Toray’s Advanced Materials
- Innovation by Chemistry -

Toray Industries, Inc.
Executive Vice President and Representative Director
Hiroaki Kobayashi

27, Sept. 2006
Toray Advanced Materials Symposium
I. Technology Innovation Supported by Materials Innovation
### Society in 21st Century & Industrial Circumstance

#### Newly Created Industrial Fields
- Ubiquitous Network
- High Speed Communication
- Next Generation Displays Etc.

#### Information Tele-communication
- Global Warming
- CO₂ Emission
- Pollution
- Oil Supply

#### Healthcare
- Global Warming
- CO₂ Emission
- Pollution
- Oil Supply

#### Environment
- Taylor-made Medicine
- Regenerative Medicine
- Nursing Care System Etc.

#### Energy
- Solar Cell
- Wind Power
- Fuel Cell Etc.

#### Safety & Security
- Personal Identification
- Air/Water Purification
- Safer Construction Materials Etc.

#### Globalization
- Global Competition, Rising Korean & Chinese Companies, Entering Chinese Market

#### CSR
- Corporate Governance, Compliance, Risk management, Safety/Disaster Prevention/Environment

#### IP
- IP Management, Employee Inventions, Technology Transfer, International Harmonization

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**Nanotechnology provides solutions for 21st century**
Advanced Materials Lead Advanced Industries

~19th Century
Natural Materials

20th Century
Emergence and Development of New Materials

21st Century
Advanced Materials

Metal
Iron & Steel
Stainless Steel
High Tensile Steel

Aluminum
Duralumin

Glass
Alkali-free Glass

Inorganic Materials
Semiconductor
Germanium
Silicon
Compound Semiconductors

Carbon Materials
CFRP

Nanocarbon
C60
CNT

Organic/Inorganic Hybrid Materials

Synthetic Polymers
Synthetic Fibers
Engineering Plastics
Non-petroleum Plastics

Precision Polymers

Functional Organics
Photopolymers

Biocompatible Materials

Electronics
Vacuum Tube
Transistor
LSI
LCD
PDP
Electronic Paper

Automobiles & Aircrafts
Airplane
Synthetic Rubber Tire
Hybrid Vehicle
Next-generation Airplane

Life Science
Contact Lens
Artificial Kidney
Catheter
DDS
Bio-tool
Innovation by Pursuing Limits

Innovation

Pursuing of Technology Limits
- Higher Strength
- Higher Heat Resistant
- Finer Structure
- Higher Sensitivity

The deeper, the newer

Social imperative
- Environmental issue
- Food Scarcity
- Energy Depletion
- Health & Healthcare

Science & Technology
- Innovative
- Universal
- Versatility
- Create New Field

New Technology & New Product
- Increasing Social Value
- Increasing Economic Value

Feedback
II. Toray’s R & D Activity

Innovation by Chemistry
Toray’s Challenge for Technology Innovation

Pursuit of Limits
finer, thinner, stronger, more …
“The Deeper, the Newer ”

Innovation by Chemistry

Core Technology of Toray
- Polymer Science
- Organic Synthetic Chemistry
- Nanotechnology
- Biotechnology

Technology Innovation
- New Material
- Nano-material
- Biotechnology
- Process

Main Strategic Area
- Information & Telecommunication
- Automobile /Aircraft
- Life Science
- Environment /Water/Energy

The Deeper, the Newer
- Example of Toray’s Advanced Materials -

Main Strategic Region

Technology Innovation
- IT-related Materials
- Automobile • Aircraft
- Life Science
- Environment • Water • Energy

New Materials
- Optical Circuit Board Materials
- Carbon Fiber Composite Materials
- Innovative Synthetic Pharmaceuticals
- Organic Semiconductor
- Biomas Fibers
- New Optical Film
- New transparent heat-resistance resin

Nano Material
- Nano–multilayer Films
- Nano-composite
- Nanofibers
- PLA Polymers
- CNT
- Nanoalloy
- DDS
- Membrane

Biotechnology
- Bio-pharmaceuticals
- Bio-tools
- Green Chemistry

Nano Process
- LCD Color Filters
- Next Generation Molding
- Human-friendly Material
- Next Generation Recycling
- PDP-related Materials
- MBR
### Example of Toray’s Advanced Materials

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### New Materials

- **Optical Circuit Board Materials**
  - New Optical Film
- **Carbon Fiber Composite Materials**
  - New transparent & heat-resistance resin
- **Innovative Synthetic Pharmaceuticals**
- **Organic Semiconductor**
  - Bio-mass Fibers

### Nano Material

- **Nano–multilayer Films**
  - CNT
- **Nano-composite**
- **Nanofibers**
  - DDS
- **PLA Polymers**
  - Membrane

### Bio

- **Bio-pharmaceuticals**
- **Bio-tools**
- **Green Chemistry**

### Nano Process

- **LCD Color Filters**
- **PDP-related Materials**
- **Next Generation Molding**
- **Human-friendly Material**
- **Next Generation Recycling**
  - MBR
**New Materials Innovation**

**Carbon Fiber**

**Composite Materials**

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**Pursuit of Ultimate Strength and Modulus**

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**Industrial process and technology for pursuit of ultimate performance**

- PAN polymerization and spinning
- Oxidization (200～300℃)
- Carbonization (Graphitization) (1000～3000℃)
- Sizing
- Carbon Fiber

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**Merit of Carbon Fiber**

- Lightweight
- Specific gravity=1.8 :2/3 of Al
- Rust resistance
- Chemical resistance
- High conductivity
- Dimensional stability etc

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**Polymer design**

**Control of fiber structure**

**Control of defect Orientation by draw**

**Control of graphite crystalline (size, orientation)**

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**Carbon Fiber**

**Graphite crystalline**

- Diameter=7um

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**Weight Specific gravity=1.8 :2/3 of Al**

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**Rust resistance**

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**Chemical resistance**

---

**High conductivity**

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**Dimensional stability etc**
New Materials Innovation
Carbon Fiber
Composite Materials

Pursuit of Ultimate Strength
/ Control of Surface Defect

Image of fiber surface at nano-size (STM)

Size of defect
Nano
Sub-micron
Micron

Strength (GPa)


0 2 4 6 8 10
Pursuit of Ultimate Strength
/Control of Graphite Crystalline

Modulus (GPa)

Fiber Axis

Orientation 80%

Graphite Crystalline

Surface (STM)

Cross Section (TEM)

Orientation 95%

6nm

1nm

10nm


0 100 200 300 400 500 600 700 800
Replacement of 50% of structure with CFRP yields 20% reduction of whole structural weight versus aluminum alloy.
**Expansion of Aircraft Application**

**B777**
- Tail Fin
- Floor Beams
- Engine Covering

**B787**
- Wings
- Fuselage
- Wing Mount

"All-composite-materials Aircraft"

<table>
<thead>
<tr>
<th>Components using composite materials</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>B767</td>
<td>B777</td>
<td>B787</td>
</tr>
<tr>
<td>Section using CFRP</td>
<td>Secondary structures</td>
<td>Primary structures (tail assembly etc.)</td>
<td>Primary structures (main wings, tail assembly, etc.)</td>
</tr>
<tr>
<td>Using CF type</td>
<td>3</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>CFRP utilization (wt%)</td>
<td>T300H</td>
<td>T800H</td>
<td>T800S</td>
</tr>
<tr>
<td>CFRP utilization/plane (ton)</td>
<td>1.5</td>
<td>9.6</td>
<td>35</td>
</tr>
</tbody>
</table>
Expansion of Automobile Applications

New Target: From exterior panels to main stricture

First full-scale test of CFRP passenger car
Front side member made of CFRP

Total weight: 2060kg
Test speed: 47km/h

CFRP Application Sections and Weight Reduction

- Roof (-10kg)
- Trunk lid (-5kg)
- Rear spoiler (-4kg)
- Impact beam (-3kg)
- Propeller shaft (-5kg)
- Hood (-12kg)
- Defuser (-10kg)
- Front side member (-6kg)
- Platform (-144kg)

Approx. 200 kg weight reduction

★ Approx. 200 kg weight reduction and improved safety by use of CFRP

“Innovation Global Warming Countermeasure Technology Program” (METI: 2003 to 2007)
- Example of Toray’s Advanced Materials -

Main Strategic Region

Technology Innovation

IT-related Materials  Automobile -Aircraft-  Life Science  Environment -Water-Energy-

New Materials


Nano Material

New Optical Film  New transparent & heat-resistance resin

Nano–multilayer Films  Nano-composite  Nanofibers  PLA Polymers

CNT  Nanoalloy  DDS  Membrane

Bio

Bio-pharmaceuticals  Bio-tools  Green Chemistry

Process

LCD Color Filters  Next Generation Molding  Human-friendly Material  Next Generation Recycling

PDP-related Materials  MBR
Pursuit of Ultimate Thin Fibers

Nano Material Innovation
Nanofibers

10,000nm (10 μm) 1,000nm (1 μm) 100nm 10nm

Conventional Fibers (Polyester, Nylon et.al.)

Microfibers (Polyester, Nylon et.al.)

Hair (~50 μm)

Man-made Suede

ECSAINE®
Innovation of Synthesis of Microfibers

Polymer-mosaic fibers (Islands in sea fibers) → Removing sea component → Microfibers

10 μm

Car interiors, Garments, Furniture, Industrial Materials

Man-made Suede (launched at 1970)

3 μm

40 μm

20 μm

Nano Material Innovation Nanofibers
Pursuit of Ultimate Thin Fibers

- **Conventional Fibers**
  - Polyester, Nylon et al.
  - Diameter: 50 μm

- **Microfibers**
  - Polyester, Nylon et al.
  - Diameter: 6 μm

- **Nanofibers**
  - Nylon, Polyester et al.
  - Diameter: 10 nm

- **Fiber Dispersion**
  - Man-made Suede
  - Ecsaine®

- **Hair**
  - Diameter: 50 μm

- **Bundles**
  - Aggregation

- **Nano Material Innovation**

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**TORAY**
Nanofibers

Pursuit of Ultimate Thin Fibers

- Surface area (m² g⁻¹)
  - Nanofibers
  - Microfibers
  - Conventional fibers

Amount of fibers to reach the moon
- Microfibers: 450g
- Nanofibers: 0.15g

Features
- fineness
- adsorption
- absorption
- slow release

Applications
- textile
- abrasive cloth
- filter
- medical device
- cosmetics

- commodity polymers: Nylon, Polyester, Polyolefin, etc.
- using existing plants
- Launched in 2006
Nano-Scale Technology for Processing Textile

(Policy) Pursue and develop “Seeing and finding nano-processing technology” “Wearing and understanding innovative function” in Toray’s textile ‘nano-scale technology for processing textile’.

“NanoMATRIX”
Continuous Coating on the single fiber surface by functional material

Expected advantages
- Level up function
- Improve durability of function
- Keep soft handle

Coating on the single fiber surface by functional material. Thickness: 10~30nm

SEM Photograph of Coated functional material on the single fiber

TEM photo of Coated single fiber cross-section

Bring a new products to market

★“BEAULAVAGE” (2004)
; Easy to wash out of rouge and etc. even if they stick

★“ANTI POLLEN” NT (2005)
; Easy not to stick pollens and easy to shake off
Nano-mutilayer Films

1000nm (=1 μm) 3 layers 100nm 10nm 1nm

Nano Effect

Tear Resistance (N/mm)

Better Thermal Shrinkage (%)

Single Layer Thickness (nm)

Expanding Applications

◆ Glass Protective Films (for safety & security)
◆ Electronic Materials
◆ Optical Functional Tapes

Nano Material Innovation Nano- multilayer Films

5nm PET Copolymerization PET

Copolymerization

PET

5nm

PET

Nano Effect

Better

Better
Nano-multiplex Films

Falling Ball Penetration Test

Failed

Penetrated

PET Film

Succeeded

[Newly Developed Film]

(Height 3m, Weight 2.2kg)

Expanding Applications

- Glass Protective Films (for safety & security)
- Electronic Materials
- Optical Functional Tapes

★ Launched in 2004
## Separation Membrane for Water Treatment

### - Types and Surface Morphologies -

<table>
<thead>
<tr>
<th>Size</th>
<th>1 nm</th>
<th>10 nm</th>
<th>100 nm</th>
<th>1000 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Ions, Small molecules</td>
<td>Polymers</td>
<td>Colloids</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monovalent ions</td>
<td>Organic matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multivalent ions</td>
<td></td>
<td>Viruses</td>
<td></td>
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<tr>
<td></td>
<td>Trihalomethanes</td>
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### Membrane

- **RO (Reverse Osmosis)**
- **NF (Nanofiltration)**
- **UF (Ultrafiltration)**
- **MF (Microfiltration)**

- Fine pores of RO Membrane (0.6~0.8nm)

### Applications

- **Seawater Desalination**
- **Drinking Water Production** (Removal of hardly decomposed substances)
- **Drinking Water production** (Removal of suspended solids & microorganisms)
- **Wastewater Reclamation & Reuse**

### Pursuit of limitation by deepening & fusion of membrane and microorganism technology
High Boron Rejection RO Membrane
(Separation Membrane for Seawater Desalination)

**New technology points**

- Densification of membrane structure by using precise molecule design & nanofabrication technology

**Concept**

- Boron (Diameter: 0.4nm)

**Performance of Membrane**

- Increase of boron removal rate

**[Positron Annihilation Spectroscopy]**

/ Nanostructure analysis technology by TRC

- Proof of correlation between pore size & boron removal (The world’s first quantification)

- Increase of boron removal rate

**Seawater RO desalination plant**

- Water Production (m3/m2/day)

- High Boron Rejection Membrane

- Conventional Membrane
High Boron Rejection RO Membrane
(Separation Membrane for Seawater Desalination)

Densification of membrane structure by using precise molecule design & nanofabrication technology

New technology points

Nano-pore Hollow Fiber Membrane for Artificial Kidney

Artificial Kidney

Nano-pore

(Radius : ~5nm)

Membrane surface

Specific removal of uremic substance from blood (first β2-microglobulin removal in the world)

Polymer Electrolyte Membrane for Fuel Cells (Direct Methanol Type)

Fuel Cells (Cell)

Anode

Cathode

Electrolyte Membrane
(Non-Fluorine)

Non-freezing water (Proton Conduction)

Methanol

Polymer

High ionic conductivity and low methanol cross over (1/10 of conventional membrane) (world top level)

Seawater RO desalination plant

Performance of Membrane

Concept

Proof of correlation between pore size & boron removal (The world's first quantification)

Pore diameter in each RO membrane

Seawater RO desalination plant

0.000 0.005 0.010 0.015 0.020 0.025 0.030 0.035 0.040

空孔半径 R / nm

相対強度(存在確率) / a.u.

增加倍率 of boron removal rate

Increase of boron removal rate

Pore diameter in each RO membrane

Conventional Membrane

Water Production (m3/m2/day)

Boron Removal (%)
Polymer Alloy/Nanoalloy

Polymer A + Polymer B

Conventional Alloy
- Transmission Electron Microscope photo
  (cross section of polymer)
- High impact PA
- High impact PBT
- High impact PPS

Phase-inversed Alloy
- Low water absorption PA

Nano-dispersed Alloy
- High thermal resistant PLA
- High thermal resistant PET
- Flexible PLA

Nano-co-continuous Alloy
- High chemical resistant PET
- Innovative PBT/PC

Polymer Design
Compatibilizer Design
+ Nano-dispersing Technology
Nano-co-continuous Alloy

Toray succeeded in developing a world’s first nano-alloy technology which makes it possible to combine only the best properties of two different polymers.

We plan to place the material on the market within one year, especially for automobile parts, electric and electronic parts, and transparent sheet and so on.
Toray is developing non-petrochemical raw materials making full use of Toray’s technologies.
Example of Application of PLA Polymer

**Improved heat-resistance**

Improved heat-resistance with original nanoalloy technology

**Non-halogenated flame-retardant**

Improved heat-resistance and realized high-level of flame-retardancy with nanoalloy technology and non-halogenated flame-retardant technology

★ Enhancing performances of PLA for electronics use with Toray’s original nanoalloy technologies.

★ Toray has contributed to global environment thorough reduction of CO2 emission and fossil resources consumption.
## Example of Toray’s Advanced Materials

### Main Strategic Region

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*Note: The image contains a diagram with various materials and technologies listed under different strategic regions.*
Interferon

Natural Human Interferon-β : Feron*

Establishment of large scale production technology (Beads culture)

The world first interferon product

Launched in 1985 (Toray, Daiichi)

Indication: Hepatitis B & C, Melanoma/Brain tumors

Fibroblast cells on the beads

New Drug Research

We discovered the optimum binding site of PEG on IFN (●)

Innovated the active PEGylated IFN-β (World’s first)

- Improved and durable therapeutic effects
- Many indications (Start clinical trial in 2008)

4 nm Polyethylene Glycol (PEG)

~140 nm

Interferon Stereo Structure

Structure elucidation of mouse interferon-β
(Tokyo Univ. & Toray)
DNA Chip

Appearance
High performance DNA chip
“3D-Gene”

Feature of TORAY DNA chip
- Flat substrate (conventional)
- Columnar structure (newly developed)
- Probe DNA
  - Conventional glass chip
  - Next generation plastic chip
- Columnar structure
- Increased probe DNA
- Accelerated reaction

High sensitivity

Performance of Toray’s DNA chip
Sensitivity: 100-fold higher than conventional chip

RNA amount (μg)

Signal/Noise

This project is partially supported by NEDO.
We have developed the diagnostic use Lab-on-a-Chip made of plastics. (Only-one in the world)
R&D Strategy of Bio-tools

Patient

Conventional diagnostic Tests

Specimens (cells and tissues)

Blood

Academia

Kyoto Univ. (cancer) et. al.

Clinical Info.

Genetic Info. (DNA Chip)

Proteome Info. (Lab-on-a-chip)

Toray

Creation of Integrated Database

Focused Disease related Genes/Proteins

Diagnostic Markers Evidence by inspection Drug Target Molecule

Development of Exam/Diagnostic Tools
*High-performance DNA Chips
*High-performance Protein Analysis

Development of New Drugs

Development of Bio-tools
- Example of Toray’s Advanced Materials -

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MBR
Pursuit of Particle Dispersion Technology

Nano-level Particle Dispersion

10 μm 1 μm 100nm 10nm 1nm

Particle Size

Micro size particles

Aggregating nano size particles

Opaque

Aggregate

Visible light wavelength

Nano size Particles

Transparent

Light

★ Expected Effect of Deepening of Nano Dispersion Technology :
Control of refractive index, Improvement of Optical property, Fulfill New function
Pigment of LCD Color Filter (CF)

Structure of LCD

- LCD TV
- CF
- TFT
- Back Light
- Liquid Crystal

Clear, Bright Display
Suppression of Light Scattering by CF
(Measure: Contrast Ratio)

Key Point: Nano-dispersion of Pigment Particle

Stabilization of Nano-Dispersion for Nano-Pigment

- Toray’s Technology
- Aggregated Nano-Pigment

Contrast Ratio: 1.8

- 100nm
- 100nm

Conventional Technology

- Frequency (%)
- Pigment Particle Size (nm)

★ 1.8 times higher Contrast Ratio → Already Applied to Mass Production
PDP Rear Panel Paste Materials

**Structure of PDP**

- Glass substrate
- Electrode
- Dielectric layer
- Barrier rib
- Phosphor

**Rear Panel Paste Materials**

- Photosensitive barrier rib paste
- Photosensitive electrode (silver) paste
- Dielectric paste
- Phosphor paste (Red, Green, Blue)

**TORAY’s technology for forming barrier rib by applying photosensitive glass paste**

1. Short process & High productivity
2. Flexibility of pattern shape
3. High accuracy forming

**Full high definition (barrier rib pitch)**

- 270 μm (HD)
- <150 μm (Full HD)

**Supply to the world largest factory of the MPDP (250,000 sets/month)**
Toray’s Challenge for Technology Innovation

- **Pursuit of Limits**
  - Innovation by Chemistry
  - Toray’s Core Technology

- **Technology Innovation**
  - New Material
  - Nano-material
  - Biotechnology
  - Process

- **Main Strategic Area**
  - Information & Telecommunication
  - Automobile /Aircraft
  - Life Science
  - Environment /Water/Energy

Aiming at the Most Excellent Company for Advanced Materials by Challenging Technology Innovation
Advanced Materials for Pioneering 21st Century

- Biotechnology
- Nanotechnology
- Environment, Safety & Security
- Integration of Technology
- Pursuit of Limits

Generation of Advanced Materials with Technology Innovation

Innovative Solutions and Products Only Come with Innovative Materials