# Crystal structures and electrical properties of the compounds DyNiSi₃, Dy₃Ni₆Si₂, and DyNiSi

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**Crystal structure determinations based on X-ray powder diffraction data were performed for three ternary silicides in the Dy–Ni–Si system. The structures of DyNiSi₃, Dy₃Ni₆Si₂, and DyNiSi belong to the structure types SmNiGe₃ (Pearson symbol *oS*20, space group *Cmmm*, *a* = 3.9225(3), *b* = 20.955(1), *c* = 3.9465(3) Å), Ce₃Ni₆Si₂ (*cI*44, *Im*-3*m*, *a* = 8.7640(5) Å), and TiNiSi (*oP*12, *Pnma*, *a* = 6.8625(6), *b* = 4.1568(5), *c* = 7.1686(6) Å), respectively. Electrical resistivity measurements confirmed metal behavior and suggested magnetic phase transitions at low temperature.**

**Dysprosium / Nickel / Silicon / X-ray diffraction / Crystal structure / Electrical properties**

## 1. Introduction

Twenty one ternary compounds have so far been reported in the Dy–Ni–Si system (Table 1). Among these, DyNi₁₀Si₂ exists in two modifications: the crystal structure of the room-temperature modification belongs to the tetragonal structure type ThMn₁₂, or its partly ordered ternary derivative Nd(Mo₀.₅Fe₀.₅)₄Fe₈, whereas the crystal structure of the high-temperature modification (1050°C) adopts the tetragonal structure type TbNi₁₀Si₂. The crystal structure of the compound DyNiSi₃ has been assigned to two closely related structure types: ScNiSi₃ and SmNiGe₃. The compound Dy₃NiSi₃ adopts the orthorhombic structure type Ba₃Al₂Ge₂ with one mixed Ni/Si site. For nine compounds, DyNi₆Si₆, rt-DyNi₁₀Si₂, Dy₂Ni₁₅.₂₋₁₄.₁Si₁.₈₋₂.₉, DyNi₄Si, DyNiSi₃, Dy₃Ni₈Si, Dy₃Ni₆Si₂, DyNiSi, and Dy₃NiSi₂, the structural investigations were limited to the determination of the cell parameters and assignment of a structure type. For four compounds only approximate compositions were reported: ~Dy₁₁Ni₆₅Si₂₆, ~Dy₁₆Ni₆₂Si₂₂, ~Dy₄₀Ni₄₇Si₁₃, and ~Dy₅Ni₂Si₃.

The aim of the present work was to perform a complete structural investigation of the ternary dysprosium nickel silicides DyNiSi₃, Dy₃Ni₆Si₂, and DyNiSi, and to measure their electrical resistivity.

## 2. Experimental

Samples of nominal compositions Dy₂₀Ni₂₀Si₆₀, Dy₂₇Ni₅₅Si₁₈, and Dy₃₃Ni₃₃Si₃₄ were synthesized from high-purity metals (Dy ≥ 99.9 wt.%, Ni ≥ 99.999 wt.%, and Si ≥ 99.999 wt.%) by arc-melting under a purified argon atmosphere, using Ti as a getter and a tungsten electrode. To achieve high efficiency of the interaction between the components, the samples were melted twice. The ingots were annealed at 800°C under vacuum in evacuated quartz ampoules for 720 h and subsequently quenched in cold water. The weight losses during the preparation of the samples were less than 1 % of the total mass, which was 2 g for each alloy.

The phase and structural analyses were performed based on X-ray powder diffraction data collected on diffractometers DRON-2.0M (Fe *K*α radiation, range 20 ≤ 2*θ* ≤ 120°, step 0.05°, for the samples Dy₂₀Ni₂₀Si₆₀ and Dy₃₃Ni₃₃Si₃₄) and STOE STADI P (Cu *K*α₁ radiation, range 6 ≤ 2*θ* ≤ 120°, step 0.015°, for the sample Dy₂₇Ni₅₅Si₁₈). The structures were refined by the Rietveld method, using the program DBWS-9807 [15] and the package FullProf Suite [16]. Structure drawings were made with the program ATOMS [17]. The electrical resistivity was measured by the standard two-point technique in the temperature range 5-290 K.

**Table 1** Crystallographic parameters of compounds reported in the Dy–Ni–Si system [1,2].

| Compound | Structure type | Pearson symbol | Space group | *a*, Å | *b*, Å | *c*, Å | Reference |
|---|---|---|---|---|---|---|---|
| DyNi$_7$Si$_6$ | SrNi$_{6.3}$Si$_{6.7}$ | *tP*56 | *P4/nbm* | 7.8232 | – | 11.1580 | [2] |
| DyNi$_6$Si$_6$ | YNi$_6$Si$_6$ | *tP*52 | *P-4b2* | 7.7335 | – | 11.1319 | [2] |
| | TbNi$_{10}$Si$_2$ | *tP*26 | *P4/nmm* | 8.1832 | – | 4.6595 | [3] |
| DyNi$_{10}$Si$_2$ | ThMn$_{12}$ | *tI*26 | *I4/mmm* | 8.236 | – | 4.641 | [4] |
| | Nd(Mo$_{0.5}$Fe$_{0.5}$)$_4$Fe$_8$ | *tI*26 | *I4/mmm* | 8.204 | – | 4.641 | [5] |
| Dy$_2$Ni$_{15.2-14.1}$Si$_{1.8-2.9}$ | Th$_2$Zn$_{17}$ | *hR*57 | *R-3m* | 8.2792-8.230 | – | 12.0456-12.107 | [2] |
| DyNi$_5$Si$_3$ | YNi$_5$Si$_3$ | *oP*36 | *Pnma* | 18.67 | 3.790 | 6.634 | [6] |
| DyNi$_4$Si | YNi$_4$Si | *oS*12 | *Cmmm* | 5.0479 | 8.2005 | 3.9499 | [2] |
| DyNiSi$_3$ | ScNiSi$_3$ | *oS*20 | *Cm2m* | 3.906 | 21.121 | 3.973 | [7] |
| | SmNiGe$_3$ | *oS*20 | *Cmmm* | 3.9174 | 20.935 | 3.9406 | [2] |
| Dy$_2$Ni$_3$Si$_5$ | U$_2$Co$_3$Si$_5$ | *oI*40 | *Ibam* | 9.527 | 11.058 | 5.615 | [8] |
| DyNi$_2$Si$_2$ | CeAl$_2$Ga$_2$ | *tI*10 | *I4/mmm* | 3.95 | – | 9.56 | [9] |
| DyNiSi$_2$ | CeNiSi$_2$ | *oS*16 | *Cmcm* | 3.9507 | 16.359 | 3.9299 | [10] |
| DyNi$_2$Si | YPd$_2$Si | *oP*16 | *Pnma* | 7.0502 | 6.3728 | 5.4122 | [2] |
| Dy$_3$Ni$_8$Si | Ce$_3$Co$_8$Si | *hP*24 | *P6$_3$/mmc* | 4.9723 | – | 16.267 | [2] |
| Dy$_3$Ni$_6$Si$_2$ | Ce$_3$Ni$_6$Si$_2$ | *cI*44 | *Im-3m* | 8.763 | – | – | [11] |
| DyNi$_{0.5-0.8}$Si$_{1.5-1.2}$ | AlB$_2$ | *hP*3 | *P6/mmm* | 3.9603-3.9876 | – | 4.0268-3.9627 | [2] |
| DyNiSi | TiNiSi | *oP*12 | *Pnma* | 6.880 | 4.132 | 7.214 | [12] |
| Dy$_3$NiSi$_3$ | Ba$_3$Al$_2$Ge$_2$ | *oI*14 | *Immm* | 3.946 | 4.106 | 17.339 | [13] |
| Dy$_3$NiSi$_2$ | Gd$_3$NiSi$_2$ | *oP*24 | *Pnma* | 11.248 | 4.119 | 11.156 | [14] |

## 3. Results and discussion

The alloys Dy$_{20}$Ni$_{20}$Si$_{60}$ and Dy$_{33}$Ni$_{33}$Si$_{34}$ appeared to be single-phase samples containing the phases DyNiSi$_3$ and DyNiSi, respectively, whereas the alloy Dy$_{27}$Ni$_{55}$Si$_{18}$ contained, in addition to the phase Dy$_3$Ni$_6$Si$_2$, small amounts of other phase(s). Experimental details and crystallographic data for the compounds DyNiSi$_3$ (structure type SmNiGe$_3$), Dy$_3$Ni$_6$Si$_2$ (Ce$_3$Ni$_6$Si$_2$), and DyNiSi (TiNiSi) are given in Table 2.

**Table 2** Experimental details and crystallographic data for the compounds DyNiSi$_3$, Dy$_3$Ni$_6$Si$_2$ and DyNiSi.

| Compound | | DyNiSi$_3$ | Dy$_3$Ni$_6$Si$_2$ | DyNiSi |
|---|---|---|---|---|
| Structure type | | SmNiGe$_3$ | Ce$_3$Ni$_6$Si$_2$ | TiNiSi |
| Pearson symbol | | *oS*20 | *cI*44 | *oP*12 |
| Space group | | *Cmmm* | *Im-3m* | *Pnma* |
| Cell parameters: | *a*, Å | 3.9225(3) | 8.7640(5) | 6.8625(6) |
| | *b*, Å | 20.955(1) | – | 4.1568(5) |
| | *c*, Å | 3.9465(3) | – | 7.1686(6) |
| Unit cell volume *V*, Å$^3$ | | 324.38(4) | 673.14(2) | 204.49(4) |
| Formula units per cell *Z* | | 4 | 4 | 4 |
| Diffractometer | | DRON-2.0M | STOE STADI P | DRON-2.0M |
| Program | | DBWS-9807 | FullProf Suite | DBWS-9807 |
| Radiation, wavelength $\lambda$, Å | | Fe *K*α, 1.9374 | Cu *K*α$_1$, 1.5406 | Fe *K*α, 1.9374 |
| Density *D*$_X$, g cm$^{-3}$ | | 6.257 | 8.822 | 8.100 |
| FWHM parameters *U*, *V*, *W* | | 0.06(1), -0,01(1), 0.032(1) | 0.006(6), 0.020(6), 0.013(2) | 0.15(3), -0.14(4), 0.09(1) |
| Mixing parameter $\eta$ | | 0.74(3) | 0.664(15) | 0.79(3) |
| Asymmetry parameter *C*$_M$ | | -0.04(2) | 0.045(8) | -0.08(2) |
| Texture parameter *G* [direction] | | 0.965(5) [010] | – | 1.34(1) [010] |
| Number of reflections | | 92 | 70 | 94 |
| Number of refined parameters | | 18 | 13 | 19 |
| Reliability factors *R*$_p$, *R*$_{wp}$, *R*$_B$ | | 0.0370, 0.0493, 0.1228 | 0.0248, 0.0396, 0.1360 | 0.0372, 0.0486, 0.0911 |
| Goodness of fit *S* ($\chi^2$) | | 0.59 | (5.03) | 0.56 |

**Table 3** Atom coordinates and isotropic displacement parameters for the compound DyNiSi$_3$: structure type SmNiGe$_3$, o$S$20, *Cmmm*, *a* = 3.9225(3), *b* = 20.955(1), *c* = 3.9465(3) Å.

| Site | Wyckoff position | *x* | *y* | *z* | $B_{iso}$, Å$^2$ |
|------|------------------|-----|-----|-----|------------------|
| Dy | 4*j* | 0 | 0.3318(2) | ½ | 0.78(8) |
| Ni | 4*i* | 0 | 0.1111(3) | 0 | |
| Si1 | 4*j* | 0 | 0.0577(7) | ½ | |
| Si2 | 4*i* | 0 | 0.2201(8) | 0 | 1.49(17) |
| Si3 | 4*i* | 0 | 0.4477(8) | 0 | |

**Table 4** Interatomic distances and coordination numbers for the compound DyNiSi$_3$.

| Atoms | | $\delta$, Å | CN | Atoms | | $\delta$, Å | CN |
|-------|--|-------------|----|-------|--|-------------|----|
| Dy | - 4 Si2 | 2.987(6) | | Si1 | - 2 Ni | 2.269(8) | |
| | **- 4 Ni** | 3.029(3) | | | - 1 Si1 | 2.42(2) | |
| | **- 2 Si1** | 3.035(12) | | | - 4 Si3 | 2.7844(9) | 9 |
| | **- 2 Si2** | 3.061(13) | | | - 2 Dy | 3.035(12) | |
| | **- 2 Si3** | 3.129(13) | 20 | Si2 | - 1 Ni | 2.284(18) | |
| | **- 2 Dy** | 3.9225(3) | | | - 2 Si2 | 2.327(13) | |
| | **- 2 Dy** | 3.9465(3) | | | - 4 Dy | 2.987(6) | 9 |
| | **- 2 Dy** | 3.949(5) | | | - 2 Dy | 3.061(13) | |
| Ni | **- 2 Si1** | 2.269(8) | | Si3 | - 1 Si3 | 2.19(2) | |
| | **- 1 Si2** | 2.284(18) | 9 | | - 2 Ni | 2.316(9) | 9 |
| | **- 2 Si3** | 2.316(9) | | | - 4 Si1 | 2.7844(9) | |
| | **- 4 Dy** | 3.029(3) | | | - 2 Dy | 3.129(13) | |

**Table 5** Atom coordinates and isotropic displacement parameters for the compound Dy$_3$Ni$_6$Si$_2$: structure type Ce$_3$Ni$_6$Si$_2$, c$I$44, *Im-3m*, *a* = 8.7640(5) Å.

| Site | Wyckoff position | *x* | *y* | *z* | $B_{iso}$, Å$^2$ |
|------|------------------|-----|-----|-----|------------------|
| Dy | 12*e* | 0.2810(3) | 0 | 0 | 0.54(6) |
| Ni | 24*h* | 0 | 0.3324(3) | 0.3324(3) | 1.28(10) |
| Si | 8*c* | ¼ | ¼ | ¼ | 4.2(5) |

**Table 6** Interatomic distances and coordination numbers for the compound Dy$_3$Ni$_6$Si$_2$.

| Atoms | | $\delta$, Å | CN | Atoms | | $\delta$, Å | CN |
|-------|--|-------------|----|-------|--|-------------|----|
| Dy | -4 Ni | 2.852(5) | | Ni | - 2 Si | 2.405(2) | |
| | **-4 Ni** | 2.924(5) | 16 | | - 4 Ni | 2.531(6) | 12 |
| | **-4 Si** | 3.110(4) | | | - 2 Dy | 2.852(5) | |
| | **-4 Dy** | 3.479(4) | | | - 2 Dy | 2.924(5) | |
| | | | | Si | **- 6 Ni** | 2.405(2) | 12 |
| | | | | | **- 6 Dy** | 3.110(3) | |

**Table 7** Atom coordinates and isotropic displacement parameters for the compound DyNiSi: structure type TiNiSi, o$P$12, *Pnma*, *a* = 6.8625(6), *b* = 4.1568(5), *c* = 7.1686(6) Å.

| Site | Wyckoff position | *x* | *y* | *z* | $B_{iso}$, Å$^2$ |
|------|------------------|-----|-----|-----|------------------|
| Dy | 4*c* | -0.0087(7) | ¼ | 0.7054(4) | 0.79(8) |
| Ni | 4*c* | 0.1829(14) | ¼ | 0.0973(12) | 1.30(15) |
| Si | 4*c* | 0.294(3) | ¼ | 0.446(3) | |

A comparison with Table 1 shows that the refined cell parameters are in good agreement with the literature data. The atomic coordinates, including isotropic displacement parameters, and selected interatomic distances are listed in Tables 3-8. For DyNiSi$_3$ and DyNiSi the isotropic displacement parameters of the Ni and Si sites were constrained to be equal. All three compounds revealed ordered distribution of the chemical elements. Observed and calculated diffraction diagrams for the samples Dy$_{20}$Ni$_{20}$Si$_{60}$, Dy$_{27}$Ni$_{55}$Si$_{18}$, and Dy$_{33}$Ni$_{33}$Si$_{34}$ are shown in Figs. 1-3.

Projections of the structures and conventional coordination polyhedra in the compounds DyNiSi$_3$, Dy$_3$Ni$_6$Si$_2$, and DyNiSi are presented in Figs. 4-6. The structures of DyNiSi$_3$ and DyNiSi are characterized by trigonal-prismatic coordination of the Si atoms, which corresponds to class 10 of the systematization of structure types of intermetallic compounds proposed by P.I. Kripyakevich [18]. In the case of DyNiSi$_3$, the Si atoms center Dy$_6$ (site Si2) and Dy$_2$Si$_4$ (sites Si1 and Si3) trigonal prisms, with three additional atoms (2 Si + 1 Ni for the site Si2 and 2 Ni + 1 Si for the sites Si1 and Si3) in front of the rectangular faces of the prisms. In DyNiSi$_3$ the coordination polyhedra of the Dy atoms have 20 vertices and in DyNiSi 16 vertices. The former can be described as hexagonal prisms of composition Ni$_4$Si$_8$,

**Table 8** Interatomic distances and coordination numbers for the compound DyNiSi.

| Atoms | | $\delta$, Å | CN | | Atoms | | $\delta$, Å | CN |
|---|---|---|---|---|---|---|---|---|
| Dy | - 2 Ni | 2.784(7) | | Ni | **- 2 Si** | 2.352(9) | |
| | **- 1 Si** | 2.788(21) | | | **- 1 Si** | 2.609(21) | |
| | **- 1 Si** | 2.847(19) | | | **- 1 Si** | 2.689(24) | |
| | **- 1 Ni** | 3.031(9) | | | **- 2 Dy** | 2.784(7) | |
| | **- 2 Si** | 3.051(16) | | | **- 1 Dy** | 3.031(9) | 12 |
| | **- 2 Si** | 3.076(15) | 16 | | **- 1 Dy** | 3.102(9) | |
| | **- 1 Ni** | 3.102(9) | | | **- 2 Dy** | 3.149(8) | |
| | **- 2 Ni** | 3.149(8) | | | **- 2 Ni** | 3.545(9) | |
| | **- 2 Dy** | 3.490(7) | | Si | - 2 Ni | 2.352(9) | |
| | **- 2 Dy** | 3.606(3) | | | - 1 Ni | 2.609(21) | |
| | | | | | - 1 Ni | 2.689(24) | |
| | | | | | - 1 Dy | 2.788(21) | 10 |
| | | | | | - 1 Dy | 2.847(19) | |
| | | | | | - 2 Dy | 3.051(16) | |
| | | | | | - 2 Dy | 3.076(15) | |
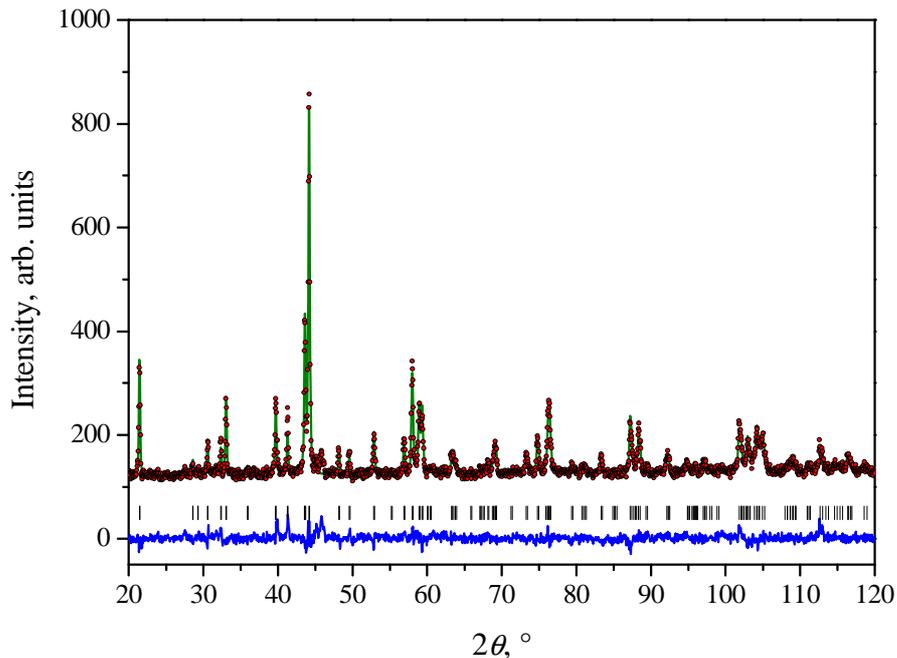


**Fig. 1** Observed (dots), calculated (line) and difference (bottom) X-ray powder diffraction patterns (Fe *K*α radiation) for the sample Dy$_{20}$Ni$_{20}$Si$_{60}$ (vertical bars indicate peak positions of DyNiSi$_3$).
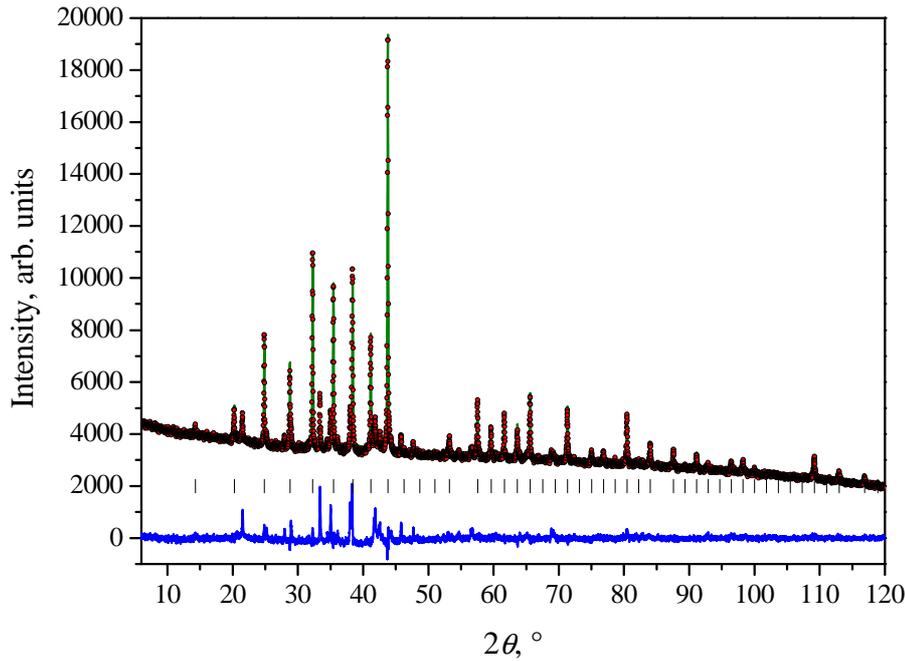
**Fig. 2** Observed (dots), calculated (line) and difference (bottom) X-ray powder diffraction patterns (Cu $K\alpha_1$ radiation) for the sample $Dy_{27}Ni_{55}Si_{18}$ (vertical bars indicate peak positions of $Dy_3Ni_6Si_2$).
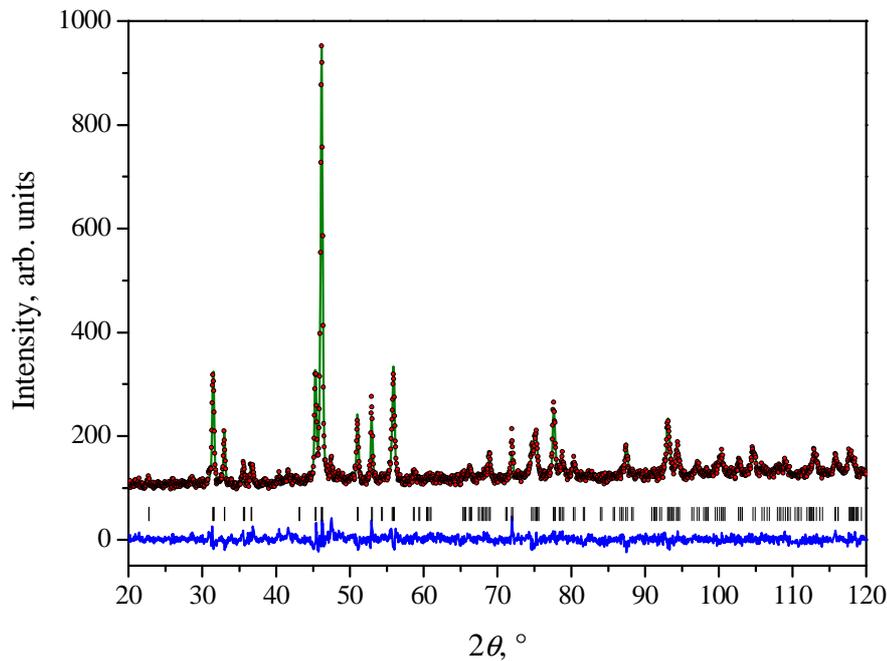


**Fig. 3** Observed (dots), calculated (line) and difference (bottom) X-ray powder diffraction patterns (Fe $K\alpha$ radiation) for the sample $Dy_{33}Ni_{33}Si_{34}$ (vertical bars indicate peak positions of DyNiSi).

**Table 9** Electrical resistivity and temperatures of probable magnetic ordering for the compounds $DyNiSi_3$, $Dy_3Ni_6Si_2$, and DyNiSi.

| Compound | $\rho_{290K}$, m$\Omega \cdot$cm | $\rho_{290K} / \rho_{5K}$ | $T_{ord.}$, K | Note |
|----------|---------|---------|---------|------|
| DyNiSi$_3$ | 72 | 18 | 20 | very weak non-linearity of $\rho(T)$ above 80 K |
| Dy$_3$Ni$_6$Si$_2$ | 239 | 2 | 19 | strong non-linearity of $\rho(T)$ above 50 K |
| DyNiSi | 176 | 10.4 | 12 | medium non-linearity of $\rho(T)$ above 50 K |

with eight additional atoms (6 Dy + 2 Si) above the lateral faces and bases of the prism, and the latter as pentagonal prisms of composition Dy$_2$Ni$_4$Si$_4$, with six additional atoms (2 Dy + 2 Si + 2 Ni) located above four faces and two edges of the prism. Trigonal-prismatic coordination is also observed for the Ni atoms in DyNiSi$_3$, with three additional Si atoms above the rectangular faces of the Dy$_4$Si$_2$ prisms. In the structure of the compound DyNiSi, the Ni atoms are located in tetragonal prisms of composition Dy$_4$Ni$_2$Si$_2$, with four additional atoms (2 Dy + 2 Si) in front of the lateral faces of the prism.

The structure of the compound Dy$_3$Ni$_6$Si$_2$ exhibits icosahedral coordination of the Ni and Si atoms, which corresponds to class 5 of the systematization of structure types of intermetallic compounds by P.I. Kripyakevich [18]. The Ni-centered icosahedron consists of three kinds of atom and has the composition Dy$_4$Ni$_6$Si$_2$, whereas the Si-centered icosahedron is built up of only Dy and Ni atoms (composition Dy$_6$Ni$_6$). The coordination polyhedron of the Dy atoms has 16 vertices and can be described as a pentagonal prism of composition Dy$_2$Si$_4$Ni$_4$ with four additional atoms (2 Dy + 2 Ni) in front of rectangular faces and two additional Ni atoms in front of the bases of the prism.

Contact distances between Ni and Si atoms, $\delta_{\text{Ni-Si}}$, exist in all the title compounds and are in the range 2.269(8)-2.689(24) Å (see Tables 4, 6, and 8). Contact distances $\delta_{\text{Ni-Ni}}$ are observed only for the compound Dy$_3$Ni$_6$Si$_2$ (2.531(6) Å), whereas contact distances $\delta_{\text{Si-Si}}$ are present only in the compound DyNiSi$_3$. The latter are slightly shorter (2.19(2) Å) than the sum of the atomic radii.



**Fig. 5** Projection of the structure of the compound Dy$_3$Ni$_6$Si$_2$ along [001] and coordination polyhedra of the different sites.
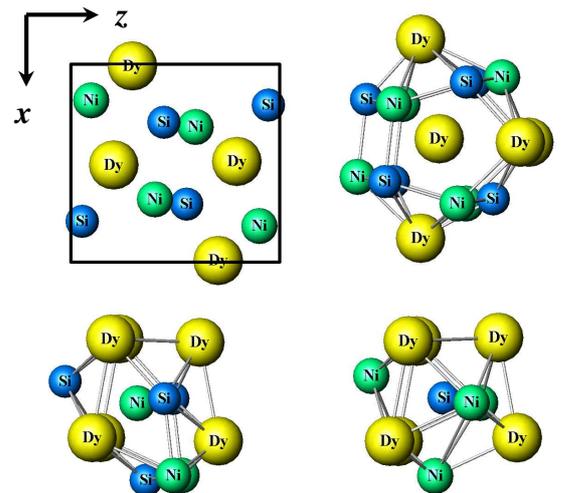


**Fig. 6** Projection of the structure of the compound DyNiSi along [010] and coordination polyhedra of the different sites.



**Fig. 4** Projection of the structure of the compound DyNiSi$_3$ along [001] and coordination polyhedra of the different sites.

As expected, the temperature dependence of the electrical resistivity of the ternary compounds DyNiSi$_3$, DyNiSi, and Dy$_3$Ni$_6$Si$_2$ exhibits metal behavior (Fig. 7, Table 9). However, in all of the plots, additional features are observed with respect to the description by the Bloch-Grüneisen law applied to classical metals. At high temperatures, the temperature dependence of the resistivity deviates from linearity, and at low temperatures (< 25 K) the transition to residual resistivity is followed by a drastic decrease of the resistivity. Such behavior indicates possible phase transitions. We can assume that these phase transitions
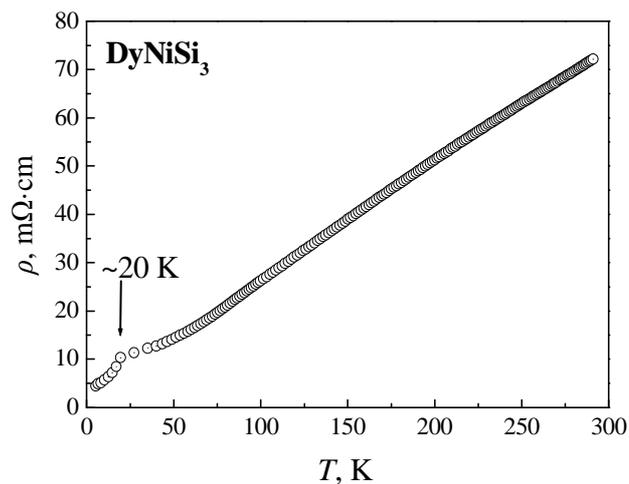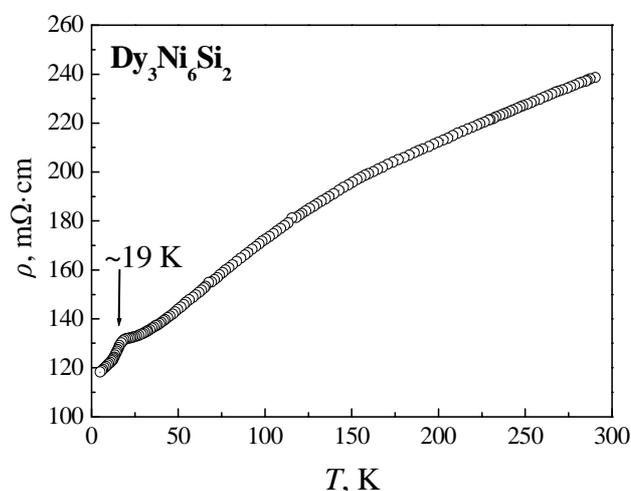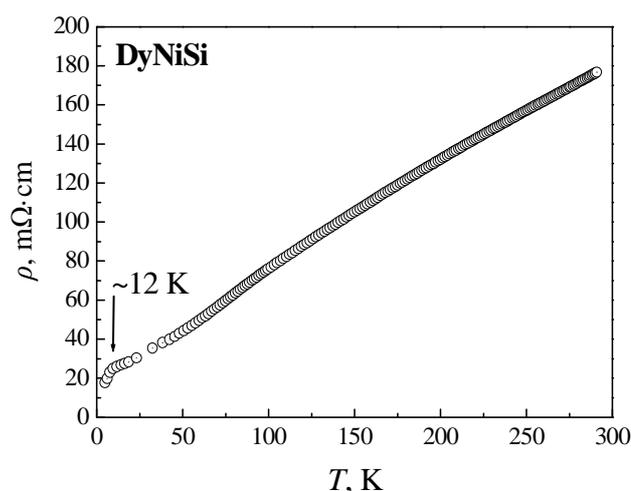
**Fig. 7** Temperature dependence of the electrical resistivity for the compounds DyNiSi$_3$ (a), Dy$_3$Ni$_6$Si$_2$ (b), and DyNiSi (c).

are related to magnetic ordering in the substructure of the rare-earth metal atoms and appear as a result of RKKY interactions. The temperatures of probable magnetic ordering are listed in Table 9. The assumption about magnetic ordering is based on investigations of other intermetallic compounds containing magnetic rare-earth metals [19-21], where the temperatures of phase transitions, obtained from the temperature dependence of the electrical resistivity, are in good agreement with the temperatures of magnetic ordering, obtained directly from magnetic measurements.

Concerning the non-linearity of the temperature dependence of the electrical resistivity of the investigated compounds, the presence, in addition to rare-earth metal atoms, of atoms of the 3$d$-transition element Ni, can influence the temperature dependence of the electrical resistivity above the temperatures of magnetic ordering through a process of scattering of $s$-$d$ conduction electrons. Such an additional scattering mechanism may cause deviations of the temperature dependence from linearity, which considers only the scattering of the lattice phonons, according to the Bloch-Grüneisen law. As can be seen from Fig. 7, the deviation of the temperature dependence from linearity increases in the order DyNiSi$_3$ – DyNiSi – Dy$_3$Ni$_6$Si$_2$, $i.e.$ with increasing Ni content. This confirms the influence of the Ni 3$d$-shell on the formation of the scattering mechanism, and the small influence of other scattering mechanisms. This conclusion implies the existence of magnetic moments only on the rare-earth elements.

## 4. Conclusions

The present, complete structural investigations confirm literature data on the crystal structures of the three ternary silicides DyNiSi$_3$, Dy$_3$Ni$_6$Si$_2$, and DyNiSi. These compounds adopt the structure types SmNiGe$_3$, Ce$_3$Ni$_6$Si$_2$, and TiNiSi, respectively. Measurements of the electrical resistivity $versus$ temperature indicate metal behavior with possible phase transitions at low temperatures.

## Acknowledgements

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