Preparation of nanoparticles by RF plasma method

Nisshin Engineering Inc.

http://www.nisshineng.com
Definition of nanoparticles

Smoke of tobacco
Mist
X-ray
UV visible
infrared

Nano-technology

molecule

Single-nano

Q. S. effect
Q. E.: Quantum Size

Our target size
RF plasma method are able to produce nanoparticles by vapor phase reactions.

RF plasma has a larger frame or reaction volume than the DC.

- The efficiency of the particle production is higher.

Another advantage of RF plasma is the ability to operate without the presence of any electrode.

- It’s enables nanoparticles to be obtained as pure as the raw material without suffering contamination from the evaporation of the electrode.
Raw material is evaporated instantaneously in high temperature plasma frame

The produced vapor condensed into nanoparticles by subsequent rapid cooling
### List of prepared nanoparticles

<table>
<thead>
<tr>
<th>Material</th>
<th>Diameter (nm)</th>
<th>Shape (SEM)</th>
<th>Crystal System (XRD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>30–60</td>
<td>Sphere</td>
<td>Cubic</td>
</tr>
<tr>
<td>Ni</td>
<td>30–60</td>
<td>Sphere</td>
<td>Cubic (Hexagonal)</td>
</tr>
<tr>
<td>Y2O3</td>
<td>50–200</td>
<td>Sphere</td>
<td>Cubic (Tetragonal)</td>
</tr>
<tr>
<td>SiC</td>
<td>30–80</td>
<td>Sphere</td>
<td>Cubic</td>
</tr>
<tr>
<td>TiN</td>
<td>30–100</td>
<td>Sphere</td>
<td>Cubic</td>
</tr>
<tr>
<td>BaTiO3</td>
<td>10–50</td>
<td>Sphere</td>
<td>Cubic</td>
</tr>
<tr>
<td>TiO2</td>
<td>30–100</td>
<td>Sphere</td>
<td>Cubic</td>
</tr>
<tr>
<td>SiO2</td>
<td>30–100</td>
<td>Sphere</td>
<td>Cubic (Tetragonal)</td>
</tr>
</tbody>
</table>
TEM image of nanoparticles

- Titania ($\text{TiO}_2$)
- Alumina ($\text{Al}_2\text{O}_3$)
- Silica ($\text{SiO}_2$)
- Yttria ($\text{Y}_2\text{O}_3$)
- Barium Titanate ($\text{BaTiO}_3$)
- Nickel (Ni)
Metal nanoparticles

- **Specific surface area (BET)**
  - 4.09 m²/g
  - BET-equivalent diameter
  - 164 nm

- **SEM image**

- **Laser diffraction**
  - \( D_{50} = 217 \text{nm} \)

- **X-ray diffraction**
  - Cubic
Preparation method of composite nanoparticles

Feed technique of raw materials

Control technique of reaction field

Raw material A

Raw material B

Core-shell particle

Plasma

Compound (Intermetallic, alloy)
Compound nanoparticles

- **SEM image**: 
  - Diameter: 100 nm

- **Specific surface area (BET)**: 
  - 23.8 m²/g
  - BET-equivalent diameter: 42 nm

- **Laser diffraction**: 
  - D₅₀ = 48 nm

- **X-ray diffraction**
  - Cubic structure
Solid solution nanoparticles

Ni:Al = 1:1

Ni:Ti = 1:1

\( D_{\text{BET}} = 70\text{nm} \)

\( D_{\text{BET}} = 90\text{nm} \)

\( 200\text{nm} \)

\( 200\text{nm} \)

NiAl

NiTi

NiTi₂

Intensity

200nm

90

70

50

30

10
Solid solution nanoparticles

\[ \theta \]  

<table>
<thead>
<tr>
<th>Compound</th>
<th>( d_{\text{cry}} )</th>
<th>( d_{\text{BET}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{BaTiO}_3 )</td>
<td>19.7 nm</td>
<td>43.5 nm</td>
</tr>
<tr>
<td>( \text{Ba(Zr}<em>{0.05}\text{Ti}</em>{0.95})_3 )</td>
<td>22.6 nm</td>
<td>39.1 nm</td>
</tr>
<tr>
<td>( \text{Ba(Zr}<em>{0.1}\text{Ti}</em>{0.9})_3 )</td>
<td>24.3 nm</td>
<td>38.6 nm</td>
</tr>
<tr>
<td>( \text{Ba(Zr}<em>{0.15}\text{Ti}</em>{0.85})_3 )</td>
<td>25.4 nm</td>
<td>36.8 nm</td>
</tr>
<tr>
<td>( \text{Ba(Zr}<em>{0.2}\text{Ti}</em>{0.8})_3 )</td>
<td>32.4 nm</td>
<td>35.4 nm</td>
</tr>
</tbody>
</table>
Core-shell nanoparticles

Nickel-Barium titanate composite nanoparticles

Purpose:
1. Prevention of oxidation of metal nanoparticles
2. Control of sintering process

Ni, Cu etc
BaTiO₃, glass etc.
Analysis of core-shell nanoparticles

Thermal analysis of core-shell particles

- Ni
- Ni-BaTiO3
- Ni-glass