Electroless ternary Nickel alloys for ENEP or ENEPIG under bump metallization (UBM) on power semiconductor for high temperature process conditions or applications

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Electroless ENIG/ENEPIG Deposition for Bonding and Soldering Applications
Applications for Electroless Metal Depositions

1. Electroless Metallization as final finishing for:
   - Bond Pad Metallization for Al-, Au- and Cu wire bonding
   - Under Bump Metallization (UBM) for soldering of Flip Chip
   - Metallization of pads of Power Modules or Power IC for thick wire bonding or soldering
   - Cu RDL housing
   - TSV Capping for solder bumping

2. Formation of an ohmic Metal-Semiconductor contact
   - Deposition on different doped semiconductor materials of Power IC for bonding or soldering

3. Seed layer deposition
   - Cu seed layer deposition for Electro Chemical Deposition (ECD)
## Typical Applications for Electroless Ni, Pd and Au

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>ENEP(IG)</th>
<th>EN(EP)IG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xenolyte Ni, Xenolyte Pd (Xenolyte Au)</td>
<td>Xenolyte Ni, Xenolyte Pd</td>
<td>Xenolyte Ni (Xenolyte Pd), Xenolyte Au</td>
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</tbody>
</table>

| Process | 
|---------|---|
| [Image] | [Image] | [Image] |

<table>
<thead>
<tr>
<th>Customer’s Application</th>
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<tbody>
<tr>
<td>Wire bonding</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer’s Products &amp; Markets</th>
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<tr>
<td>Power Transistors</td>
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</table>
Advantages of ternary Ni Layer
Motivation for a Ternary Ni Alloy

Standard binary NiP layers for ENEP or ENEPIG

- amorphous NiP deposition
- phase transition to crystalline state and layer stress change are obtained at 350-360°C
- therefore binary eless NiP is not recommended for higher temperature (>350°C):
  - process steps post Ni deposition (e.g. final anneal at 400-430°C)
  - high temperature soldering processes
  - applications e.g. some components for automotive or power devices

Ternary Ni layers

- no phase transition at 350-360°C → crystalline deposition needed
- suitable for high temperature process conditions or applications

Goal: Crystalline NiP deposition to prevent phase transition
Thermal Behavior of binary Ni Layer

The conversion mechanism of thermodynamic unstable & irregular material structure into a regular stable structure at a certain temperature.

1. Structural Relaxation
   (mainly diffusion driven) at temp. > 210°C
   - short range movement = annihilation of point defects & dislocations by formation of ordered clusters

2. Nucleation
   at temp. 250°C (L/MPEN) – 320°C (HPEN)
   - short range movement = creation of ordered atomic Ni-cluster

3. Crystallisation
   at temp. > 320°C
   - long range movement = creation of grain boundaries
   - Nucleation seeds support formation of pure Ni & P-Ni-crystallites (< 6.8% at P)

→ Exothermic process
→ Stress change in layer
Crack Issue on large plated Areas for ENEP/ENEPIG

Crack formation at higher temperature due to layer stress change! → e.g. high temperature soldering process

→ Preferred at large plated areas like power transistors, IGBT, diodes, ...
X-Ray Diffraction Analysis of binary NiP Layers

Standard binary mid. P Ni layer with 7.5%w P

98% amorphous deposition

Critical temp. range for strong change in Ni layer morphology

Crack formation post indenter test due to phase transition at higher temperature

Crack formation → layer stress change
Influence of P Content in Ni on Layer Morphology

NiP crystal size depending on P-content

Definition of P content $\rightarrow$ %w vs. %at

<table>
<thead>
<tr>
<th>Process</th>
<th>P% by weight</th>
<th>P% by atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low P</td>
<td>1 – 3</td>
<td>2 – 7</td>
</tr>
<tr>
<td>Low-Medium P</td>
<td>4 – 6</td>
<td>8 – 12</td>
</tr>
<tr>
<td>Medium P</td>
<td>7 – 9</td>
<td>13 – 18</td>
</tr>
<tr>
<td>High P</td>
<td>10 – 13</td>
<td>&gt; 19%</td>
</tr>
</tbody>
</table>

- The lower the P content the higher the NiP crystal size
- With lower P content crystalline NiP deposition possible $\rightarrow$ no phase transition
- **How to reduce the P content below 3 %w (7%at)?**
  $\rightarrow$ co-deposition of an additional high melting metal like Mo or W
Comparison of binary and different ternary Ni layers
Layer Morphology

Standard binary NiP layer

Ternary Ni alloy with W co-deposition

Ternary Ni alloy with Mo co-deposition

Amorphous Ni layer

Crystalline Ni layer

Crystalline Ni layer

→ Crystalline Ni layer morphology for ternary systems with W and/or Mo co-deposition
Thermal Behavior

### Standard binary mid & high NiP layer (P: > 5%w)

- DSC Analysis (differential scanning calorimetry)
  - 20 K/min
  - 25 – 600 °C

### Low P binary NiP layer (P: 3-4%w)

- P content > 4% → phase transition from amorphous to crystalline state at around 350-360°C
- P content 3-4% → increase of phase transition temperature > 400°C
- P content < 3% → no exothermic peak → no phase change observed

### Ternary Ni layer with W and/or Mo co-deposition (P: < 3%w)

- SEMICON EUROPA 13-16 NOV 2018 MUNICH GERMANY
X-Ray Diffraction Analysis and Indenter Test

Standard mid P Ni (6-8%w P)

→ Crystal growth and layer stress change
→ Crack formation post indenter test due to phase transition at higher temperature (> 360°C)

→ Improved but still crystal growth and Ni₃P formation observed
→ Still leads to cracks at temperature > 380°C
X-Ray Diffraction Analysis and Indenter Test

Ternary Ni system with W co-deposition (NiWP)

>75% crystalline deposition

> Very little change in layer morphology

> Very few cracks post indenter test after 400°C anneal observed

Crystal size

Ni₃P → no Ni₃P crystal formation detected

Ni → only slight Ni crystal size increase > 400°C
X-Ray Diffraction Analysis and Indenter Test

Ternary Ni system with Mo co-deposition (NiMoP)

- >70% crystalline deposition
- No Ni₃P crystal formation detected
- >70% crystalline deposition
- No change of layer morphology!
- No cracks post indenter test after anneal > 400°C
Layer Stress

Layer stress post deposition*

- Mid. P Ni
- High P Ni
- Low P Ni
- Ternary Ni alloys

Ni Layer Stress [$N/mm^2$] post 24h

Ni bath

Thermal behavior of layer stress**

- binary Ni
- ternary Ni

Temperature [°C]

Layer Stress [$N/mm^2$]

- Linear thermal expansion
- Exponential thermal expansion

- In general lower stress post deposition for ternary Ni layers in particular for NiMoP systems
- Reduced increase of layer stress at higher temperature for ternary Ni compared to binary NiP layers

* Stress determination by stress stripes
** Stress determination by wafer bow and thick Ni
Resistivity

- Low P Ni: mainly used for ENEPIG
- Mid P Ni: mainly used for ENIG
- High P Ni: mainly used for ENIG
- Ternary Ni layers: lower resistivity compared to mid or high P binary Ni layers

Graph showing P content of different Ni layers vs. resistivity:

- Pure Ni
- Low P Ni
- Mid P Ni
- High P Ni

Lower resistivity of ternary Ni systems compared to mid or high P binary Ni layers
Plating Results of Electroless ternary Ni and Pd

- Plating on Al structures and no crack formation after 400°C anneal
- Conformal grows on Cu profile
- Pure Pd layer conformal on ternary Ni layer
- No erosion or corrosion of Cu
- Closed sidewall
Summary of ternary Ni Layer

- Low P Ni alloy with an additional metal → Mo or/and W
- Crystalline Ni layer
- Capable for high temperature >350°C → high temperature process steps post Ni deposition or high temperature applications
- Low stress Ni layers in particular for NiMoP systems
- Reduced increase of layer stress at higher temperature compared to binary NiP layers
- Higher fracture toughness and hardness → e.g. stronger mechanical reinforcement of structures
- Lower resistivity compared to standard binary mid. or high P Ni layers
- No Ni layer crack formation by intrinsic stress change at higher temperature in particular for large plated areas on power devices
Summary – new Product Xenolyte NiTR

Main Benefits
- Effective diffusion/migration barrier
- Suitable for conformal housing of fine pitch Cu RDL structure
- Lower resistivity compared to mid/high P Ni
- Suitable for high temperature >400°C*
- Low stress post deposition and at higher temp.
- High hardness and fracture toughness
- Long bath life

Examples

Xenolyte Ni TR applications:
Al Pad final finishing with Ni TR + PdLL for bonding applications and CuRDL housing

* applications or process steps post deposition
Thank you for your attention!

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