Electro-deposited alloys for backscattering-mode positron moderators

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a continuation of the work of
- and of several Master theses prepared at Ecole Nationale Supérieure d’Arts & Métiers-Paris.

▪ PURPOSE : search for
  - a moderator material, solid at room T. and with lower annealing temperature than that needed for W (~2000°C) but with similar re-emission characteristics
  - a material that can be “painted” (electro-deposited) on special focussing shapes or on pieces which are difficult to access (e.g.:high radioactive environment)
Electro-deposition of W in aqueous solution can only be achieved by co-deposition with a transition metal. The Ni-W system was chosen since both elements have suitable re-emission characteristics. The highest concentration achievable is about 25 at % and, in the 15-25% range, chances are that the alloy is in the amorphous state.

During temperature annealing, these alloy will tend to crystallize into the Ni₄W compound. 1500°C can be considered a their melting point limit.

The Ni-W phase diagram shows the following:

- **L** phase
- Eutectic point at 1496°C
- Peritectoid reaction at 1060°C
- Crystallization at 1500°C
- Amorphous alloy range: 15 - 25 % W

The diagram indicates that the Ni-W system has a complex phase diagram with multiple phases and transformation temperatures.
Defect recovery not yet completed at crystallization temperature (~720°C) since lifetime still shows a long component attributed to small bubbles possibly filled with hydrogen (generated by electrodeposition).
**Ni$_{80}$W$_{20}$**

- **e+ Incident energy:** 1keV
- **As-prepared**
- **Highest yield similar to that of pure W but no need to anneal above 1350 °C (close to melting point)**

**Graph:**
- **X-axis:** Annealing Temperature (K)
- **Y-axis:** Slow Positron Yield (%)

- **1350°C**
- **After crystallization**
- **Amorphous state**

**Text:**

Slow Positron re-emission Yield versus annealing temperature
Slow Positron re-emission Yield versus Time (short term stability)

$\text{Ni}_{80}\text{W}_{20}$

e+ Incident energy: 2keV

As-annealed at 1350°C

Recovery after 1250°C re-annealing

~10% “prompt” decrease then stabilization. Re-annealing restores original value. Behavior similar to W
Slow Positron re-emission Yield vs. sample age (Long term stability : storage)

Ni$_{80}$W$_{20}$

e$^+$

Incident energy: 1keV

Sample annealed at 1350°C and left 6 months in air

As-prepared
Checking the work function

- Measure of the gamma counts dependence on the sample bias. Range: [-5, +5] volts
  Incident beam energy: 2keV (to avoid epithermal e+)

- References:
  - Ni annealed *in situ* at 1250°C
  - W annealed *ex situ* at 2000°C

- Samples:
  - Ni$_{80}$W$_{20}$ annealed *in situ* at 1050°C
  - Ni$_{80}$W$_{20}$ annealed *in situ* at 1350°C
Sample Bias dependence of re-emitted Positrons

Reference samples

\[ \text{Reference sample}

\text{Ni} \quad (T_a = 1523 \text{ K})

\text{W} \quad (T_a = 2273 \text{ K})

\text{Normalized number of re-emitted positrons}

\text{Sample bias (V)}

\text{e+ Incident energy: 2keV}
Sample Bias dependence an maximum Energy of re-emitted Positrons: work function $\phi^+$

$\text{Ni}_{80}\text{W}_{20}$ Alloy after annealing at $T_a$

$e^+$ Incident energy: 2keV

High-T anneal NiW alloy similar to W but substructure recalls Ni spectrum

Diagram showing normalized number of re-emitted positrons versus sample bias (V) with curves for Ni, W, NiW ($T_a=1523$ K), NiW ($T_a=1823$ K), and NiW ($T_a=1623$ K). Key points include $3.3 \text{ eV } \pm 0.3$, $\sim 3.0 \text{ eV}$, and $\sim 1.1 \text{ eV}$. 
“Axial” energy spectra

Normalized number of re-emitted positrons

First derivative

Sample bias (V)

“axial” energy spectra

Ni
W
Ni\textsubscript{80}W\textsubscript{20}(1623 K)
Comparison of “Axial” energy spectra

Linear combination of Ni and W contributions does not fully account for Ni$_{80}$W$_{20}$ alloy effect.

Surface segregation of atoms W: W area growing at the expense of Ni area: possible effect but not exclusive.

Additional correlation effect between Ni and W seems to occur.
Conclusion

- New metallic moderator: Ni - 20% W
  - Re-emission yield at 1 keV: more than 25%
  - Estimated primary (overall) moderation efficiency \( \sim 10^{-3} \)
- Annealing Temp. much lower than Tungsten (~half!)
- Stable short term stability: re-emission yield remains constant after prompt slight decrease (similar to W); initial value restored after annealing at 1250°C
- Long term stability: re-emission recovered after 1350°C anneal
- Work function closer to W (~3 eV) than to Ni
  - Suggests surface segregation of W atoms
  - Substructure on the “axial energy” spectrum ==> simple linear contribution Ni and W does not fully account for Ni-W alloy behavior ==> possible interactions of e+ with Ni and W atom
- Electro-deposition ==> possibility of making special shapes for backscattering moderators