Simultaneous measurement of thickness and drying process of paint film by terahertz electromagnetic pulse

**T. Yasuda**, T. Yasui, T. Araki, and T. Iwata

Grad. Sch. of Engg. Sci., Osaka Univ.

Faculty of Engg., Univ. of Tokushima
Quality control of painting film

Painting thickness  
Painting quality  
(drying process, paint-off)  
In-process monitoring

In-process monitoring of paint film using THz electromagnetic pulse

Conventional methods can not meet all the requirements!

Painting film

○ Visual effect
○ Protection  
(Rust prevention, Water proof)

Multi-layer paint

Substrate

Paint

Background
# Quality control of painting film

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Conventional method (contact-type)</th>
<th>THz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Painting thickness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-contact, Remote</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Dried / Wet</td>
<td>Δ (only dried)</td>
<td></td>
</tr>
<tr>
<td>Single- / Multi-layer</td>
<td>Δ (only single)</td>
<td></td>
</tr>
<tr>
<td>Thickness distribution</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Metal / Non-metal substrate</td>
<td>Δ (only metal)</td>
<td></td>
</tr>
<tr>
<td>Precision = ±0.5 μm</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td><strong>Painting quality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paint-off</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Drying process</td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

Present talk
Principle

THz pulse

(1) Painting Film \( n_g \)

(2) Substrate

Time delay \( \Delta t \)

\[ \Delta t = \frac{n_g d}{c} \]

Electric field

if \( n_g \) is known

d can be determined by \( \Delta t \)
Experimental setup

Modelocked-Ti:Sapphire laser
(100fs, 1W, 80MHz, 800nm)

Basic performance

Pulse duration : 0.8ps
Spatial resolution : 1.7mm
SNR : 100
1 delay scan : 1sec
(1) Painting thickness measurement
Relationship between painting thickness and optical thickness

- **White enamel** (alkyd resin, pigment, paint thinner)
- **Black acryl** (acryl resin, pigment, nitrate, paint thinner)

![Graph showing the relationship between painting thickness and optical thickness for white enamel and black acryl.]

- **OT = 2.59d** (White enamel)
- **OT = 1.66d** (Black acryl)

**Group refractive index** $n_g$

- **White enamel**: 2.59
- **Black acryl**: 1.66

**Thickness measurement**

- **Precision**: 5 µm
- **Resolution**: 80 µm

**Insufficient!**
Improvement of thickness resolution

~ Separation of convoluted echo pulse based on two-parameter fitting ~

Signal $E_{\text{sig}}(t) = E_{\text{ref}}(t) + T E_{\text{ref}}(t + \Delta t)$

$\Delta t$: time delay
$T$: transmittance

Parameter fitting to $E_{\text{sig}}(t)$
Measurement of thin painting film

Sample: black acryl (thickness=17µm)

Green: fitting signal
Red: measurement signal

Blue: Residual between measurement signal and fitting signal

Thickness = 18µm

Resolution is improved
(2) Distribution measurement of painting thickness
Thickness distribution of multi-layer painting

THz pulse echo

Sample

Black acryl: $n_g = 1.66$
White enamel: $n_g = 2.59$
Plastic plate: $n_g = 1.8$

Total measurement time = 5min

Black acryl: $238.82 \pm 33 \mu m$
White enamel: $158.4 \pm 11 \mu m$

THz imaging
Detection of paint-off area

Max paint-off thickness: 555µm
(3) Monitoring of dry process
Temporal change of wet paint film

- Paint
- Wet film
- THz pulse

![Graph showing electric field over time for before painting, end of painting, complete drying at 0min, 2min, 4min, 6min, and 8min.]
Dry-state monitoring based on delay time of pulse echo

During drying process
- $d \rightarrow$ decrease, $n_g \rightarrow$ increase
- $n_g \times d \rightarrow$ constant

Drying process $\propto t_1$
Relative thickness $\propto t_2$
## Summary

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Conventional method (contact-type)</th>
<th>THz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Painting thickness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-contact, remote</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Dried / wet</td>
<td>Δ (only dried)</td>
<td>○</td>
</tr>
<tr>
<td>Single- / Multi-layer</td>
<td>Δ (only single)</td>
<td>○</td>
</tr>
<tr>
<td>Painting distribution</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Metal / non-metal substrate</td>
<td>Δ (only metal)</td>
<td>○</td>
</tr>
<tr>
<td>Precision = 0.5 μm</td>
<td>○</td>
<td>Δ</td>
</tr>
<tr>
<td><strong>Painting quality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paint-off</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Drying process</td>
<td>×</td>
<td>△</td>
</tr>
</tbody>
</table>

## Acknowledgements

NEDO and Mazda Motor Corporation, Japan