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*Indicates key paper.
#Indicates presence of a phase diagram.

Co-Ge evaluation contributed by **K. Ishida** and **T. Nishizawa,** Department of Materials Science, Faculty of Engineering, Tohoku University, Sendai 980, Japan. This work was supported by the Japanese Committee for Alloy Phase Diagrams. Part of the literature search was provided by ASM International. Literature searched through 1987. Professor Nishizawa is the Alloy Phase Diagram Program Category Editor for binary cobalt alloys.

# The Co-Pd (Cobalt-Palladium) System

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## Equilibrium Diagram

The equilibrium phases of the Co-Pd system are: (1) the liquid, L; (2) the fcc solid solution with complete solubility at all compositions, ($\alpha$Co,Pd); and (3) the Co-rich cph solid solution, ($\varepsilon$Co). The assessed Co-Pd phase diagram (Fig. 1) is based on the experimental liquidus and solidus data listed in Table 1 [36Gru]. The magnetic transformation temperature changes continuously from 1121 °C for pure Co to –266 °C for a 99.9 at.% Pd alloy [35Gru, 36Gru, 61Boz, 67Bag, 68Bag] (see "Magnetism"). The equilibrium between ($\alpha$Co) and ($\varepsilon$Co) is unknown, but it is estimated from the data on the ($\alpha$Co) ↔ ($\varepsilon$Co) transformation temperatures that the allotropic phase boundary is lowered by the addition of Pd (see "Metastable Phases").

**Table 1 Co-Pd Liquidus and Solidus Data from Thermal Analysis**

| Composition, at.% Pd | Temperature, °C Liquidus | Solidus |
|---|---|---|
| 5 | 1432 | 1408 |
| 10 | 1372 | 1331 |
| 15 | 1318 | 1270 |
| 20 | 1279 | 1244 |
| 25 | 1255 | 1238 |
| 30 | 1239 | 1218 |
| 35 | 1229 | 1220 |
| 40 | 1224 | 1216 |
| 45 | 1220 | 1216 |
| 50 | 1217 | 1214 |
| 55 | 1231 | 1225 |
| 60 | 1258 | 1245 |
| 65 | 1285 | 1272 |
| 70 | 1311 | 1300 |
| 75 | 1340 | 1329 |
| 80 | 1371 | 1357 |
| 85 | 1407 | 1390 |
| 90 | 1452 | 1437 |
| 95 | 1505 | 1499 |

From [36Gru].

## Metastable Phases

The martensitic transformation temperatures of ($\alpha$Co) ↔ ($\varepsilon$Co) on heating and cooling were measured by [35Gru] and [70Kra] and are listed in Table 2. The $M_s$ point is lowered, but the reverse temperature $A_s$ is raised by the addition of Pd. The allotropic

**Table 2 ($\alpha$Co) ↔ ($\varepsilon$Co) Transformation Temperatures**

| Reference | Method | Composition, at.% Pd | Temperature, °C Heating, $A_s$ | Cooling, $M_s$ | $T_0 = (A_s + M_s)/2$ |
|---|---|---|---|---|---|
| [35Gru] | Magnetic | 0 | 442 | 408 | 425 |
| | | 5 | 456 | 277 | 367 |
| | | 5 | 480 | 275 | 378 |
| | | 10 | <473 | 180 | <327 |
| [70Kra] | Dilatometric | 0.29 | 451 | 390 | 421 |
| | | 1.62 | 464 | 338 | 401 |

phase boundary, $T_0 = (M_s + A_s)/2$, is lowered. This fact suggests that Pd stabilizes (αCo), rather than (εCo).

Electron diffraction studies on vapor deposited thin films of Co-Pd alloys revealed two types of ordered phases; one is an $L1_2$, $AuCu_3$-type structure (α′) found in the composition range between 60 and 90 at.% Pd, with an order-disorder transition temperature estimated to be about 830 °C for the 80 at.% Pd alloy; the other has the $L1_0$, AuCu-type structure (α″), with a narrow region of composition around 50 at.% Pd [72Mat]. These phases are indicated to be metastable, because bulk samples with the compositions $Co_3Pd$, CoPd, and $CoPd_3$ did not show any trace of the corresponding superlattice reflections. The metastable phase diagram for thin films proposed by [72Mat] is shown in Fig. 2.

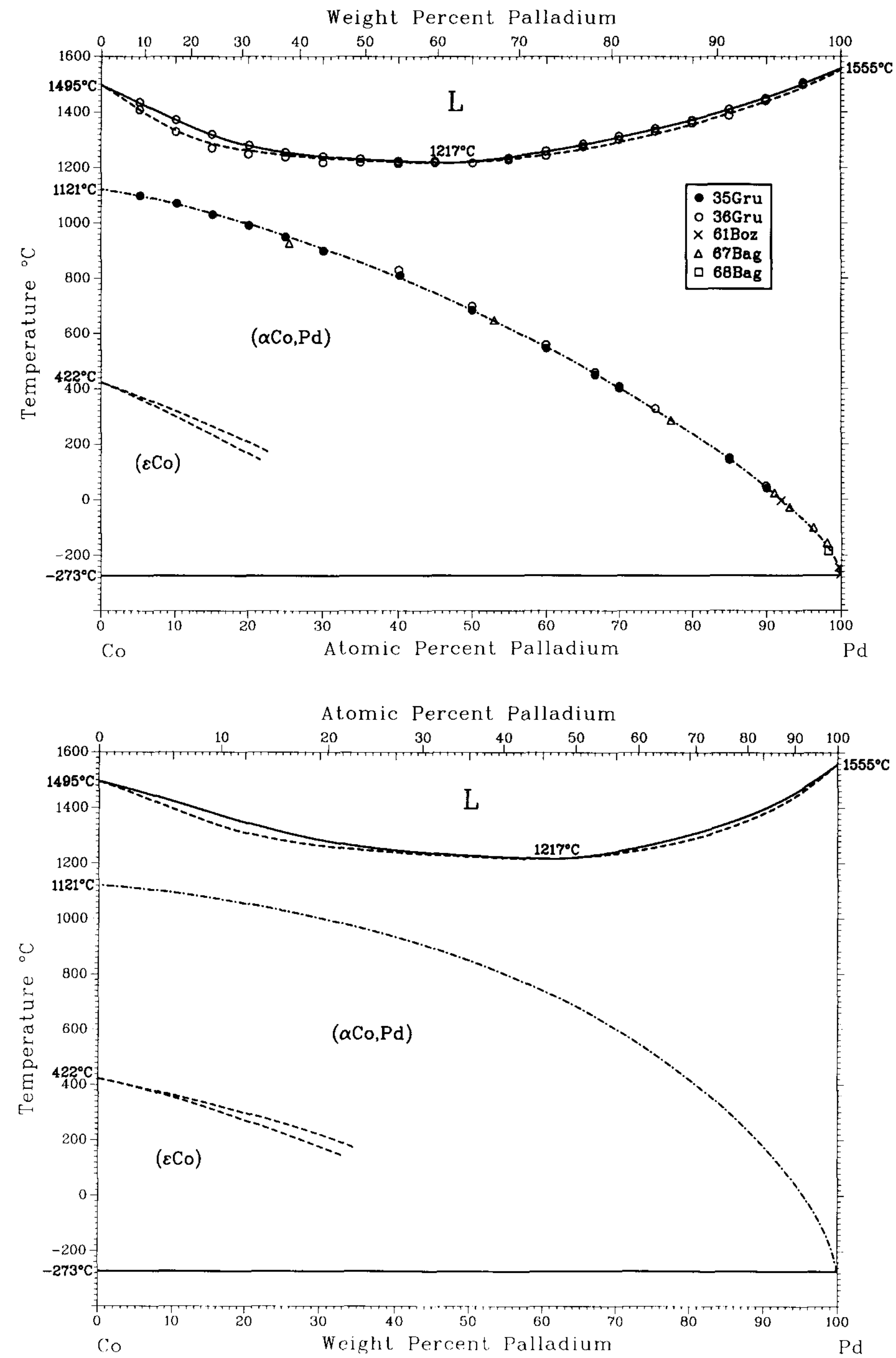


Fig. 1 Assessed Co-Pd phase diagram.

Table 3 Co-Pd Crystal Structure Data

| Phase | Composition, at.% Pd | Pearson symbol | Space group | Strukturbericht designation | Prototype | Reference |
|---|---|---|---|---|---|---|
| (αCo,Pd) | 0 to 100 | *cF*4 | *Fm*$\bar{3}$*m* | *A*1 | Cu | [83Nis] |
| (εCo) | 0 to ~20 | *hP*2 | *P*6$_3$/*mmc* | *A*3 | Mg | [83Nis] |
| **Metastable phases(a)** | | | | | | |
| α″ | ~48 to ~52 | *tP*2 | *P*4/*mmm* | *L*1$_0$ | AuCu | [72Mat] |
| α′ | 60 to 90 | *cP*4 | *Pm*$\bar{3}$*m* | *L*1$_2$ | $AuCu_3$ | [72Mat] |

(a) Evaporated films.

Table 4 Co-Pd Lattice Parameter Data

| Phase | Composition, at.% Pd | Lattice parameters, nm *a* | *c* | Comment | Reference |
|---|---|---|---|---|---|
| (αCo,Pd) | 0 | 0.35446 | ... | ... | [83Nis] |
| | 20 | 0.3633 | ... | Read from figure | [61Boz] |
| | 40 | 0.3708 | ... | Read from figure | [61Boz] |
| | 60 | 0.3778 | ... | Read from figure | [61Boz] |
| | 80 | 0.3839 | ... | Read from figure | [61Boz] |
| | 87 | 0.3854 | ... | Read from figure | [61Boz] |
| | 92 | 0.3864 | ... | Read from figure | [61Boz] |
| | 95 | 0.3871 | ... | Read from figure | [61Boz] |
| | 99 | 0.3877 | ... | Read from figure | [61Boz] |
| | 100 | 0.389 | ... | Read from figure | [61Boz] |
| | 25 | 0.366 | ... | Read from figure | [72Mat] |
| | 50 | 0.375 | ... | Read from figure | [72Mat] |
| | 75 | 0.383 | ... | Read from figure | [72Mat] |
| | 100 | 0.38901 | ... | ... | [King1] |
| (εCo) | 0 | 0.25071 | 0.40695 | ... | [83Nis] |
| **Metastable phases** | | | | | |
| α″ | <50 | 0.4106 | 0.3888 | Quenched from 700 °C | [72Mat] |
| | | 0.4118 | 0.3912 | Quenched from 800 °C | [72Mat] |
| | >50 | 0.4048 | 0.3928 | Quenched from 700 °C | [72Mat] |
| | | 0.4071 | 0.3952 | Quenched from 800 °C | [72Mat] |
| α′ | ~62 | 0.3800 | ... | Quenched from 700 °C | [72Mat] |
| | ~69 | 0.3820 | ... | Quenched from 800 °C | [72Mat] |

## Crystal Structures and Lattice Parameters

Crystal structure and lattice parameter data on the stable and metastable phases in the Co-Pd system are summarized in Tables 3 and 4, respectively. The lattice parameters of the (αCo,Pd) fcc solid solution are shown in Fig. 3 [61Boz, 72Mat, 83Nis, King1]. The form of the lattice parameter vs composition curve is convex upwards.

## Thermodynamics

Low-temperature specific heats were studied in Co-rich alloys [67Tak, 69Boe], as well as over the whole range of composition [69Whe].

The enthalpy of mixing in the liquid phase at 1600 °C was determined by calorimetry; results show a small positive deviation from ideal solution behavior [77Vat]. [77Vat] also calculated the activities and compared them with the experimental values by Sryvalin quoted in [77Vat]. A model calculation of the surface energy of the Co-Pd melt was presented by [70Bog]. The activities in the fcc solid solution were determined from solid electrolyte emf measurements by [65Sch] and [70Bid]. These data show that the activity of Co in Pd exhibits a positive departure from ideal solution behavior in Co-rich alloys and a negative departure in Pd-rich alloys, whereas the activities of Pd indicate a negative departure from ideality at all compositions. These complexities were discussed in connection with the magnetic contribution by [70Bid].

## Magnetism

The magnetic properties of the Co-Pd system were studied extensively [35Gru, 36Gru, 61Boz, 67Bag, 67Tak, 68Bag, 69Boe, 69Whe] and are summarized in Table 5. Ferromagnetism exists in solution up to 99.9 at.% Pd, where the Curie temperature is –266 °C [61Boz].

**Table 5 Magnetic Properties of the Co-Pd System**

| Reference | Method | Composition, at.% Pd | Curie temperature, °C | Magnetic moment, μB | Saturation magnetization, G |
|---|---|---|---|---|---|
| [35Gru] | Magnetic | 0 | 1119 | ... | ... |
| | | 5 | 1094 | ... | ... |
| | | 5 | 1097 | ... | ... |
| | | 10 | 1068 | ... | ... |
| | | 15 | 1030 | ... | ... |
| | | 20 | 990 | ... | ... |
| | | 25 | 948 | ... | ... |
| | | 30 | 900 | ... | ... |
| | | 40 | 808 | ... | ... |
| | | 50 | 686 | ... | ... |
| | | 60 | 546 | ... | ... |
| | | 66.7 | 448 | ... | ... |
| | | 70 | 400 | ... | ... |
| | | 85 | 145 | ... | ... |
| | | 90 | 43 | ... | ... |
| [36Gru] | Electrical resistivity | 40 | 830 | ... | ... |
| | | 50 | 700 | ... | ... |
| | | 60 | 557 | ... | ... |
| | | 66.7 | 458 | ... | ... |
| | | 70 | 405 | ... | ... |
| | | 75 | 325 | ... | ... |
| | | 85 | 147 | ... | ... |
| | | 90 | 48 | ... | ... |
| [61Boz] | Magnetic | 20 | ... | 1.55(a) | ... |
| | | 40 | ... | 1.30 | ... |
| | | 60 | ... | 1.05 | ... |
| | | 80 | ... | 0.74 | ... |
| | | 87 | ... | 0.60 | ... |
| | | 92 | –3 | 0.38 | ... |
| | | 95 | ... | 0.30 | ... |
| | | 99.5 | –247 | 0.10 | ... |
| | | 99.9 | –266 | 0.05 | ... |
| [67Bag] | Magnetic | 25.3 | 927 | ... | 1130 |
| | | 52.7 | 647 | ... | 850 |
| | | 77.0 | 287 | ... | 510 |
| | | 91.1 | 22 | ... | 310 |
| | | 93.1 | –23 | ... | 280 |
| | | 96.5 | –103 | ... | 190 |
| | | 98.2 | –153 | ... | 130 |
| | | 99.5 | –248 | ... | 20 |
| [68Bag] | ... | 98.5 | –188 | ... | 69 |

(a) Data read from the figure.

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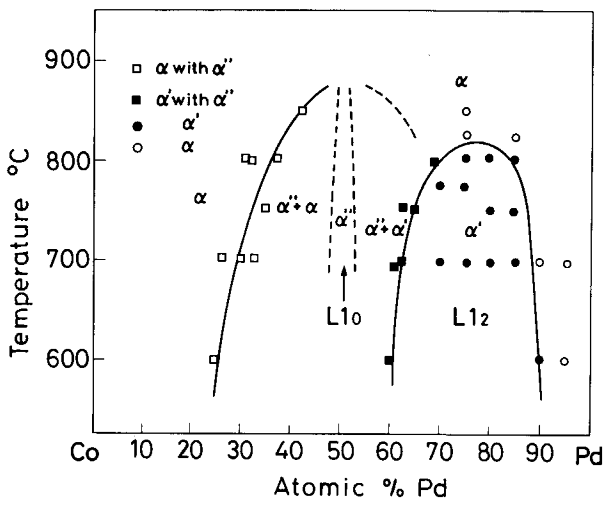


**Fig. 2** Metastable phase diagram for Co-Pd films from [72Mat].

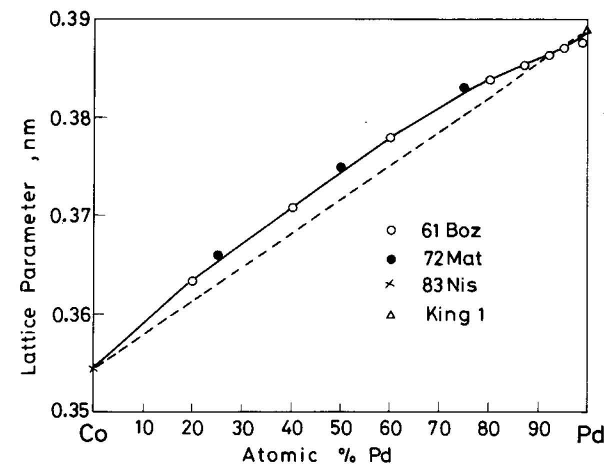


**Fig. 3** Lattice parameters of (αCo,Pd) solid solution.


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*Indicates key paper.

#Indicates presence of a phase diagram.


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