Silver – Gold – Palladium

Alan Prince†, updated by Joachim Gröbner, Manga V. Rao, Viktor Kuznetsov

Literature Data

The ternary system Ag-Au-Pd was investigated because of its importance for dental alloys with corrosion resistivity comparable to more expensive alloys with higher Au content. Alloys of these elements are also used in jewelry. Ag, Au and Pd are completely soluble in each other in both the molten and solid states (>900°C). The Ag-Au-Pd ternary system shows only two-phase equilibrium, L+(Pd,Au,Ag), but the effect of Ag additions to the ordered compounds Au3Pd and AuPd3 has not been studied. The presence of a continuous series of solid solutions in the ternary system was established from the X-ray work of [1946Kuz] and thermal analysis by [1946Nem] and [1977Mia].

Binary Systems

The binary systems were accepted from [Mas2].

Solid Phases

Table 1 summarizes the solid phases present. (Pd,Au,Ag) is the ternary solid solution phase that is formed on solidification throughout the ternary system.

Liquidus Surface

The liquidus has been studied by [1946Nem, 1977Mia]. [1978Ven] present a liquidus of [1967Pau] but the reference in [1978Ven] is to a 1967 doctoral thesis and it is not the thesis of [1967Pau] quoted in this assessment. [1946Nem] thermally analyzed 47 ternary alloys prepared from > 99.99% pure elements; they also measured hardness, strength, ductility, electrical resistance, temperature coefficient of electrical resistance and thermoelectric force of alloys against Pt. [1977Mia] used DTA to measure the liquidus and solidus temperatures of a total of 14 ternary alloys on the sections Ag - 50Au, 50Pd; Au - 50Ag, 50Pd and Pd - 50Ag, 50Au. Quoted temperatures were the mean of 4 heating + cooling cycles at rates of 5°C·h⁻¹.

The liquidus isotherms presented by [1978Ven] from the work of Pauley are seriously in error in terms of the compositions at which the isotherms intersect the binary Au-Pd edge. For instance, the 1450°C isotherms should [Mas2] meet the Au-Pd binary at 52.4 at.% Au and not 61.3 Au from the diagram in [1978Ven]. As a result of these discrepancies the isotherms presented by [1978Ven], based on the data of Pauley, have been amended so that they agree with assessed binary data. Fig. 3, Fig. 4 and Fig. 5 are sections Ag - 50Ag, 50Pd, Au - 50Ag, 50Pd and Pd - 50Ag, 50Au respectively. A liquidus projection developed from the three binary systems and Figs. 3, 4, 5, is given in Fig. 1. Figure 2 is an equivalent solidus projection.

There is uncertainty in the solidus isotherms of ±1 at.% Pd; at the Au rich corner this uncertainty widens to ±2 at.% Pd.

Notes on Materials Properties and Applications

Miscellaneous

[1971Nag1] used 99.99% Ag and 99.97 Au, Pd powders to form compacts that were induction melted under H. The ingots were worked and annealed at 900°C for 7 days. Filings were annealed 2-3 h at 600°C in argon-flushed capsules and furnace cooled. X-ray diffraction data were obtained for three ternary alloys and the end members on the section Pd - 50 at.% Ag, 50 at.% Au. [1978Ven] used the same preparative technique and studied the same ternary alloys as [1971Nag1]. An alloy containing 33.33 at.% Ag, 33.33 at.% Au, 33.33 at.% Pd was studied by [1979Ven]. The agreement between [1971Nag1] and [1979Ven] is very good and both sets of data indicate a small negative departure from Vegard's law on this ternary section. The temperature dependence of the lattice parameters for these ternary alloys is a linear function of temperature up to the limit of measurement, Table 2 [1986Ven]. [1946Kuz] measured the lattice spacings of 38 ternary alloys that were cold worked from wires of 0.5 mm diameter to 0.2 mm diameter, annealed for 30 min at 800°C and quenched, Fig. 6. The experimental data of [1946Kuz] are in reasonably good agreement with those of [1971Nag1] and [1986Ven] for alloys containing > 40 at.% Pd. At lower Pd contents [1946Kuz] reports lower values of lattice spacing. The data of [1946Kuz] have been amended to conform with that of [1971Nag1] and [1986Ven] on the Pd - 50Ag, 50Au section and with the Au-Pd binary data [1964Mae]. Support for this amendment is provided by [1967Pau] who determined the lattice parameters of six ternary alloys on the section Ag - 35 at.% Au, 65 at.% Pd; agreement between the data is satisfactory. Although ordering occurs in the Au-Pd system in the range of the stoichiometric compositions Au3Pd and AuPd3, [1946Kuz] found no evidence of superlattice formation in ternary alloys slowly cooled form 800°C. [1986Hoe] measured the activity of Au in 5 ternary alloys with compositions 9.3 Ag, 5.3 Au; 9.1 Ag, 9.8 Au; 8.6 Ag, 14.7 Au; 8.1 Ag, 20.0 Au and 6.6 Ag, 34.4 Au over the temperature range 800°C-1025°C. [1978Ven2] presents isoparametric curves calculated from the results of [1946Kuz].

References


### Table 1: Crystallographic Data of Solid Phases

<table>
<thead>
<tr>
<th>Phase/ Temperature Range °C</th>
<th>Pearson Symbol/ Space Group/ Prototype</th>
<th>Lattice Parameters [pm]</th>
<th>Comments/References</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Pd,Ag,Au) &lt; 1555</td>
<td>cF4/ Fm3m</td>
<td>a = 389.03</td>
<td>composition dependence [1981Kin], see Fig. 6</td>
</tr>
<tr>
<td>(Pd) &lt; 961.93</td>
<td>Cu</td>
<td>a = 408.57</td>
<td>at 25°C [Mas2]</td>
</tr>
<tr>
<td>(Ag) &lt; 1064.43</td>
<td></td>
<td>a = 407.82</td>
<td>at 25°C [Mas2]</td>
</tr>
<tr>
<td>Au$_3$Pd ≤ 850</td>
<td>cP4/ Pm3m</td>
<td></td>
<td>[Mas2]</td>
</tr>
<tr>
<td>AuPd$_3$ ≤ 870</td>
<td>cP4 (?)/ Pm3m (?)/ AuCu$_3$ (?))</td>
<td></td>
<td>[Mas2]</td>
</tr>
</tbody>
</table>

### Table 2: Analytical Representation of Temperature Dependence of the Lattice Spacing for Alloys on the Pd - 50 at.% Ag, 50 at.% Au Section [1986Ven]

<table>
<thead>
<tr>
<th>Alloy Composition (at.%)</th>
<th>Analytical Expression</th>
<th>Temperature Range °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag 12.5 12.5 75.0</td>
<td>$a = 393.166 + (549.814) \cdot 10^{-5} \cdot T$</td>
<td>30-899</td>
</tr>
<tr>
<td>Ag 25.0 25.0 50.0</td>
<td>$a = 397.601 + (624.546) \cdot 10^{-5} \cdot T$</td>
<td>30-899</td>
</tr>
<tr>
<td>Ag 33.33 33.33 33.33</td>
<td>$a = 400.671 + (663.481) \cdot 10^{-5} \cdot T$</td>
<td>30-710</td>
</tr>
<tr>
<td>Ag 37.5 37.5 25.0</td>
<td>$a = 402.537 + (696.193) \cdot 10^{-5} \cdot T$</td>
<td>30-899</td>
</tr>
<tr>
<td>Ag 50.0 50.0 0</td>
<td>$a = 407.528 + (646.713) \cdot 10^{-5} \cdot T + (131.936) \cdot 10^{-8} \cdot T^2$</td>
<td>30-900</td>
</tr>
</tbody>
</table>
Fig. 1: Ag-Au-Pd
Liquidus surface projection

Fig. 2: Ag-Au-Pd
Solidus surface projection
Fig. 3: Ag-Au-Pd.
Vertical section
Ag - Pd$_{50}$Au$_{50}$

Fig. 4: Ag-Au-Pd.
Vertical section
Au - Pd$_{50}$Ag$_{50}$
**Fig. 5:** Ag-Au-Pd.
Vertical section
Pd - Ag$_{50}$Au$_{50}$

**Fig. 6:** Ag-Au-Pd.
Lattice parameters of (Pd,Ag,Au) solid solutions, in pm