Sputter deposition of multi-component alloy thin films by using power targets

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Design, Research And Feasibility of Thin Films
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Multi-component alloys

Ni-based superalloys
Zr-based metallic glasses
Ti- and Mg-based alloys
High-Entropy Alloys (HEA)

B. Gludovatz et al., Science 345, pp. 1153-1158 (2014)
High-Entropy Alloys (HEA)

contain at least 5 different elements

near-equimolar concentrations, no dominant elements

Boltzmann hypothesis:

\[
\Delta S_{\text{mix}} = -R \sum_{i=1}^{n} c_i \ln(c_i) = R \ln(n)
\]

\[
\Delta G_{\text{mix}} = \Delta H_{\text{mix}} - T \Delta S_{\text{mix}}
\]

simple solution structures: crystalline FCC/BCC or amorphous

High-Entropy Alloys (HEA)

properties of bulk HEA:
corrosion resistance
high hardness
high toughness
high wear resistance
stability at high temperatures

influence of deposition conditions

also for thin films?
influence of composition
**Powder targets**

**magnetron sputtering**

1) multiple magnetrons
   - good control over composition
   - complex geometry

2) sintered alloy targets
   - good control over composition
   - time-consuming target production

3) cold-pressed powder targets
   - fast to make
   - single magnetron

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**Powder targets**

**preparation of the target**

![Sequence of steps](image)

- no limits on composition
- low thermal conductivity
- low cathode power
**Experimental**

where do we start?

many possible combinations: CuNiCoZnAlTi, FeCoNiCrAlSi, AlCrMoTaTiZr, AlCoCrFeNiAl
AlMoNbSiVZr, AlCoCrFeNiMo, AlCoCrFeNiTi, VNbMoTaWMn, AlCoCrFeNbNi, ...

base alloy: CoCrFeNi

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**Experimental: CoCrFeNi**

deposition conditions:

- pumping speed: 125 l/s
- gas flow: 30 sccm Ar
- discharge current: 0.09 A

Ar gas pressure: 0.40 – 0.55 Pa

target-substrate distance: 7 – 9 – 11 cm

average film thickness: 500 nm

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**FCC**
**Experimental: CoCrCuFeNi**

**influence of the deposition conditions**

- **Scheerer grain size (nm)**
  - Decrease in p-d
  - Change from tensile to compressive stress

**Experimental: addition of 6th element**

**what happens when another element is added?**

CoCrCuFeNi + Al/Nb

- 125-128-127-125 pm
- Atomic radii within ±2.5%

The 6-element HEA is topologically a binary alloy with small and large atoms

<table>
<thead>
<tr>
<th>element</th>
<th>atomic radius (pm)</th>
<th>crystal structure</th>
<th>valence electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>143</td>
<td>FCC</td>
<td>3s²3p¹</td>
</tr>
<tr>
<td>Nb</td>
<td>143</td>
<td>BCC</td>
<td>4d⁴5s¹</td>
</tr>
</tbody>
</table>
Experimental: AlCoCrCuFeNi

Al fraction increases → lattice distortion of FCC structure increases
packing fraction of BCC is lower, incorporation of the large Al atoms

Experimental: NbCoCrCuFeNi

now replace Al with Nb
→ change p-d
→ increase the Nb fraction

XRD spectra fitted with Voigt profiles

FCC → amorphous transition
Experimental: NbCoCrCuFeNi

increasing lattice distortion

reflected Ar neutrals densify the film
Conclusions & outlook

CoCrCuFeNi base HEA

Al addition: FCC → BCC
Al: (Ne)3s²3p¹
Nb addition: FCC → amorphous
Nb: (Kr)4d⁴5s¹

transition metals have a partially filled d-shell

e.g. FCC to BCC transition of Cu

Multi-component alloys
Powder targets
Experimental
Conclusions & outlook

1) HEA thin films were deposited by using powder targets
2) Al and Nb addition cause structure transitions
3) HEAs are topologically binary alloys
4) atomic radius and electron configuration determine the structure

Future experiments:
- TEM to check the atomic structure
- mechanical and electrical characterisation of HEA coatings
Thank you!

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www.draft.ugent.be