

Molybdenum – Silicon – Uranium

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Introduction

Interest in low enriched uranium (LEU) proliferation resistant reactor fuel systems triggered investigations on phase equilibria and compatibility of U_3Si and U_3Si_2 with Mo-metal. Irradiation tests on U-4Mo-0.1Si (mass%) alloys discovered high swelling resistance in solution-quenched structures with effective control of fission-gas nucleation and bubble growth [1968Far].

Early reports on the ternary system mentioned the existence and crystal structure of two ternary compounds: a Laves-phase $\text{UMo}_{1.25}\text{Si}_{0.75}$ with the MgZn_2 type [1963Sik] and $\text{U}_2\text{Mo}_3\text{Si}_4$ with a unique structure type [1978Sik]. The crystal structures of both compounds were confirmed from X-ray single crystal counter data [1993LeB, 1995LeB, 1996LeB1]. To supplement the fission product chemistry in U_3Si_2 -fuel burn-up, partial phase equilibria in the U rich part of the diagram at 850°C were studied by [1994Uga] reporting the existence of three ternary compounds: $\text{U}_2\text{Mo}_3\text{Si}_4$, “ U_3MoSi_2 ”, “ U_4MoSi_3 ”, without defining the crystal structures of “ U_3MoSi_2 ” and “ U_4MoSi_3 ”. Based on a phase diagram investigation at 1400°C [1993LeB], phase relations were reinvestigated by [2001Rog] providing (i) a partial isothermal section at 1400°C for concentrations smaller than 70 at.% U, (ii) a partial isothermal section at 850°C for concentrations smaller than 70 at.% Si; and (iii) an evaluation of crystal structures from X-ray data. Physical properties (*i.e.* magnetic susceptibility and electrical resistivity) of the ternary compounds were reported from several sources [1988Ali, 1993LeB, 1994Was, 1995LeB, 1996LeB1, 1996Pat, 2001Rog]. The various experimental activities related to the constitution of the ternary Mo-Si-U system are summarized in Table 1.

Binary Systems

The binary boundary systems, Mo-U and Mo-Si, have been accepted from [Mas2]. The system U-Si is taken from reinvestigations by [1992Rem, 1993LeB, 1998Noe], but the U rich part of the diagram up to 4 at.% Si is from [1965Str]. A listing of the crystallographic and melting data pertinent to the Mo-Si-U system is given in Table 2.

Solid Phases

Three ternary compounds have been characterized by means of X-ray diffraction techniques: (i) stoichiometric $\text{U}_2\text{Mo}_3\text{Si}_4$ ($\text{Y}_2\text{Mo}_3\text{Si}_4$ type [1978Sik, 1993LeB, 1995LeB]), (ii) a ternary MgZn_2 type Laves phase $\text{U}(\text{Mo}_{1-x}\text{Si}_x)_2$ [1963Sik, 1993LeB, 1996LeB1] with a homogeneous region extending at 1400°C from $\text{UMo}_{1.25}\text{Si}_{0.75}$ to $\text{UMo}_{1.5}\text{Si}_{0.5}$ [1993LeB, 2001Rog], but with a rather small field of existence at 850°C ranging from $\text{UMo}_{1.32}\text{Si}_{0.68}$ to $\text{UMo}_{1.4}\text{Si}_{0.6}$ [2001Rog] and (iii) a novel ternary compound $\text{U}(\text{Mo}_y\text{Si}_{1-y})_2$ extending at 850°C from $y = 0.25$ to $y = 0.33$. For the latter compound a proper structural chemical formula, $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ ($0 < x < 0.33$), was derived from X-ray powder and single crystal data proving isotypism with the W_5Si_3 type and with statistical Mo/Si substitution only on the $4a$ sites [2001Rog]. Furthermore, it became obvious, that the phases labeled “ U_3MoSi_2 ”, “ U_4MoSi_3 ”, by [1994Uga], are both part of the same homogeneity region $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ ($0 < x < 0.33$) [2001Rog]. Accordingly, the X-ray powder pattern, reported by [1998Uga] for U_3MoSi_2 (and tentatively indexed by [1998Uga] as cubic with $a = 1069$ pm), was successfully re-indexed on the basis of the tetragonal W_5Si_3 type unit cell ($a = 1071.0$, $c = 533.6$ pm) [2001Rog]. The X-ray pattern of single phase U_3MoSi_2 after various heat treatments (1100°C for 5 days, 650°C for 5 days and 500°C for 22 days) was said to be unchanged, suggesting the absence of phase transitions in this temperature interval [2001Uga].

Unsuccessful attempts to prepare single-phase composition U_4MoSi_3 even after 8 days of annealing at 850°C were said to stem from the sluggishness of the reaction kinetics at this low temperature [1998Uga]. Although the ternary Laves phase, $\text{U}(\text{Mo}_{1-x}\text{Si}_x)_2$ ($0.25 < x < 0.375$), comprises the composition $\text{UMo}_{1.25}\text{Si}_{0.75}$ for which full atom order is expected, single crystal X-ray data refinement for $\text{UMo}_{1.25}\text{Si}_{0.75}$

showed a random distribution of Mo/Si atoms on both the 2a and 6h sites, but with slight preference of Mo atoms for the 6h site (1Mo + 1Si in 2a, 4Mo + 2 Si in 6h; $R = 0.018$) [1996LeB1]. The X-ray powder pattern of $\text{UMo}_{1.25}\text{Si}_{0.75}$ annealed at 1000°C and slowly cooled were said to be unchanged with respect to that from an alloy quenched from the melting point (ca. 2000°C) [1963Sik]. Furthermore, a DTA experiment from RT to 1000°C confirmed the absence of any signs for atom ordering or phase transition [1963Sik] in good agreement with Rietveld refinements of an X-ray powder spectrum of $\text{UMo}_{1.25}\text{Si}_{0.75}$ annealed at 850°C [2001Rog]. Lattice parameter data given for $\text{UMo}_{1.25}\text{Si}_{0.75}$ ($a = 537.0$, $c = 858.2$ pm) [1963Sik], however, seem to match rather the Mo rich part of the phase field [2001Rog] (see also Table 2). Whereas $\text{U}(\text{Mo}_{1-x}\text{Si}_x)_2$ ($0.25 < x < 0.375$) and $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ ($0 < x < 0.33$) exhibit solution ranges with Mo/Si substitution, the compound $\text{U}_2\text{Mo}_3\text{Si}_4$ only exists at its stoichiometric composition with full atom order [1978Sik, 1993LeB, 1994Was, 1995LeB].

Minor variations of unit cell dimensions of the boundary phases in ternary multiphase alloys annealed at 850°C or at 1400°C indicate negligible mutual solid solubility among binary uranium and binary molybdenum silicides (see also Fig. 1). This is particularly true for U_3Si_2 , which showed insignificant solubility for molybdenum (0.1 mass% Mo = 0.16 at.% Mo [1994Uga, 1998Uga], ≤ 0.5 at.% Mo [2001Rog]. Even in arc melted alloys the solubility of Mo in U_3Si_2 was measured (EMPA) to be less than ~ 1.6 at.% Mo [2001Rog]. Most of the binary boundary phases engage in two-phase equilibria with $\text{U}_2\text{Mo}_3\text{Si}_4$ inferring a relatively high thermodynamic stability of the ternary compound.

Invariant Equilibria

A peritectic formation of U_3MoSi_2 was proposed by [1994Uga, 1998Uga] via the invariant reaction $\text{U}_4\text{MoSi}_3 + \text{U}_2\text{Mo}_3\text{Si}_4 + \text{L} \rightleftharpoons \text{U}_3\text{MoSi}_2$ at $1480 \pm 30^\circ\text{C}$; the corresponding composition of the peritectic liquid was given as 74U16Mo10Si (in at.%). However, with the conclusion that the phases labeled “ U_3MoSi_2 ”, “ U_4MoSi_3 ”, by [1994Uga, 1998Uga], are both part of the same homogeneity region $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ ($0 < x < 0.33$) [2001Rog], the peritectic reaction given by [1998Uga] needs to be corrected. Playing on the facts, that the microstructures of both as-cast alloys, U_4MoSi_3 and U_3MoSi_2 , contain primary precipitates of U_3Si_2 [2001Rog], the peritectic formation of the phase $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ was reformulated as $\text{L} + \text{U}_3\text{Si}_2 + \text{U}_2\text{Mo}_3\text{Si}_4 \rightleftharpoons \text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$, x being close to $x = 0.33$ [2001Rog]. $\text{U}_2\text{Mo}_3\text{Si}_4$ was described as congruently melting compound [1993LeB, 1995LeB, 1998Uga].

Liquidus, Solidus and Solvus Surfaces

No information is available on liquidus, solidus or solvus surfaces. Silicon-poor alloys with less than 20 at.% Si at 1400°C appeared partially molten [2001Rog]. Eutectic islands in the as-cast microstructure of U_4MoSi_3 , evaluated by EMPA area scans, were reported at a composition 74U10Mo14Si [2001Rog], rather close to the peritectic liquid claimed by [1998Uga].

Isothermal Sections

Phase equilibria have been established in an isothermal section at 1400°C for the region with less than 70 at.% U and at 850°C for the region with less than 70 at.% Si [2001Rog]. The isothermal sections are presented in Figs. 1 and 2.

At 1400°C two ternary compounds were encountered: stoichiometric $\text{U}_2\text{Mo}_3\text{Si}_4$ and the Laves phase extending in a homogeneity region $\text{U}(\text{Mo}_{1-x}\text{Si}_x)_2$ from $x = 0.25$ to $x = 0.375$. Si poor alloys (< 20 at.% Si) were found to be molten. Mutual solid solubilities between binary uranium and molybdenum silicides from EMPA were said to be negligible, and solubility of Mo in U_3Si_2 was less than 0.5 at.% Mo [2001Rog].

Phase equilibria at 850°C are characterized by three ternary compounds: $\text{U}_2\text{Mo}_3\text{Si}_4$, the ternary Laves phase $\text{U}(\text{Mo}_{1-x}\text{Si}_x)_2$ with a reduced homogeneity region from $x = 0.30$ to $x = 0.33$, and the ternary phase $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ with a homogeneity region from $x = 0$ to $x = 0.33$. The detailed investigation [2001Rog] showed that the phases “ U_3MoSi_2 ”, “ U_4MoSi_3 ” - reported by [1994Uga, 1998Uga] as individual compounds - were in fact part of one single-phase region $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$. The microstructure data of a set of alloys (annealed at 850°C) listed by [1998Uga], i.e. 25U25Mo50Si, 50U10Mo40Si, $\text{U}_3\text{Si}_2 + 0.5$

(2.0, 3.0, respectively) mass% Mo and $\text{U}_3\text{Si} + 5$ mass% Mo, were all compatible with the phase triangulation in the isothermal section at 850°C as given by [2001Rog]. Due to the formation of ternary phases, U_3MoSi_2 and $\text{U}(\text{Mo}_{0.67}\text{Si}_{0.33})_2$, within the join U_3Si_2 - Mo no equilibrium exists between Mo and U_3Si_2 [1998Uga, 2001Rog]. Similarly, the observed two-phase equilibria, $\text{U}_2\text{Mo}_3\text{Si}_4 + (\gamma\text{U},\text{Mo},\text{Si})$, $\text{U}(\text{Mo}_{0.67}\text{Si}_{0.33})_2 + \gamma(\text{U},\text{Mo},\text{Si})$, $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2 + (\gamma\text{U},\text{Mo},\text{Si})$, excluded thermodynamic compatibility between Mo and U_3Si [2001Rog]. Below about 925°C U_3Si ties with the Si poor end of $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ [1994Uga, 2001Rog]. It should be mentioned, that $(\gamma\text{U},\text{Mo},\text{Si})$ in quenched alloys was easily retained at room temperature, although binary $(\gamma\text{U},\text{Mo})$ is metastable below about 550°C [2001Rog]. The vertex of the three-phase equilibrium $(\text{U}) + \text{U}_3\text{Si} + \text{U}_3\text{MoSi}_2$ at the U-metal at 850°C was given by [1998Uga] as 0.4 mass% Mo and 0.1 mass% Si (98.2U1.0Mo0.8Si in at.%).

Miscellaneous

[1964Kam] studied various analytical methods for chemical analysis of U, Mo, Si in nuclear materials. Metallographic studies and hot-hardness measured on an alloy U-350 ppm Fe - 350 ppm Si - 800 ppm Al - 1000 ppm Mo, aged 100 h at 600°C , revealed the formation of $\text{UMo}_{1.25}\text{Si}_{0.75}$ (no further details given) [1965Far]; the addition of Mo to the base alloy U-350 ppm Fe - 350 ppm Si - 800 ppm Al was said to cause an insignificant hardness change. It was observed that $\text{UMo}_{1.25}\text{Si}_{0.75}$ is relatively insoluble in (γU) at 800°C [1965Far]. From various irradiation tests on U - 4mass% Mo - 0.1mass% Si alloys, metal fuels with high swelling resistance were envisaged: the solution-quenched structures (24 h 1100°C or 1050°C , respectively and water quenched) resulted in effective control of fission-gas nucleation and bubble growth [1968Far]. The effect of 0.1 to 0.5 mass% Mo-additives on the corrosion resistance of U_3Si against water at 300°C under 90 MPa was investigated by [1993Kon]. The speed of corrosion was measured for various length of time from 100 to 1000 h. After 300 h the speed of corrosion for instance for the alloys with 0.4 mass% Mo was given as $0.3 \text{ mg}/(\text{cm}^2\text{h})$. Molybdenum seems to decrease the rate of corrosion with amount (from 0.1 to 0.4 mass% Mo) and with time.

Physical properties (*i.e.* magnetic susceptibility and electrical resistivity) of the ternary compounds were reported from several sources [1988Ali, 1993LeB, 1994Was, 1995LeB, 1996LeB1, 1996Pat, 2001Rog], which all agree on a weakly almost temperature independent paramagnetism of all the three ternary compounds. $\text{U}_2\text{Mo}_3\text{Si}_4$ is temperature independent paramagnetic below 30 K but weakly paramagnetic above 50 K with $\mu_{\text{eff}} = 2.30 \text{ } \mu\text{B}/\text{U}$, $\Theta_{\text{p}} = -240 \text{ K}$ and $\chi_0 = 1.4 \cdot 10^{-3} \text{ emu}\cdot\text{mol}^{-1}$ [1993LeB]. These data supersede earlier measurements of [1988Ali] claiming weak paramagnetism in the range $100 < T < 250 \text{ K}$ with $\mu_{\text{eff}} = 0.42 \text{ } \mu\text{B}/\text{U}$. The small abrupt increase in magnetic susceptibility at 40 K (however, no transition to magnetic ordering seen in resistivity data) was attributed to an impurity phase [1988Ali]. Alternatively, the authors of [1996Pat] attributed the “anomalous” susceptibility behavior to crystal field influences. All authors [1988Ali, 1993LeB, 1994Was, 1996Pat] agree on the fact, that no intrinsic magnetic order arises in $\text{U}_2\text{Mo}_3\text{Si}_4$ above 1.5 K. $\text{UMo}_{1.25}\text{Si}_{0.75}$ is temperature independent paramagnetic for the temperature range from 5 to 300 K with $\chi_0 = 4.3 \cdot 10^{-3} \text{ emu}\cdot\text{mol}^{-1}$ [1993LeB]. $\text{U}_4\text{Mo}(\text{Mo}_{0.33}\text{Si}_{0.67})\text{Si}_2$ is temperature independent paramagnetic with $\chi_0 = 2.7 \cdot 10^{-3} \text{ emu}\cdot\text{mol}^{-1}$ exhibiting a slight increase of susceptibility below 180 K [2001Rog].

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Table 1: Experimental Investigations of the Mo-Si-U Phase Relations, Structures and Thermodynamics

Reference	Method/Experimental Technique	Temperature/Composition/Phase Range Studied
[1963Sik]	Electron beam melting of cold-compacted elemental powder mixtures yielded single phase $UMo_{1.25}Si_{0.75}$. Heat treatment at 1000°C with slow cooling to 300°C for 170 h DTA from RT to 1000°C.	X-ray powder refinement for $U(Mo,Si)_2$ at 33U42Mo25Si (in at.%); $MgZn_2$ type
[1964Kam]	Determination of U, Mo, Si in various U-Mo-silicides by chemical analyses.	For analysis, the silicide was decomposed by (i) with sodium peroxide, (ii) dissolved in a mixture of $HF+H_2SO_3$; (iii) dissolved in a mixture of $HF+HNO_3$.
[1965Far]	Alloy U-350 ppm Fe - 350 ppm Si - 800 ppm Al - 1000 ppm Mo, aged 100 h at 600°C.	Metallography and measurement of hot-hardness.
[1968Far]	Alloys U- 4mass% Mo - 0.1 mass%, were heat treated for 24 h at 1100°C, water-quenched, annealed for 240 h at 670°C, air cooled prior to irradiation (at 550°C and 645°C, respectively) up to 0.8 at.% and 1.4 at.% burnup, respectively. Selected specimens were irradiated at 400 to 510°C to 0.5 at.% burnup. Metallography and measurement of volume increase.	Investigation of swelling after various irradiation treatments. Control of fission gas bubble nucleation.
[1978Sik]	Arc melted alloy $U_2Mo_3Si_4$	Determination of the crystal structure of $U_2Mo_3Si_4$ from X-ray single crystal data
[1988Ali]	No details given on alloy preparation. Measurement range for ρ and χ : $4.2 < T < 300$ K	Electrical resistivity and magnetic susceptibility of $U_2Mo_3Si_4$

Reference	Method/Experimental Technique	Temperature/Composition/Phase Range Studied
[1993LeB]	Arc melting of elemental ingots; heat treatment at 1400°C. A single crystal of $U_2Mo_3Si_4$ was obtained from an alloy annealed for long time at 1450°C in an argon-sealed Mo-crucible. Prolonged annealing of an as cast alloy yielded a single crystal of $UMo_{1.25}Si_{0.75}$. X-ray single crystal counter data for structure determination. Measurement range for ρ and χ : $2 < T < 300$ K; magnetization at 5 K up to 6 Tesla.	Partial phase equilibria at 1400°C for compositions < 60 at.% U. Determination of the crystal structures of $U_2Mo_3Si_4$ ($R_F = 0.07$) and $UMo_{1.25}Si_{0.75}$ ($R_F = 0.018$) Magnetic susceptibility $2 < T < 300$ K; magnetization < 2.5 Tesla at 5 K for $U_2Mo_3Si_4$ and $UMo_{1.25}Si_{0.75}$.
[1993Kon]	Arc-melted alloys U_3Si annealed at 800°C for 100 h. Starting materials 99.8 mass% U, chemical analysis, XPD, metallography.	Investigation of the effect of 0.1 to 0.5% Mo-additives on the corrosion resistance of U_3Si in water at 300°C under 90 MPa (in an autoclave) from 100 to 1000 h.
[1994Uga]	Argon-arc melting of elemental ingots; heat treatment for 3 to 10 days in muffle furnaces at 800° to 1100°C; water quench. Starting materials 99.8 mass% U, 99.95%Mo,Si. Metallography, EMPA, X-ray powder diffraction.	Partial phase equilibria at 850°C. 0.1 mass% Mo solubility limit of Mo in U_3Si_2 . Identification of ternary compounds $U_2Mo_3Si_4$, U_3MoSi_2 and U_4MoSi_3 . Proposition of a ternary peritectic invariant reaction at some temperature $T > 1100^\circ C$: $U_4MoSi_3 + U_2Mo_3Si_4 + L \rightleftharpoons U_3MoSi_2$. Peritectic liquid at 74U16Mo10Si (in at.%). No tie-line between U_3Si and Mo.
[1994Was]	Argon-arc melted alloy $U_2Mo_3Si_4$. Metallography and X-ray PD.	Magnetic susceptibility of $U_2Mo_3Si_4$ for $1.5 < T < 300$ K indicates paramagnetism.
[1995LeB]	A single crystal of $U_2Mo_3Si_4$ was obtained from an arc-melted alloy annealed for long time at 1450°C in an argon-sealed Mo-crucible.	Determination of the crystal structure of $U_2Mo_3Si_4$ from X-ray single crystal data. Temperature independent paramagnetism in the range $2 < T < 300$ K
[1996LeB1]	A single crystal of $UMo_{1.25}Si_{0.75}$ was obtained from an arc-melted alloy after prolonged annealing.	Determination of the crystal structure of $UMo_{1.25}Si_{0.75}$ from X-ray single crystal data. Temperature independent paramagnetism in the range $10 < T < 300$ K. Small increase of the magnetic susceptibility below 10 K due to impurities.
[1996Pat]	No details given on alloy preparation	Study of the magnetic behavior of $U_2Mo_3Si_4$ $2 < T < 300$ K.

Reference	Method/Experimental Technique	Temperature/Composition/Phase Range Studied
[1998Uga]	Alloys prepared by arc melting under argon. Heat treatment in sealed quartz capsules at 500 to 1100°C for 4 to 22 days, followed by water quenching. Starting materials: 99.8 mass% U, 99.95% Mo 99.99% Si. Metallography, EMPA, X-ray powder diffraction.	Determination of melting point of U_3MoSi_2 at $1480 \pm 30^\circ C$ in a W-mesh heater (Seeger-cone technique); ternary peritectic invariant reaction $U_4MoSi_3 + U_2Mo_3Si_4 + L \rightleftharpoons U_3MoSi_2$. Peritectic liquid at 74U16Mo10Si (in at.%). Density measurements by immersion in metaxylene. Electric resistivity of U_3MoSi_2 measured by four-point technique $1.8 < T < 300$ K. Magnetic susceptibility measurements for U_3MoSi_2 in 0.1 Tesla. Partial phase diagram at $850^\circ C$. Confirmation of ternary compounds U_3MoSi_2 , U_4MoSi_3 and $U_2Mo_3Si_4$. Tentative unit cell ($a = 1069$ pm) for U_3MoSi_2 . Congruent melting of $U_2Mo_3Si_4$.
[2001Rog]	Alloys prepared by arc melting or levitation melting under argon. Heat treatment at $1400^\circ C$ on tungsten substrates in a high vacuum W-sheet furnace for 200 h. For equilibria at $850^\circ C$, samples within alumina crucibles were vacuum-sealed in quartz capsules and heat treated for 250 h and water quenched. Starting materials: 99.9 mass% U, 99.9% Mo, 99.9999% Si. Metallography, EMPA, X-ray powder diffraction. A single crystal of $U_4Mo(Mo_{0.33}Si_{0.67})Si_2$ was obtained from an arc melted alloy U_3MoSi_2 after treatment in an alumina crucible at $1150^\circ C$ under argon for 6 h and slow cooling. Measurement range for χ : $2 < T < 300$ K; magnetization at 5 K up to 6 Tesla.	Partial phase equilibria at $1400^\circ C$ for compositions < 60 at.% U. Partial phase equilibria at $850^\circ C < 70$ at.% Si. Determination of the crystal structure of $U_4Mo(Mo_xSi_{1-x})Si_2$. Determination of atom order as $f(x)$ in $U(Mo_{1-x}Si_x)_2$ from Rietveld refinements. Magnetic susceptibility $2 < T < 300$ K; magnetization < 2.5 Tesla at 5 K for $U_2Mo_3Si_4$ and $UMo_{1.25}Si_{0.75}$.

Table 2: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Mo) < 2623	<i>cI2</i> <i>Im$\bar{3}m$</i> W	<i>a</i> = 314.70	[Mas2]
(Si) < 1414	<i>cF8</i> <i>Fd$\bar{3}m$</i> C _{diamond}	<i>a</i> = 543.06	[Mas2]
(γU) 1135 to 774.8	<i>cI2</i> <i>Im$\bar{3}m$</i> W	<i>a</i> = 353.35	refined at 787°C [Mas2]
(βU) 774.8 to 667.7	<i>tP30</i> <i>P4₂/mnm</i> βU	<i>a</i> = 1075.89 <i>c</i> = 565.31	[Mas2]
(αU) < 667.7	<i>oC4</i> <i>Cmcm</i> αU	<i>a</i> = 285.37 <i>b</i> = 586.95 <i>c</i> = 495.48	[Mas2]
Mo ₃ Si < 2025	<i>cP8</i> <i>Pm$\bar{3}n$</i> Cr ₃ Si	<i>a</i> = 489.7	[Mas2, V-C2]
Mo ₅ Si ₃ < 2180	<i>tI38</i> <i>I4/mcm</i> W ₅ Si ₃	<i>a</i> = 964.25 <i>c</i> = 490.96	37.5 to 40 at.% Si [Mas2, V-C2]
βMoSi ₂ 2020 - 1900	<i>hP9</i> <i>P6₃22</i> CrSi ₂	<i>a</i> = 464.2 <i>c</i> = 652.9	[Mas2, V-C2]
αMoSi ₂ < 1900	<i>tI6</i> <i>I4/mmm</i> MoSi ₂	<i>a</i> = 320.6 <i>c</i> = 784.6	[Mas2, V-C2]
USi ₃ < 1510	<i>cP4</i> <i>Pm$\bar{3}m$</i> Cu ₃ Au	<i>a</i> = 403.53	[1992Rem]
USi ₂ < 450	<i>tI12</i> <i>I4₁/amd</i> ThSi ₂	<i>a</i> = 392.2 <i>c</i> = 1415.4	(metastable) [1992Rem]
α ₁ , USi _{2-x} < 1710	<i>tI12</i> <i>I4₁/amd</i> def-ThSi ₂	<i>a</i> = 394.23 <i>c</i> = 1371.2	65 at.% Si [1992Rem]
α ₂ , USi _{2-x}	<i>oI12</i> <i>Imma</i> def-GdSi ₂	<i>a</i> = 395.3 <i>b</i> = 392.9 <i>c</i> = 1365.6	at 64 at.% Si [1992Rem]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
α_3 , U_3Si_5 (o_2)	<i>oP6</i> <i>Pmmm</i> (?) distorted AlB_2	$a = 389.3$ $b = 671.7$ $c = 404.2$	at ~ 63 at.% Si [1992Rem]
α_4 , U_3Si_5 (o_1)	<i>oP6</i> <i>Pmmm</i> distorted AlB_2	$a = 86.4$ $b = 666.0$ $c = 407.3$	at 63 at.% Si [1992Rem]
α_5 , U_3Si_5 (hex) < 1770	<i>hP3</i> <i>P6/mmm</i> def- AlB_2	$a = 384.75$ $c = 407.40$	[1992Rem]
USi < 1580	<i>tI138</i> <i>I4/mmm</i> USi	$a = 1058.7$ $c = 2431.0$	[1992Rem, 1993LeB, 1996LeB2]
USi (metastable)	<i>oP8</i> <i>Pnma</i> FeB	$a = 758.5$ $b = 390.3$ $c = 566.3$	probably impurity (O) stabilized [1992Rem, 1993LeB]
U_5Si_4 < 1100	<i>hP18</i> <i>P6/mmm</i> U_5Si_4	$a = 1046.7$ $c = 391.2$	Single crystal study [2006Noe]
U_3Si_2 < 1665	<i>tP10</i> <i>P4/mbm</i> U_3Si_2	$a = 732.99$ $c = 390.04$	[V-C2, Mas2]
$\gamma\text{U}_3\text{Si}$ 930 - 759	<i>cP4</i> <i>Pm\bar{3}m</i> Cu_3Au	$a = 434.6$	[V-C2, 1965Str]
$\beta\text{U}_3\text{Si}$ 762 - -153	<i>tI16</i> <i>I4/mcm</i> $\beta\text{U}_3\text{Si}$	$a = 603.28$ $c = 869.07$	[V-C2, 1965Str]
$\alpha\text{U}_3\text{Si}$ < -153°C, at -193°C	<i>oF32</i> <i>Fmmm</i> $\alpha\text{U}_3\text{Si}$	$a = 865.4$ $b = 854.9$ $c = 852.3$	[V-C2, 1965Str]
* τ_1 , $\text{U}_2\text{Mo}_3\text{Si}_4$	<i>mP18</i> <i>P2_1/c</i> $\text{Y}_2\text{Mo}_3\text{Si}_4$	$a = 687.6$ $b = 688.3$ $c = 676.0$ $\beta = 109.79^\circ$	[1993LeB, 1995LeB] $R_F = 0.074$ $\rho_{\text{Xray}} = 8.76 \text{ Mgm}^{-3}$

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_2 , $\text{U}(\text{Mo}_{1-x}\text{Si}_x)_2$	$cP12$ $P6_3/mmc$ MgZn_2	$a = 537.30$	for $\text{UMo}_{1.25}\text{Si}_{0.75}$ [2001Rog]
		$c = 853.34$	at $x = 0.375$, 1400°C; Mo poor
		$a = 537.35$	for $\text{UMo}_{1.5}\text{Si}_{0.5}$ [2001Rog]
		$c = 859.58$	at $x = 0.250$, 1400°C; Mo rich
		$a = 536.70$	for $\text{UMo}_{1.34}\text{Si}_{0.66}$ [2001Rog]
		$c = 859.01$	at $x = 0.33$, 850°C; Mo poor
* τ_3 , $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ < 1480 [1998Uga]	$tI38$ $I4/mcm$ W_5Si_3	$a = 536.63$	for $\text{UMo}_{1.40}\text{Si}_{0.60}$ [2001Rog]
		$c = 854.17$	at $x = 0.30$, 850°C; Mo rich
		$a = 537.29$	for $\text{UMo}_{1.25}\text{Si}_{0.75}$ [1996LeB2]
		$c = 852.7$	
		$a = 537.0$	for $\text{UMo}_{1.25}\text{Si}_{0.75}$
		$c = 858.2$	$\rho_{\text{exp}} = 11.56 \text{ Mgm}^{-3}$ [1963Sik]
* τ_3 , $\text{U}_4\text{Mo}(\text{Mo}_x\text{Si}_{1-x})\text{Si}_2$ < 1480 [1998Uga]	$tI38$ $I4/mcm$ W_5Si_3	$a = 1069.42$	for U_4MoSi_3 [2001Rog]
		$c = 532.40$	at $x = 0.0$, 850°C; $R_F = 0.029$
		$a = 1071.00$	for $\text{U}_4\text{Mo}_{1.11}\text{Si}_{2.89}$ [2001Rog]
		$c = 533.65$	at $x = 0.11$, 850°C; $R_F = 0.049$
			$\rho_{\text{exp}} = 12.1 \text{ Mgm}^{-3}$ for U_3MoSi_2 [1998Uga]

Fig. 1: Mo-Si-U.
Partial isothermal
section at 1400°C

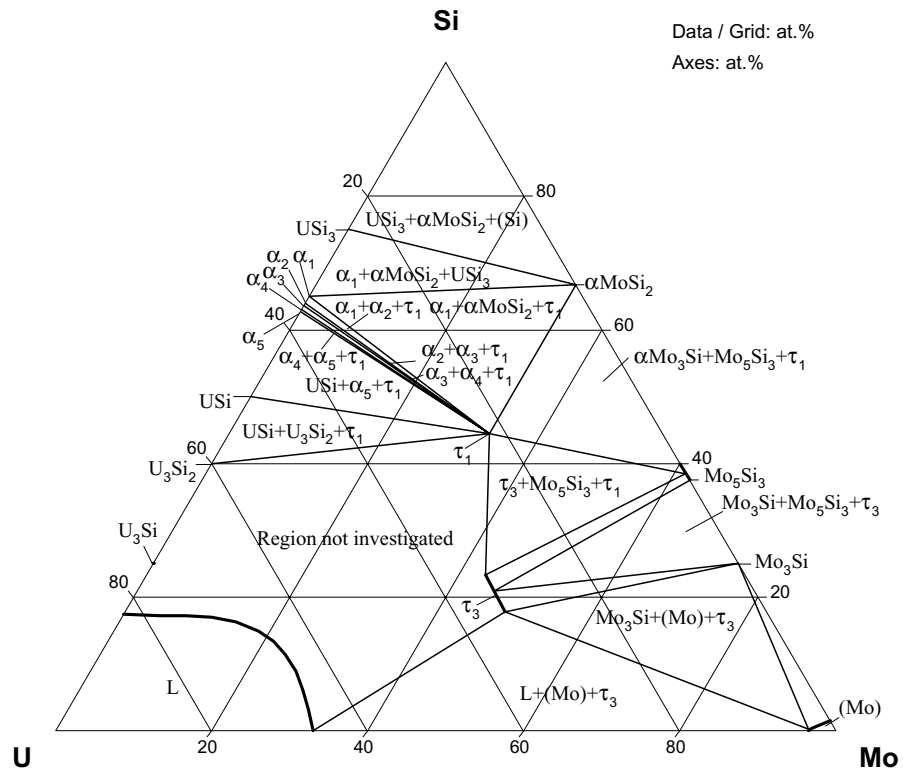


Fig. 2: Mo-Si-U.
Partial isothermal
section at 850°C

