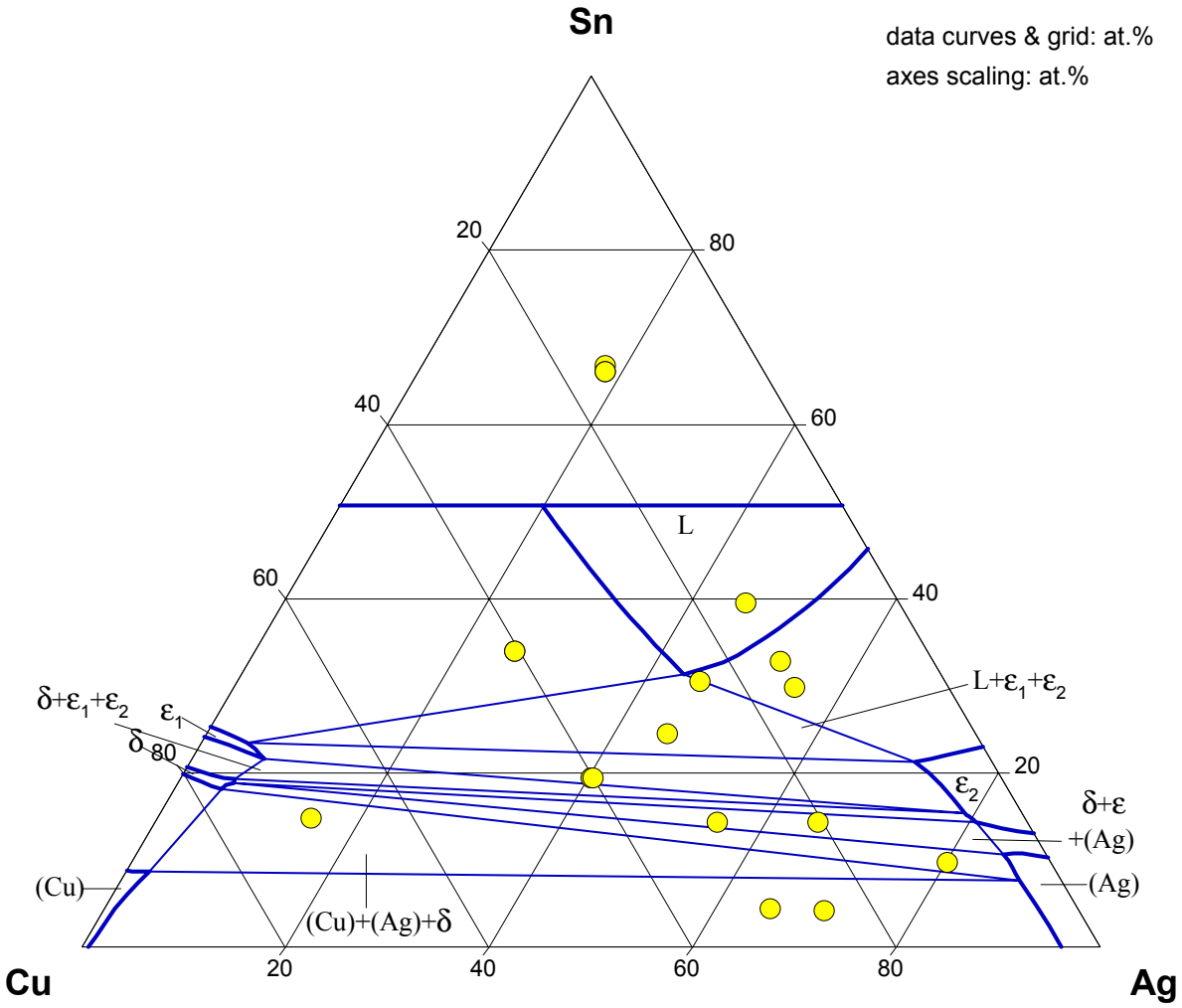

Fig.4 :Partial isothermal section at 500° C [59 Geb]

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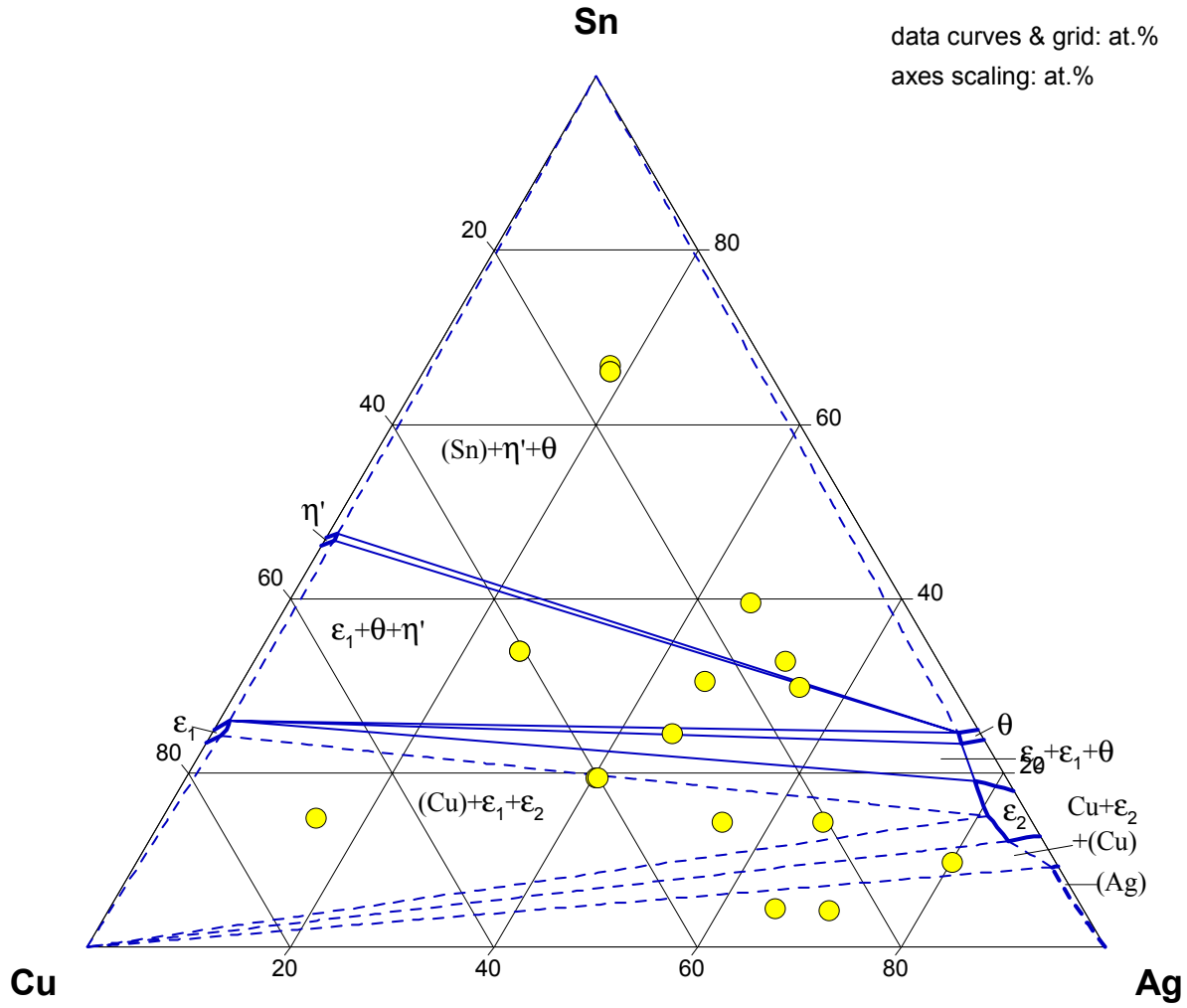

Fig.5 :Isothermal section at 37° C

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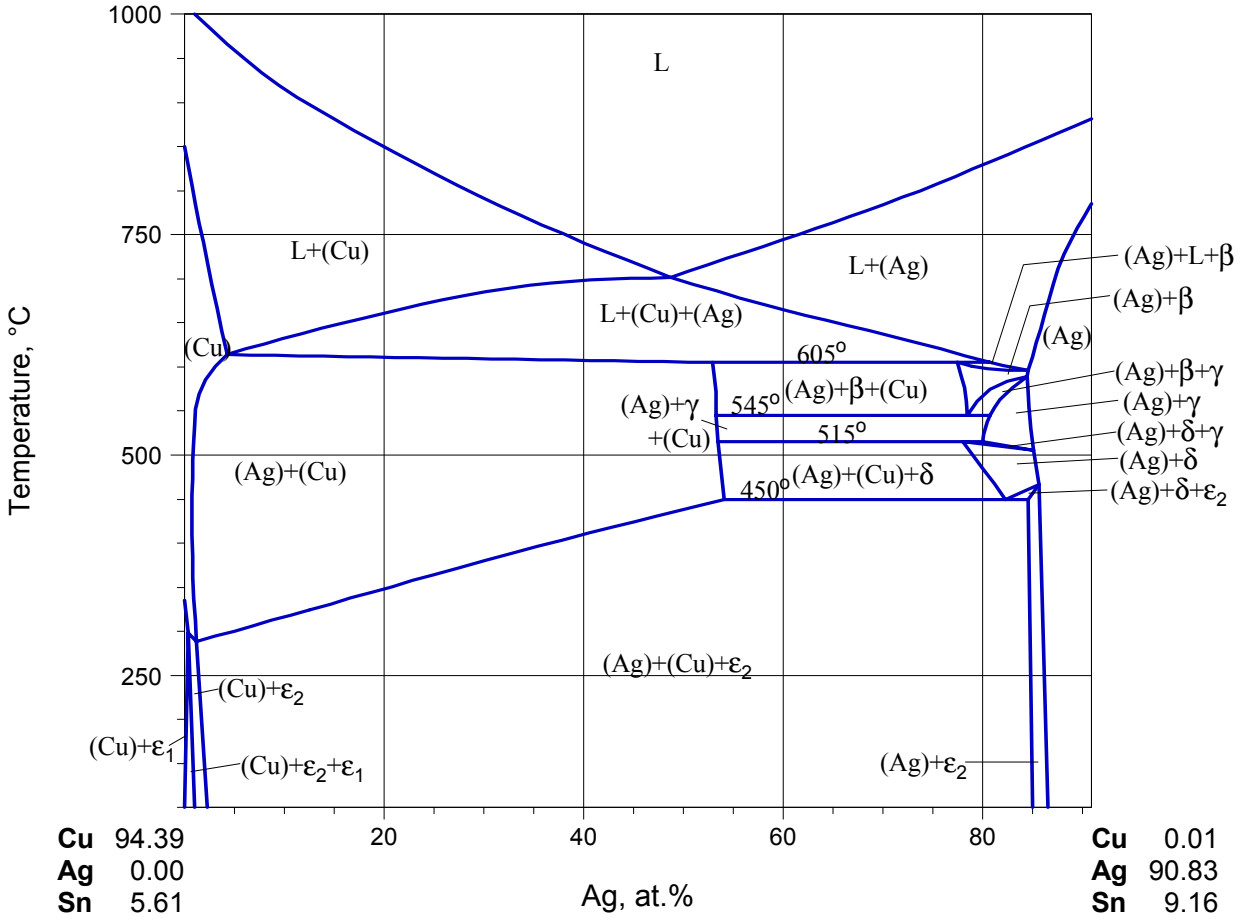

Fig.6: Vertical section at 10 mass % Sn [59 Geb]

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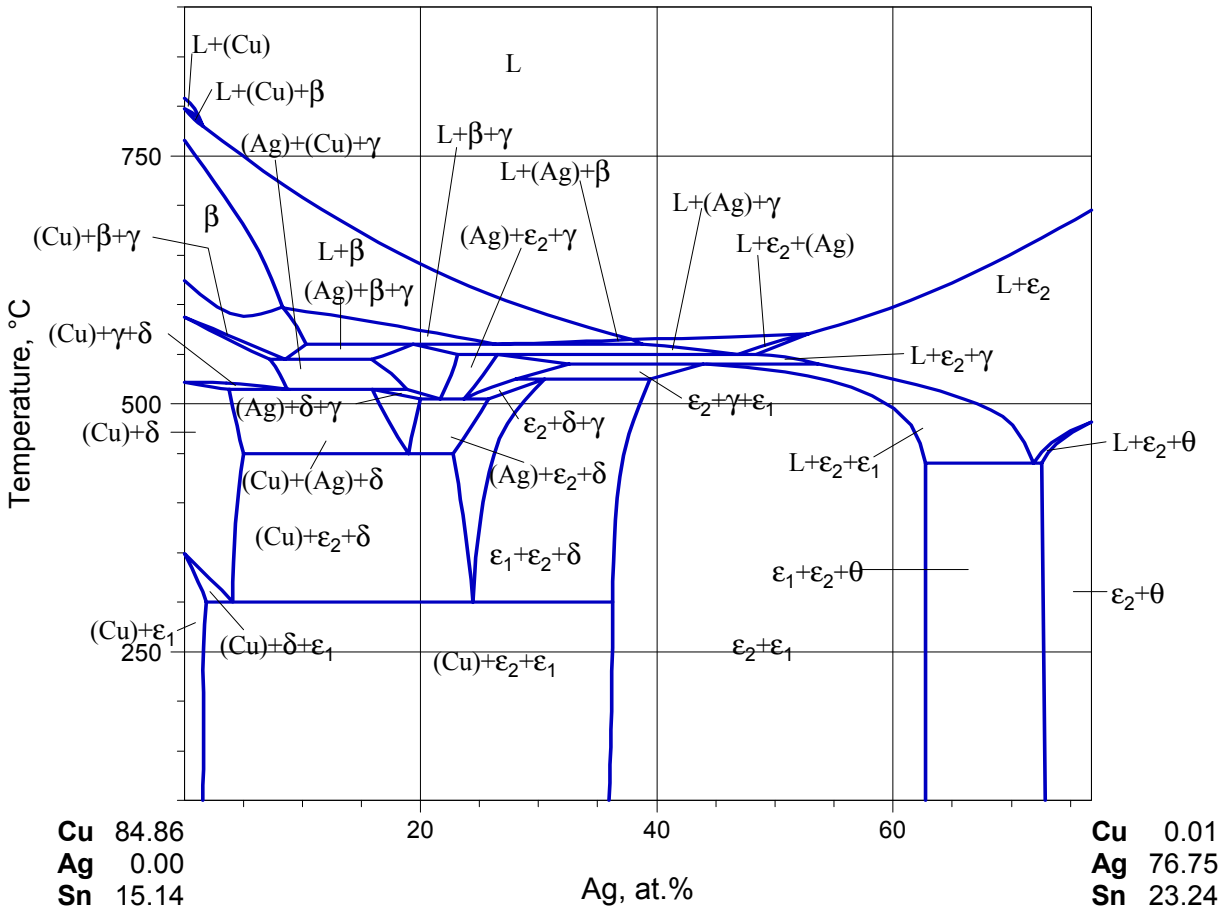

Fig.7 :Vertical section at 25 mass % Sn /59 Geb/

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