INOEL Yamagata University
Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Academia-Industry Cooperation "Needs First"

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

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Professor
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"Award from Minister of State for Science and Technology Policy" Cabinet Office, Government of Japan (2017)

Activity

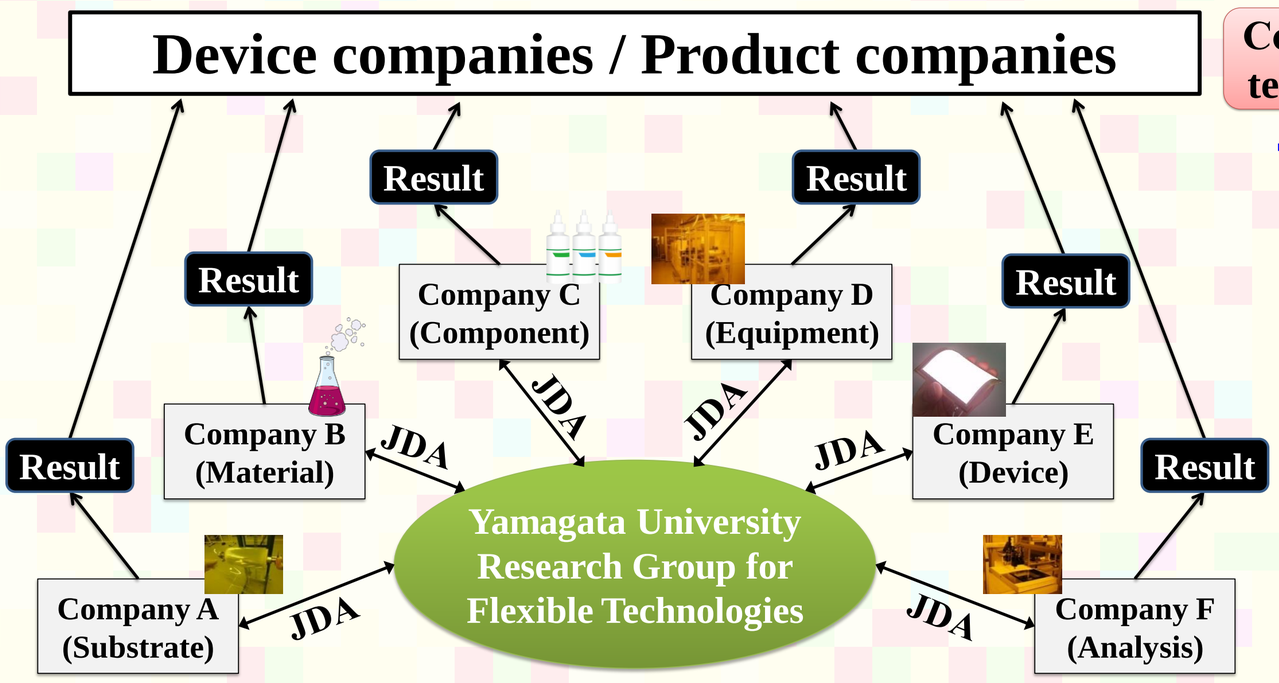
Mission and Activity

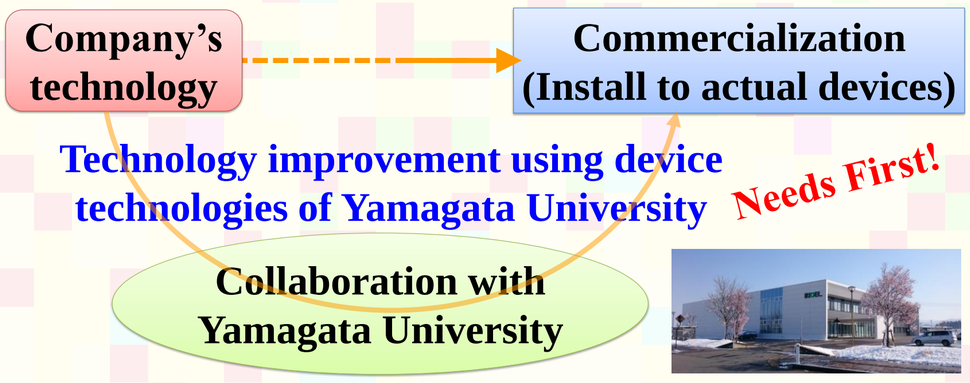
In flexible organic electronics technologies, we offer academia-industry collaboration with "Needs First", in which needs and requests from collaborating companies are the first priority.
We support R&D for practical technologies of the collaborating companies, aiming at contribution to actual businesses.
Our activity with "Needs First" was awarded from Minister of State for Science and Technology Policy, Government of Japan in 2017.

"Award from Minister of State for Science and Technology Policy" Cabinet Office, Government of Japan (2017)

(Main technologies)

- OLED devices and processes
- Materials and components for flexible organic electronics
- Flexible substrates (ultra-thin glass, stainless steel foil, barrier film)
- Barrier technologies / Barrier evaluation and analysis
- Flexible encapsulating technologies
- Printing and roll-to-roll (R2R) technologies for flexible organic electronics





- ✓Experts for practical development
- ✓Evaluation in terms of practical devices
- ✓Prototype using G1 substrate
- ✓Feedback of all data and prototype samples to collaborating company for the utilizing to their business.
- ✓Merits for IPs

Features

- "Needs First" (Business First)
  Company's needs is the first priority
- Merits in IPs
- Self-supporting accounting system
  Unique model based on collaboration with industry
- Individual collaboration / Consortium

Activities

- Support to company's R&D
- Evaluation by actual devices
- Proposal of solution
- Prototype samples

Skills

- Flexible substrate
- OLED devices and processes
- Barrier technologies
- Barrier evaluation and analysis
- Printing and R2R

Cooperation

- Academia-Industry Cooperation Consortium (p.3～p.5)
  1) Yamagata University Flexible Organic Electronics Practical Key Technology Consortium (YU-FOC) [Apr. 2016～Mar. 2019]
  2) Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2021] (p.4)
  3) Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) [Jan. 2018～Mar. 2023] (p.5)
- National Project (p.3)
- Individual Collaboration
- Evaluation support (p.8)
  WVTR (Water Vapor Transmission Rate) evaluation with MORESCO

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Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Activity

Academia-Industry Collaboration “Needs First!”

Our concept is “Needs First”, in which needs and requests from participating companies are the first priority in our academia-industry cooperation.

Academia-Industry Collaboration Consortium

FY2013 FY2014 FY2015 FY2016 FY2017 FY2018 FY2019 FY2020

“Award from Minister of State for Science and Technology Policy”, Cabinet Office, Government of Japan (2017)

Support from MITI

Yamagata University Organic Thin Film Device Consortium

non-ITO electrode
Barrier / Planarization
Flexible substrate

Flexible substrate with non-ITO transparent electrode

21 companies

Yamagata University Flexible Organic Electronics Practical Key Technology Consortium（YU-FOC）

Flexible substrate
Encapsulating layer
Cathode
Organic layers
non-ITO electrode
Barrier / Planarization
Flexible substrate

Flexible organic electronics device

6 Companies (Jan. 2019)
FEBACS / SCREEN Finetech Solutions, Nippon Electric Glass, SERIA ENGINEERING, Shin-Etsu Chemical, TOYO INK, TEIJIN

Mr. Furukawa

Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC)

14 Companies (Jan. 2019)
FUJIKURA KASEI, The Japan Steel Works, KEIHIN RAMTECH, KOMORI, Mitsuboshi Diamond Industrial, Nippon Electric Glass, Nippon Steel Chemical & Material, SEIEIDO Printing, SERIA ENGINEERING, SurFtech, TAKEDA PRINTING, TEIJIN, Tokyo Process Service, WIREDGATE

Needs First!

Dr. Yuki

Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC)

7 companies (Jan.2019)

Participation to National Projects

FY2013 FY2014 FY2015 FY2016 FY2017 FY2018 FY2019 FY2020 FY2021 FY2022

MEXT: Regional Innovation Strategy Support Program

MEXT: Regional Innovation Eco-system Program

MEXT: Construction Program of Open Innovation Organization

JST: A-STEP

JST: Program on Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA)

JST: Program on Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA)

MITI: “R&D subsidiary program for promotion of academia-industry cooperation”

NEDO Project

NEDO: Development of high efficient OLED materials

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Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Consortium

Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC)

Yamagata University has constructed close connection with Saxony/Dresden in Germany in the field of organic electronics, coworking with Yamagata prefecture and Yonezawa city. Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) collaborates with companies and institutes in Germany, aiming at novel flexible electronics products.

Project term

October 2017 ～ March 2021

Subjects

- LAOLA: Large Area Organic Lighting Applications on ultra-thin substrates
- IonT: Internet on Things - Intelligent OLED-OPV based Signage for interactive Advertisement
- F2E: Free Form Electronics - Freedom in design by thermo-formed printed electronics

Leaders

- Project leader: Associate Prof. T. Furukawa
- Fellow: Prof. T. Takahashi
- Secretary: Prof. M. Koden

Participants (Jan. 2019)

FUJIKURA KASEI CO., LTD.
KEIHIN RAMTECH CO., LTD.
KOMORI Corporation
Mitsuboshi Diamond Industrial Co., Ltd.
Nippon Electric Glass Co., Ltd.
NIPPON STEEL Chemical & Material Co., Ltd.
Seieido Printing Co., Ltd.
SERIA ENGINEERING, INC.
SurFtech Transnational Co., Ltd.
TAKEDA PRINTING CO., LTD.
TEIJIN LIMITED
Tokyo Process Service Co., Ltd.
The Japan Steel Works, LTD.
WIREDGATE Inc.

Collaboration with German activity

YU-FIC collaborates with 24 German companies and institutes which are organized by Organic Electronics Saxony (OES), having twice visits a every year, respectively.

Activity

Germany (Nov. 2017)

Japan (Feb. 2018)

LOPEC/Germany (Mar. 2018)

Germany (Sep. 2018)

Nippon Electric Glass

Mitsuboshi Diamond

Fintech 2018 (Dec. 2018)

IDW'18 (Dec. 2018)

Related program

- JST: Program on Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA) [FY2016～FY2020]
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]
- MEXT: Regional Innovation Eco-system Program [FY2018～FY2022]

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Consortium

Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC)

Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) is constructed by one-by-one collaboration with individual companies, proposing practical development based on the concept of "Needs First". We would appreciate it if you are interested in YU-FLEC.

Project term

January 2018 ～ March 2023

Participants

7 Companies (Jan. 2019)

Subjects

- Flexible electronics
- Organic electronics such as OLED
- Others which collaborating companies request

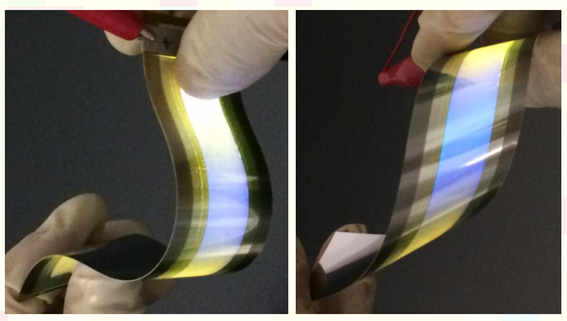
Leaders

- Project leader: Associate Prof. T. Yuki
- Fellow: Prof. H. Nakada
- Secretary: Prof. M. Koden

Activity

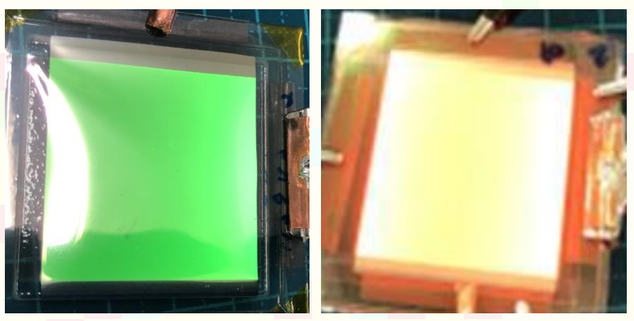
■ **Flexible OLEDs on stainless steel foil (p.11)**
(Nippon Steel & Sumitomo Metal Corporation)

- ✓ To apply stainless steel foil with excellent gas barrier, temperature stability chemical stability, size stability, etc. to flexible OLEDs
- ✓ To fabricate electrodes on stainless steel foil by using roll-to-roll (R2R) technologies



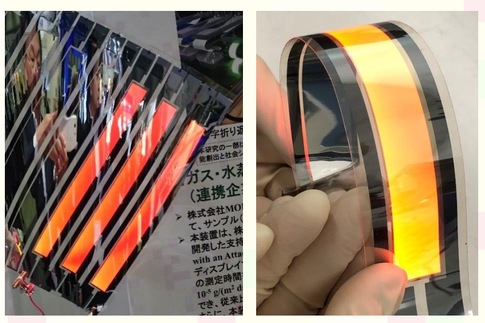
■ **Barrier films with high temperature tolerance for flexible OLEDs (p.13)**
（KURABO INDUSTRIES LTD.）

- ✓ To apply barrier films with high temperature tolerance to flexible OLEDs



■ **Flexible encapsulating technologies for OLEDs (p.18)**
（Ajinomoto Co., Inc. / Ajinomoto Fine-Techno Co., Inc.）

- ✓ To develop laminating encapsulation for flexible OLEDs



■ **Solution materials for novel light emitting devices.**

- ✓ To evaluate solution materials for novel light emitting devices
- ✓ To develop novel light emitting devices with solution materials

■ **Equipment technologies for OLEDs**

- ✓ To develop novel technologies for OLED fabrication equipment

Related program

●MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]

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Background technologies

OLED Device Fabrication

Various types of OLED devices are fabricated based on the requests from collaborating companies. The fabricated OLED devices are utilized for the evaluation of technology potential and prototype samples.

Material

- Small molecular OLED materials
- Polymer OLED materials
- Fluorescent, phosphorescent and TADF materials
- Quantum dot (QD) materials

Device structure

- Bottom emitting OLED
- Top-emitting OLED
- Transparent OLED (Both side emitting)

Barrier layer

- Inorganic barrier layer: CVD, Sputtering, ALD
- Inorganic/organic alternative stacking barrier layer

R2R sputtering & CVD

Sputtering

Ink-jet

Process for organic layers

- Vacuum evaporation
- Solution processes: Spin-coat, Ink-jet, etc.

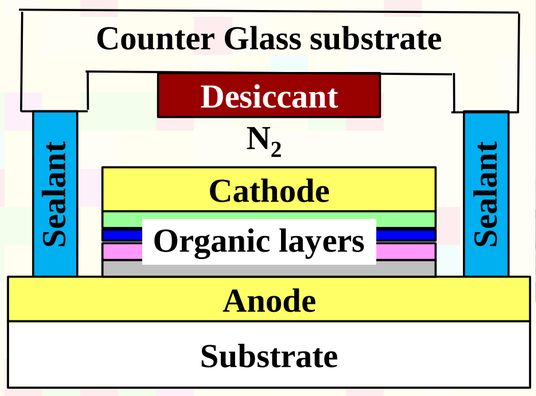
Vacuum evaporation

Ink-jet

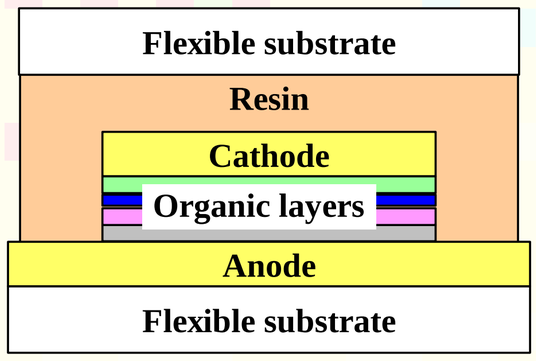
Encapsulation

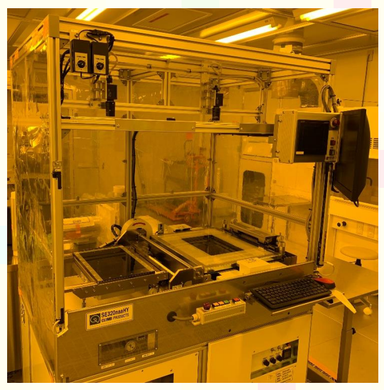
Various encapsulating technologies are applied

- Common encapsulation with desiccant
- Laminating encapsulation



Sheet-type lamination



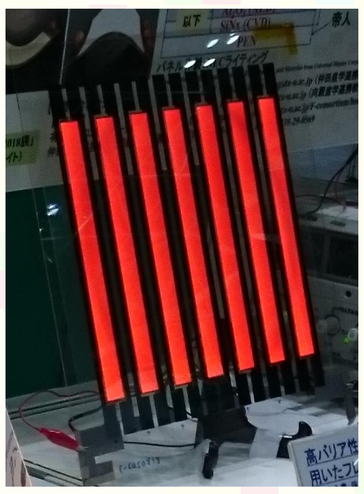


Roll-type lamination

Large size OLED

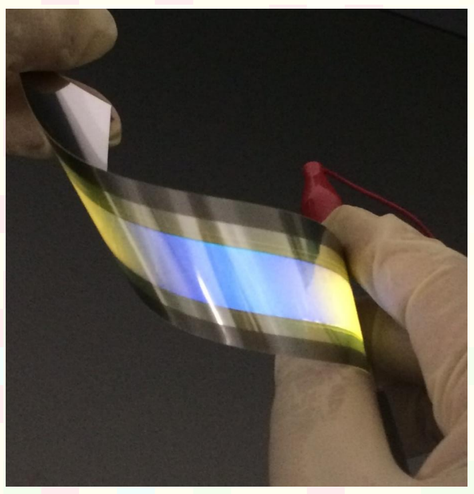
Large size OLED devices can be fabricated.
The maximum substrate size: 30cm × 30cm

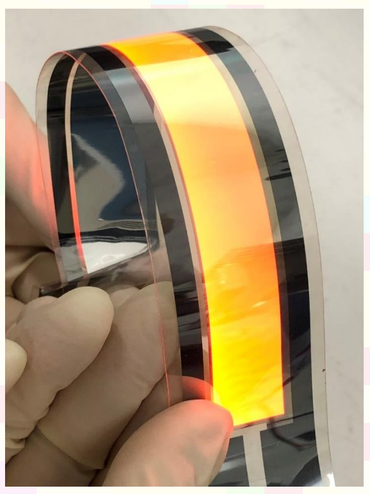
OLED vacuum evaporation equipment “ELVESS” (Tokki)



Flexible OLED

Flexible OLED devices with various designs can be fabricated.





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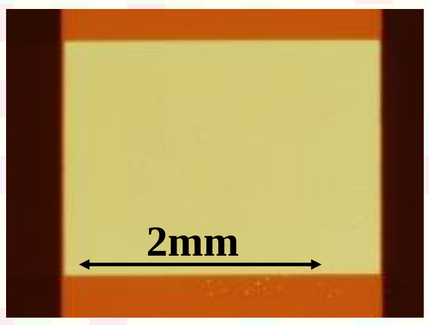
Background technologies

Evaluation of OLED Materials and Devices

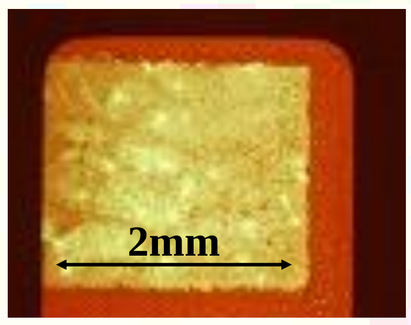
OLED devices with technologies of collaborating companies are evaluated from practical points of view. All evaluating results are feedbacked to the collaborating company and can be utilized to not only the next development but also the demonstration to their customers.

Emission uniformity

- Emission quality such as uniformity, defects, etc. of OLED devices are evaluated by visual microscopic observations.



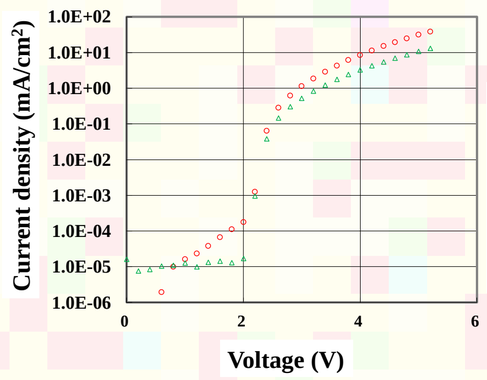
Uniform emission



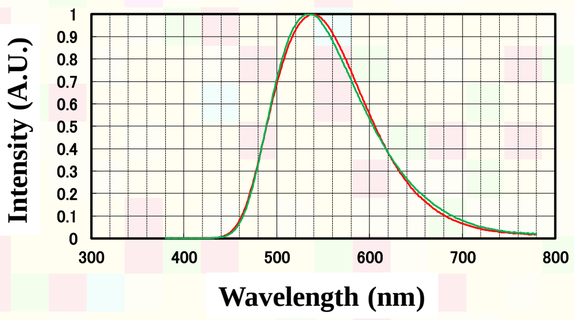
Non-uniform emission with defects

I-L-V characteristics

- OLED device characteristics are evaluated.
  * I-V characteristics
  * L-I characteristics
  * Emission spectrum, etc.



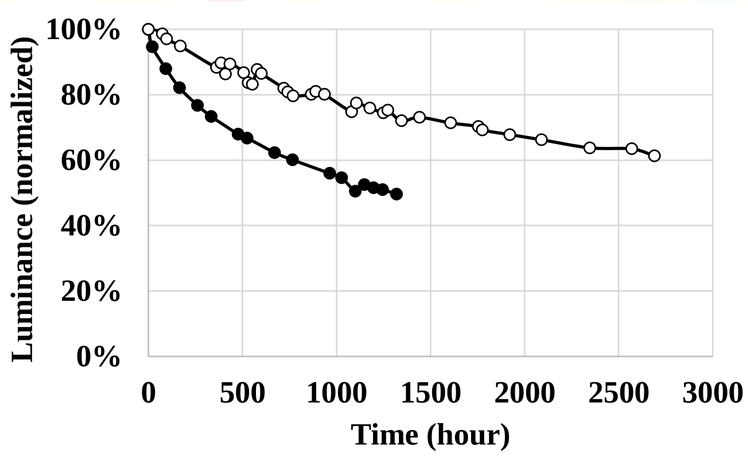
I-V characteristics



Emission spectrum

Driving lifetime

The reduction of emission intensity of OLED devices under constant current driving is evaluated.

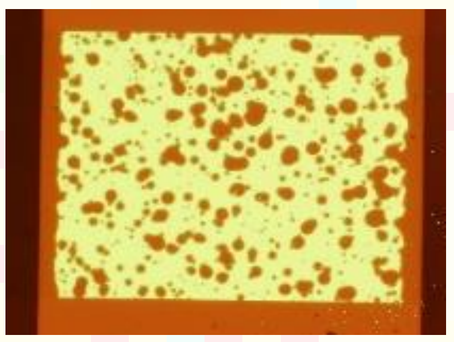


Driving lifetime

Storage lifetime

The change of emission is observed after storage test with high temperature and high humidity.

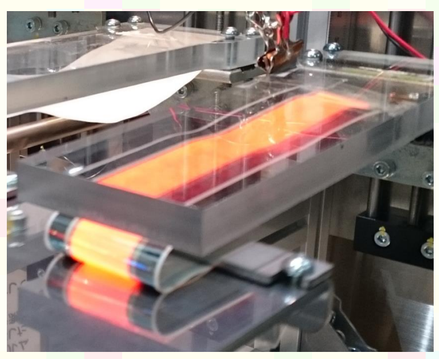
Initial emission (No defect)



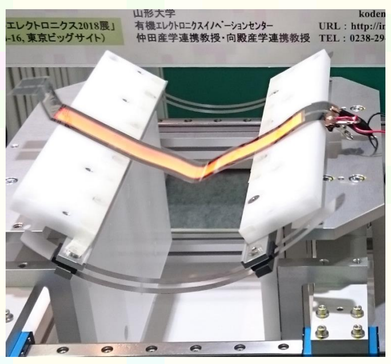
Emission after storage test (Dark spot)

Bending tests

The influences of various bending stress on device characteristics, lifetime, etc. are evaluated using bending equipment.



U-shape sliding



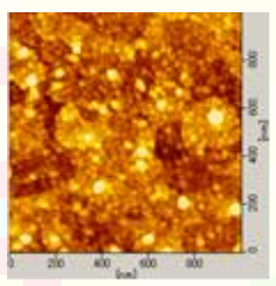
Folding

Both-side bending

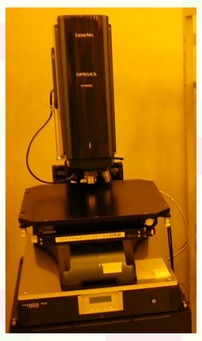
Others

Other evaluations can be used, based on the request from collaborating companies.
(Example)

- Defect analysis
- SEM, AFM
- 3D profile, etc.



AFM



Hybrid confocal microscopy

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Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

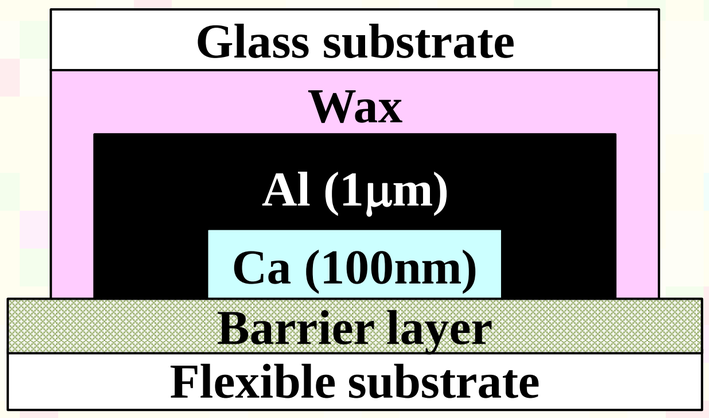
Background technologies

Evaluation of Barrier Properties

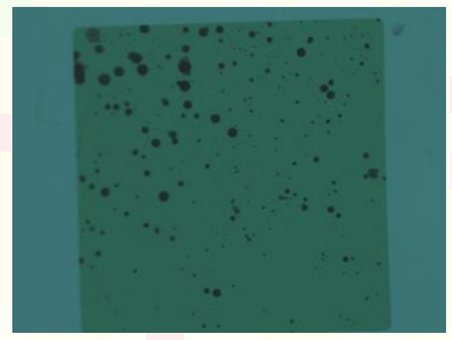
Evaluation of barrier properties is very important in flexible organic electronics development. We provide two evaluation methods which are "Calcium corrosion method" and "MA method (Modified differential pressure method with an Attached support)".

Ca corrosion method

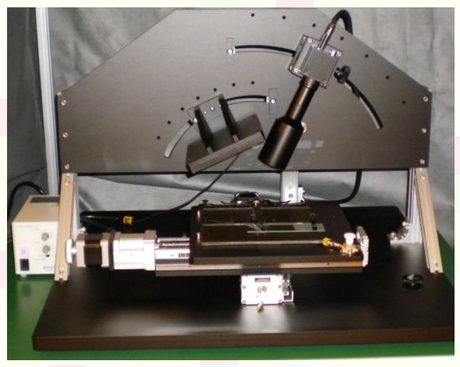
- ✓ **Ca corrosion method utilizes the change in Ca reflectivity which changes by the reaction of Ca and H_2O. This method is useful for the evaluation of defects in barrier layer.**
- ✓ **WVTR (Water Vapor Transmission Rate) is calculated from the evaluation results in Ca corrosion method.**



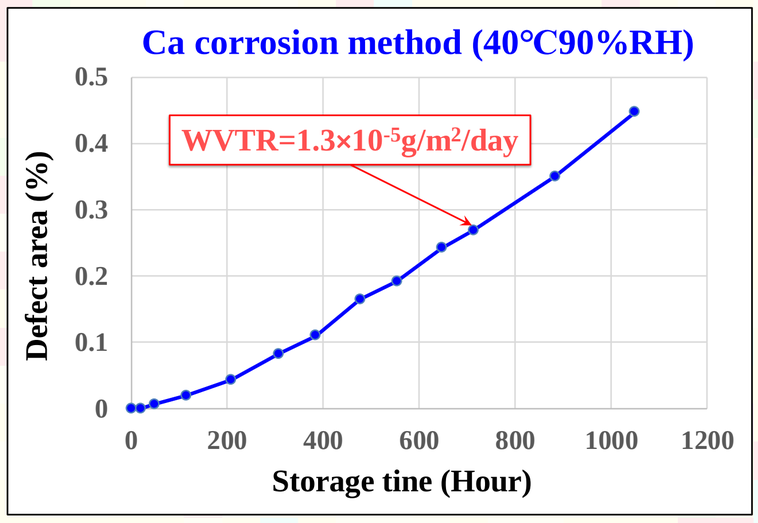
Structure of Ca corrosion device



Microscopic observation of Ca corrosion



Evaluation equipment of Ca corrosion

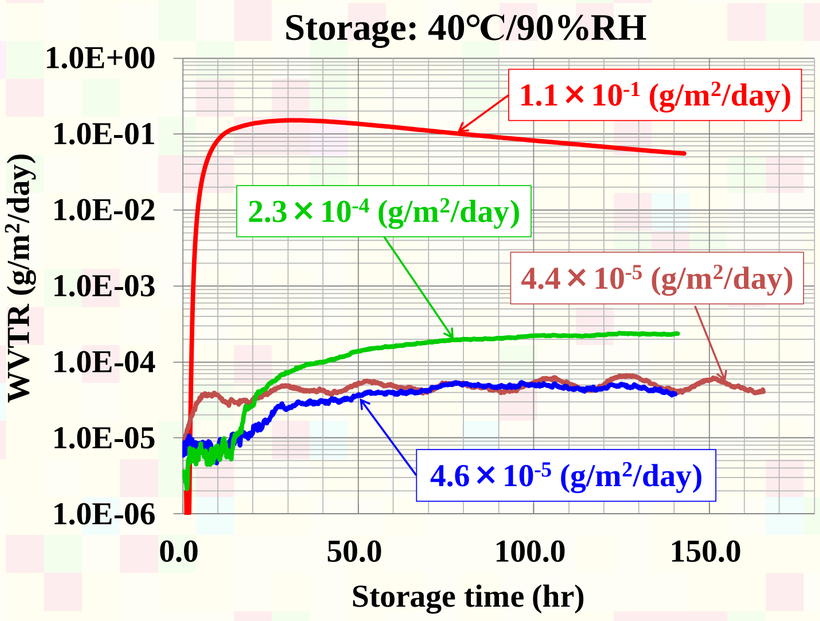


WVTR calculation from Ca corrosion test

MA method

WVTR (Water Vapor Transmission Rate) evaluation (Collaborating with MORESCO)

- ➢ **We provide WVTR (Water Vapor Transmission Rate) evaluation, using the WVTR measurement equipment "Super Detect" of MORESCO.**
- ➢ **The "Super Detect" utilizes the MA method (Modified differential pressure method with an Attached support) developed by the collaboration of MORESCO and AIST (National Institute of Advanced Industrial Science and Technology).**
- ➢ **The MA method reduces measurement time of high gas barrier film such as higher than 10^{-4} g/(m^2 day), which are required in flexible OLED, OPV, etc. For example, the "Super Detect" requires only about 20 hours for the WVTR measurement of barrier films with the order of 10^{-5} g/(m^2 day), for which the previous methods require about 100 hours. It should be noticed that the measurement time of the "Super Detect" is only 1/5 of previous methods.**
- ➢ **In addition, the "Super Detect" is able to evaluate wide ranges of WVTR such as 10^{+1}~10^{-7} g/(m^2 day).**
- ➢ **The "Super Detect" with the MA method is able to warrant the WVTR value by the attached compensating unit developed by AIST.**
- ➢ **Moreover, the "Super Detect" is able to evaluate the transmission rate of not only water vapor but also various gasses.**



WVTR equipment (MA method)

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Background technologies

Printing and Roll-to-roll (R2R) Technologies

We provide printing and roll-to-roll (R2R) technologies, aiming at an innovation of production in flexible organic electronics.

Printing / Coating

Various printing and coating equipment can be utilized for printing tests and device fabrications.

Screen printing

Flexography and gravure offset printing

Ink-jet

Spin-coating

Roll-to-roll (R2R)

Four types of unique roll-to-roll (R2R) equipment are utilized for fabrications of electrodes, barrier layers, organic layers, etc.

- **Substrate width : 30cm**
- **Substrate: ultra-thin glass, stainless steel foil, flexible film**

R2R sputtering &CVD (KOBELCO)

R2R screen printing (SERIA)

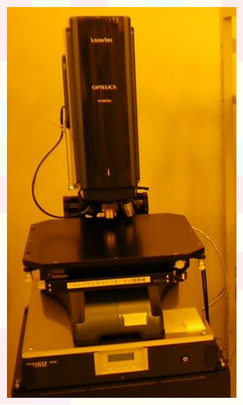
R2R gravure offset and flexography printing (Komori Machinery / Taiyo Kikai)

R2R wet cleaning (FEBACS)

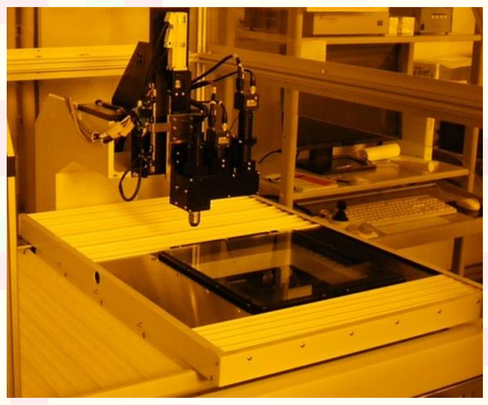
Evaluation

Various evaluation equipment are used for R&D of printing and roll-to-roll (R2R) technologies.

Viscoelasticity measurement



Hybrid confocal microscopy



Precise position detector

Contact angle measurement

Related prpgram

- **MITI: “R&D subsidiary program for promotion of academia-industry cooperation” [FY2013～FY2014]**
- **MEXT: Regional Innovation Strategy Support Program [FY2011～FY2015]**

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

Flexible OLEDs on Ultra-Thin Glass

We develop flexible OLED devices on ultra-thin glass G-Leaf® (Nippon Electric Glass).

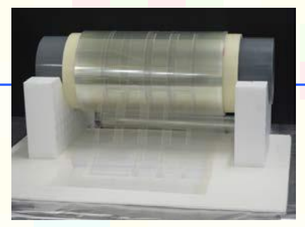
Technological features

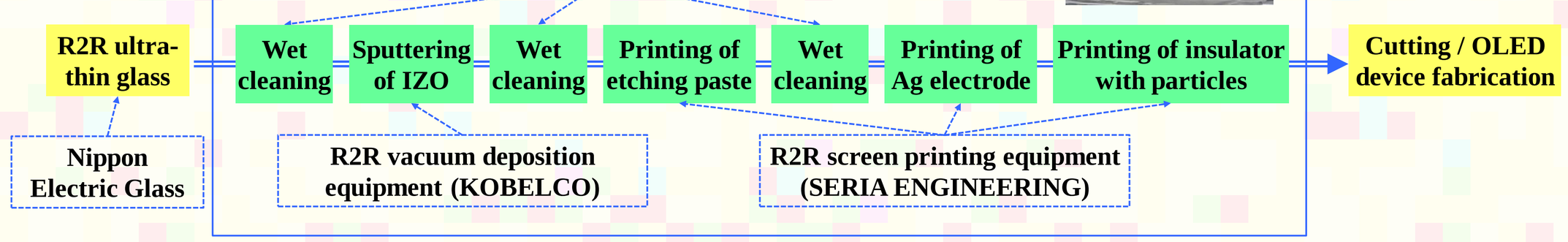
■ Advantages of ultra-thin glass G-Leaf® of Nippon Electric Glass
- ・Flexible and roll shape due to thin thickness such as 50μm
- ・Intrinsic advantages of glass (gas barrier, surface smoothness, temperature stability, chemical stability, size stability, etc.)

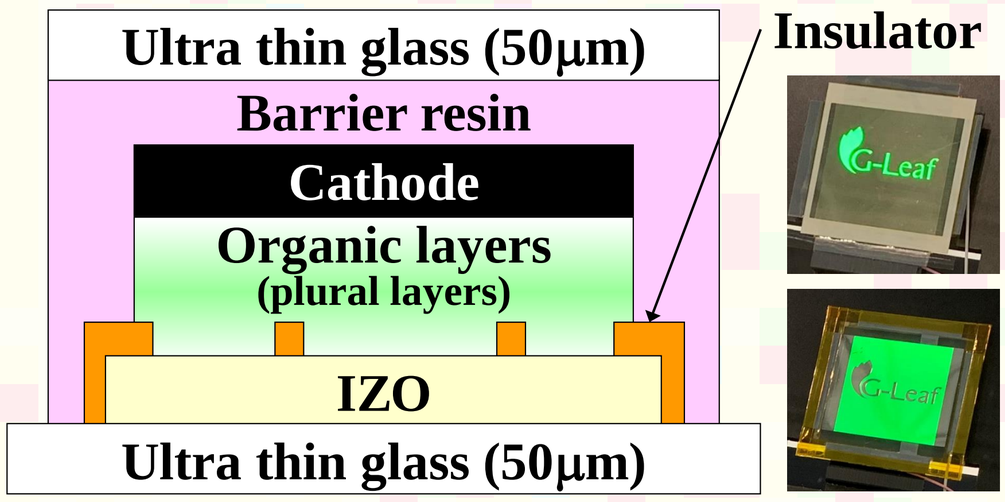
■ Application of ultra-thin glass to flexible OLED devices.
- ・Handling technologies overcoming the brittleness of ultra-thin glass

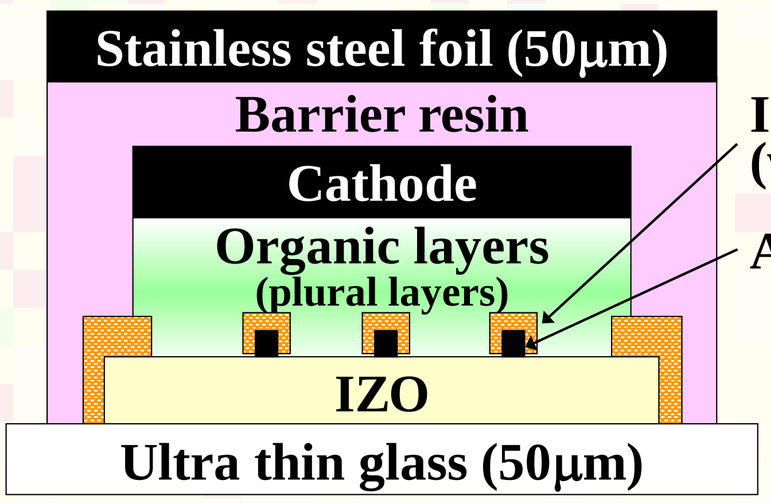
Developed technologies

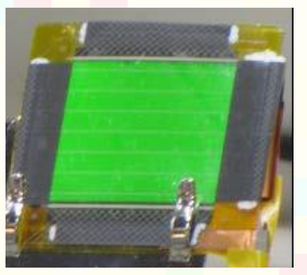
■ Flexible OLED devices on ultra-thin glass with the thickness of 50μm
- ・Roll-to-roll (R2R) fabrication of transparent electrodes on ultra-thin glass without photolithography
- ・Application of ultra-thin glass to OLED substrate and encapsulating substrate.











Collaboration

Nippon Electric Glass, SERIA ENGINEERING, FEBACS, Mitsuboshi Diamond Industrial, NIPPON STEEL Chemical & Material

Related program

- Yamagata University Flexible Organic Electronics Practical Key Technology Consortium (YU-FOC) [Apr. 2016～Mar. 2019]
- Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2021]
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]

Publication

- Nippon Electric Glass; “LED JAPAN 2018” (Oct. 2018), “FINETECH JAPAN 2018” (Dec. 2018).
- Mitsuboshi Diamond Industrial; “FINETECH JAPAN 2018” (Dec. 2018).
- T. Furukawa, N. Kawamura, T. Noda, Y. Hasegawa, D. Kobayashi, M. Koden, *IDW’17*, FLX6-2 (2017). “Novel Roll-to-Roll Fabrication Processes of Transparent Electrodes on Ultra-Thin Glass”
- T. Furukawa, M. Koden, *IEICE Trans. Electron*, E100-C, 949-954 (2017). “Novel roll-to-roll deposition and patterning of ITO on ultra-thin glass for flexible OLEDs”

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

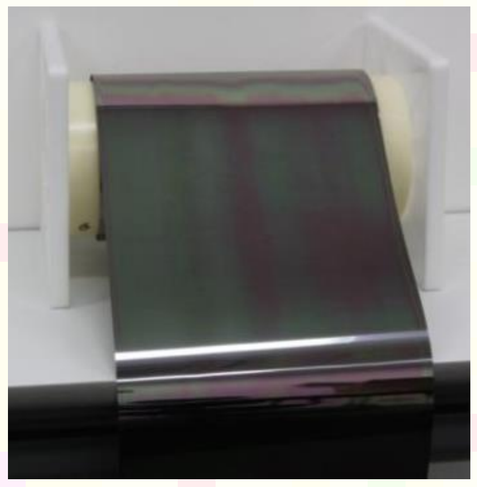
Flexible OLEDs on Stainless Steel Foil

We develop flexible OLED devices with stainless steel foil (thickness: 50μm) of NIPPON STEEL & SUMITOMO METAL CORPORATION GROUP.

Technological features

■ **Advantages of stainless steel foils of NIPPON STEEL & SUMITOMO METAL CORPORATION GROUP**

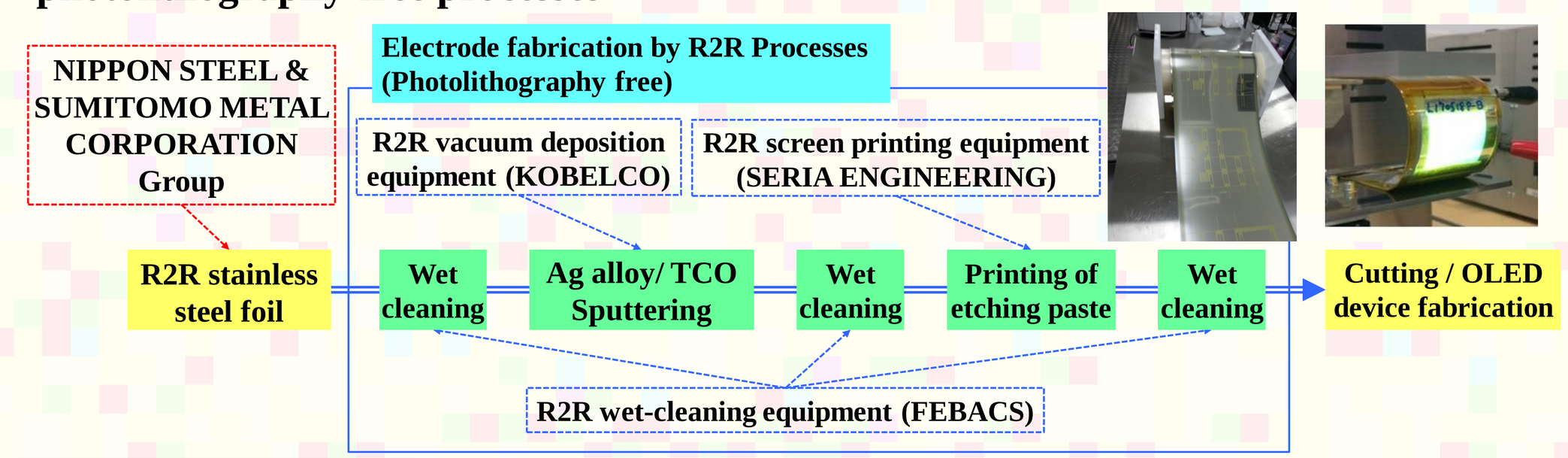
- **Thickness: 50μm**
- **Excellent surface smoothness（Ra～0.6nm）**
- **Excellent temperature and process resistances**
- **High gas barrier ability**



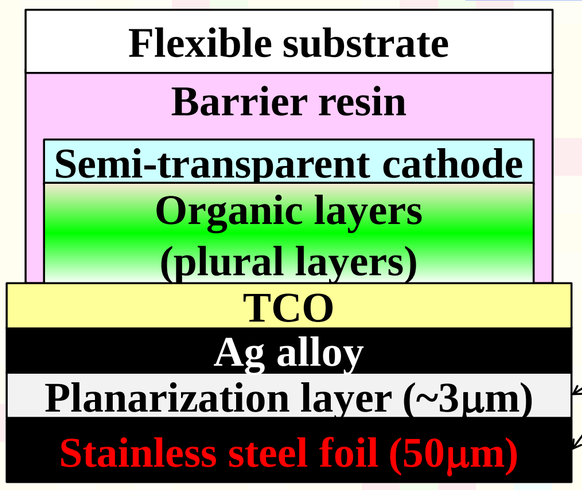
Stainless steel foil

Developed technologies

■ **Flexible OLED on stainless steel foil**
Electrode (reflective anode) is fabricated on stainless steel foil by roll-to-roll (R2R) photolithography-free processes



Flexible OLEDs on stainless steel foil



NIPPON STEEL & SUMITOMO METAL CORPORATION Group

(TCO: Transparent conducting oxide)

Collaboration NIPPON STEEL & SUMITOMO METAL CORPORATION GROUP

Related program

- Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) [Jan. 2018～Mar. 2023]
- Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2021]
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]

Publication

- Y. Hagiwara, T. Furukawa, T. Yuki, S. Yamaguchi, N. Yamada, J. Nakatsuka, M. Koden, H. Nakada, *IDW'17*, FLXp1-9L(2017). "Roll-to-Roll Patterning of Reflective Electrode on Planarized Stainless Steel Foil"
- M. Koden, T. Furukawa, T. Yuki, H. Kobayashi, H. Nakada, *IDW/AD'16*, FLX3-1 (2016). "Substrates and Non-ITO Electrodes for Flexible OLEDs"
- Y. Hagiwara, H. Itoh, T. Furukawa, H. Kobayashi, S. Yamaguchi, N. Yamada, J. Nakatsuka, M. Koden, H. Nakada, *IDW/AD'16*, FLXp1-5 (2016). "Roll-to-Roll Processing of Silver/ITO Continuous Deposition on Planarized Stainless Steel Foil"

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

Barrier Films for Flexible OLEDs

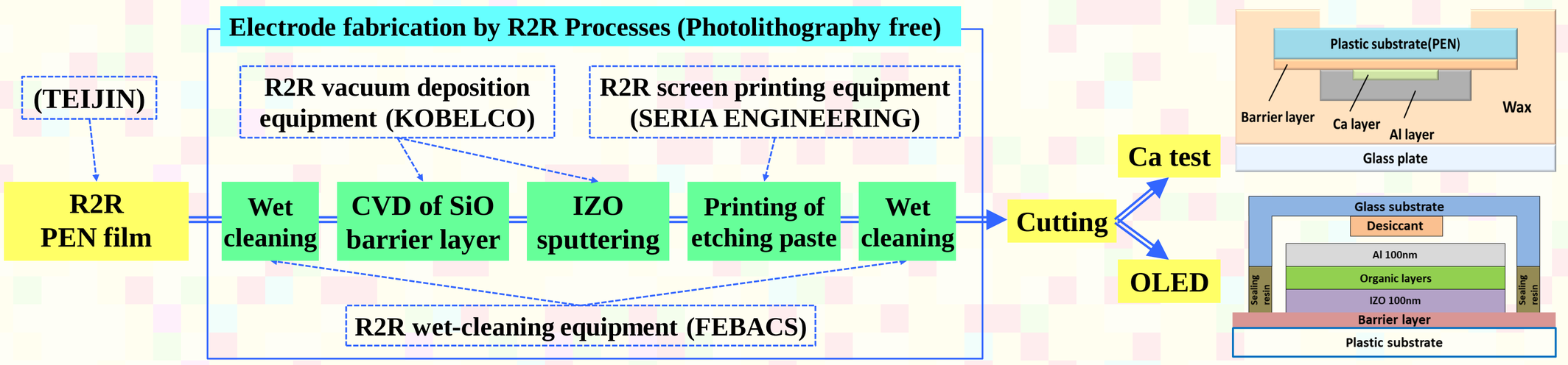
We develop fabrication technologies of gas barrier layer on PEN film (TEIJIN), using roll-to-roll (R2R) PE-CVD.

Technological features

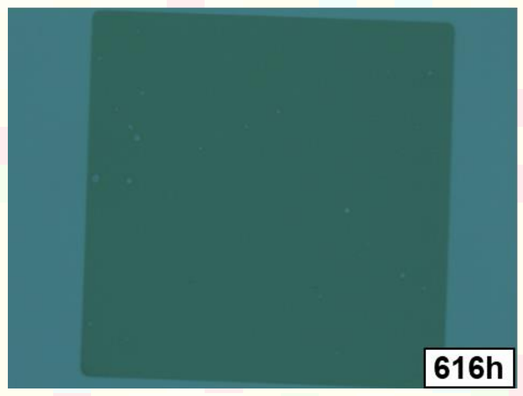
- Roll-to-roll (R2R) PE-CVD deposition of gas barrier layer on PEN film
- High barrier ability with WVTR of the order of 10^{-6}g/m^2/day
- High gas barrier films with transparent electrode

Developed technologies

- Roll-to-roll (R2R) fabrication of barrier layer and transparent electrode on PEN film

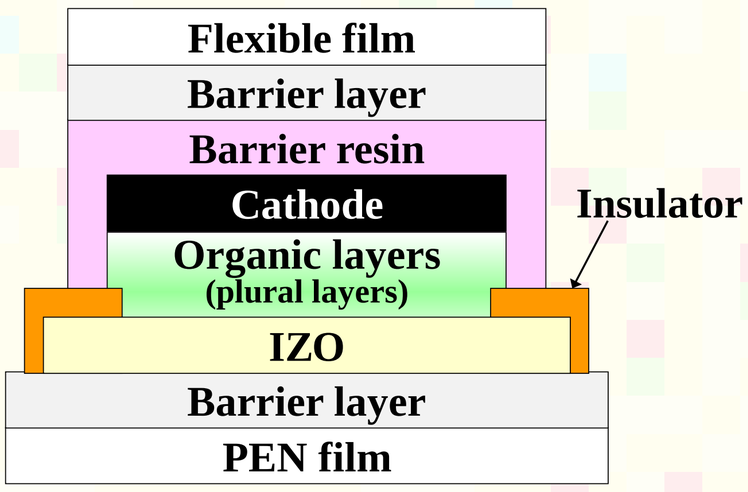


- High gas barrier property (WVTR: 6.3×10^{-6}g/m^2/day)



Ca corrosion device after 616 hours under 40℃/90%RH
(Thickness of barrier layer: 720nm)

- Flexible OLED devices



Collaboration TEIJIN LIMITED, Tosoh Corporation, FEBACS CO., LTD.

Related program

- Yamagata University Flexible Organic Electronics Practical Key Technology Consortium (YU-FOC) [Apr. 2016～Mar. 2019]
- Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2021]
- JST: Program on Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA) [FY2016～FY2020]
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]

Publication

- K. Taira, Taiga Suzuki, W. Konno, H Chiba, H. Itoh, M. Koden, T. Takahashi, T. Furukawa, *IDW'18*, FLX2-4L (2019). "Development of High Gas Barrier Film Using Novel Precursor by Roll to Roll PECVD"
- ・T. Suzuki, W. Konno, K. Taira, H Chiba, H. Itoh, M. Koden, T. Takahashi, T. Furukawa, *IDW'18*, FLXp1-10L (2019). "High Gas Barrier Films with Heterogeneous Multilayer"
- K. Taira, T. Furukawa, N. Kawamura, M. Koden, T. Takahashi, *IDW'17*, FLXp1-8L (2018). "High gas barrier film for OLED"

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

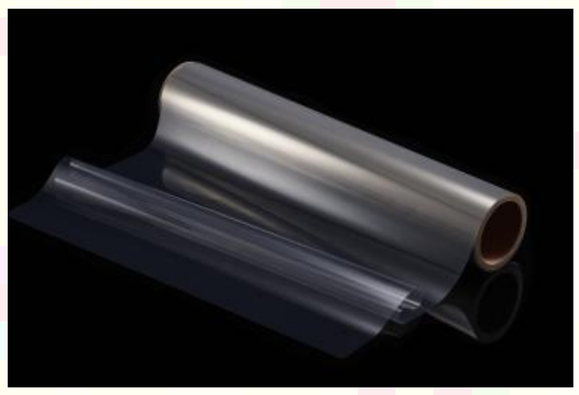
Developed technologies

High Temperature Tolerant Barrier Films for Flexible OLEDs

OLED fabrication often requires high temperature processes (higher than 200℃). From this point of view, we develop high temperature tolerant barrier films for flexible OLEDs, using EXPEEK film developed by KURABO.

Technological features

■ **Advantages of high temperature tolerant film EXPEEK (KURABO INDUSTRIES LTD.)**
- **Biaxially stretched PEEK (polyetheretherketone) film**
- **Similar temperature tolerance to polyimide (PI) (Tg：320℃)**
- **Excellent solvent tolerance**
- **Excellent transparency**
- **Low thermal shrinkage**

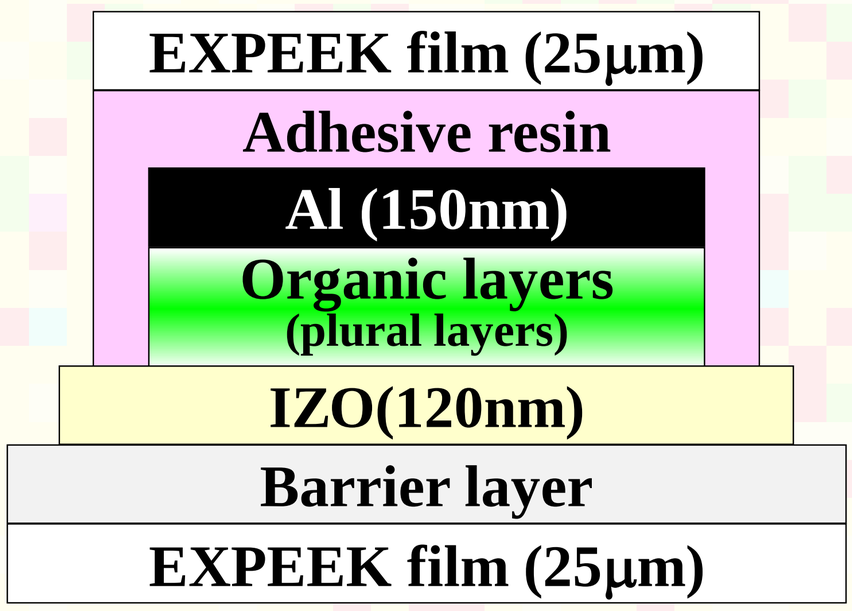


EXPEEK (KURABO INDUSTRIES)

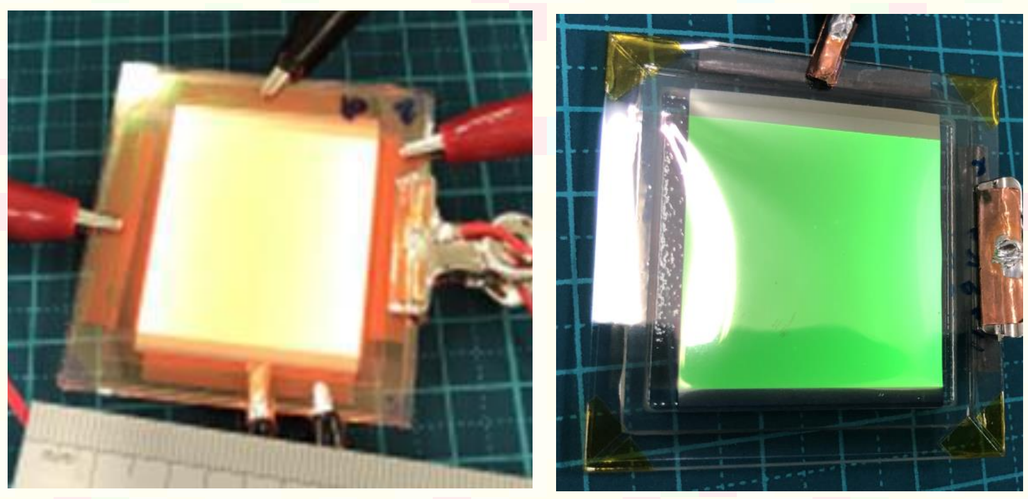
■ **Application of EXPEEK with gas barrier layer to flexible OLED devices**
- **No requirement of reduction in process temperature (Ordinal fabrication processes for OLEDs can be used.)**

Developed technologies

■ **Flexible OLED devices on high temperature tolerant film EXPEEK with gas barrier layer**
- **Barrier evaluation of high temperature tolerant film EXPEEK with gas barrier layer**
- **Flexible OLED device prototypes on high temperature tolerant film EXPEEK with gas barrier layer**



Example of flexible OLED device



Prototypes of flexible OLED devices

Collaboration KURABO INDUSTRIES LTD.

Related program
- **Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) [Jan. 2018～Mar. 2023]**
- **MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]**

Publication
- **KURABO; “7th Fine Plastic Exhibition” (Dec. 2018), “SEMICON Japan 2018” (Dec. 2018).**

EXPEEK® is a registered trademark of KURABO INDUSTRIES LTD.

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

Fabrication Technologies of Inorganic Barrier Layers for OLEDs

OLED devices require high gas barrier technologies. We develop fabrication technologies of inorganic gas barrier layers by using LIA(Low Inductance Antenna)-CVD developed by SCREEN Finetech Solutions.

Technological features

■ **Inorganic gas barrier layer produced by LIA-CVD developed by SCREEN Finetech Solutions**

＜Advantages of LIA-CVD＞

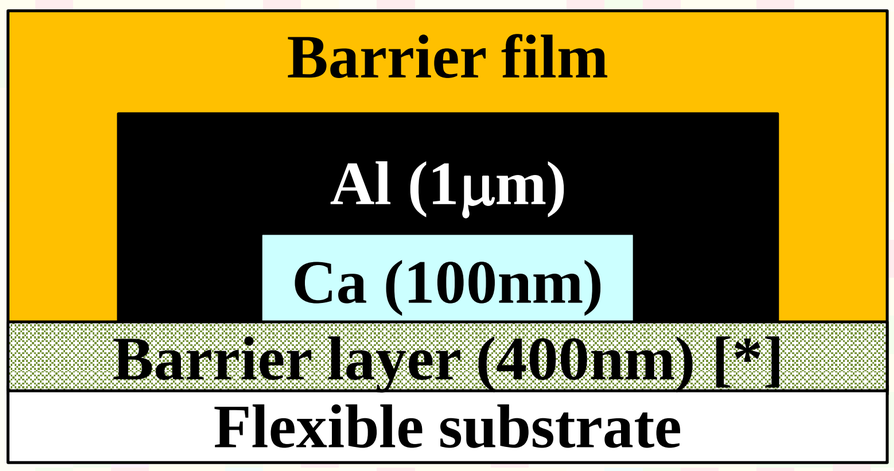
- **High deposition rate：SiNx faster than 3.0nm/sec**
- **Excellent thickness uniformity within ±3% (Deposition area 1,200mm×1,000mm)**
- **Deposition-up architecture**

LIA（Low Inductance Antenna）Plasma CVD & Sputtering equipment
Example of substrate size: W 1,400mm × L 1,100mm

Developed technologies

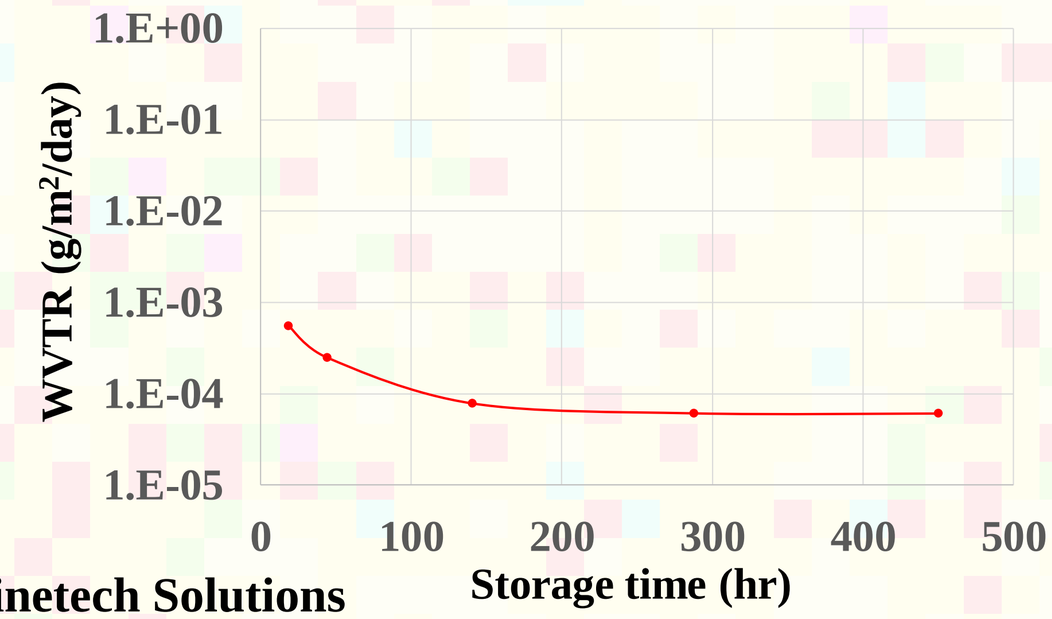
■ **Inorganic gas barrier layers fabricated by LIA-CVD**

- **Fabrication of barrier layer (thickness: 400nm) on PEN film**
- **WVTR (Water Vapor Transmission Rate): order of 10^{-5}g/m^2/day (Ca corrosion method, 40°C/90%RH)**



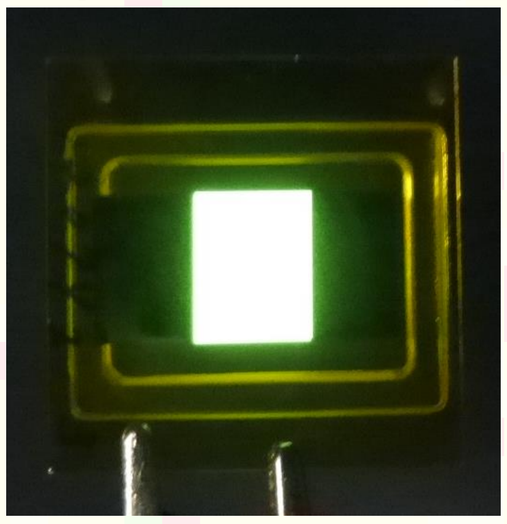
Ca corrosion device
[*] fabricated by LIA-CVD in SCREEN Finetech Solutions

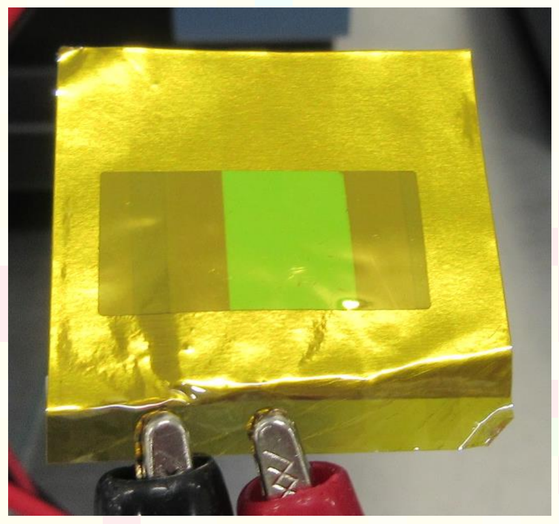
Ca corrosion test (40°C/90%RH)

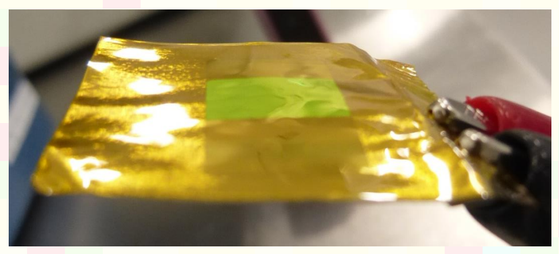


■ **OLED devices with inorganic gas barrier layer fabricated by LIA-CVD**

Al (100nm)
ETM:Liq(25%) (45nm)
Alq_3:Coumarin(C545T,1.5%) (30nm)
HTL (120nm)
HATCN (5nm)
IZO (150nm)
Barrier layer [*]
Flexible substrate







[*] fabricated by LIA-CVD in SCREEN Finetech Solutions

Collaboration SCREEN Finetech Solutions

Related program

- **Yamagata University Flexible Organic Electronics Practical Key Technology Consortium (YU-FOC) [Apr. 2016～Mar. 2019]**

INOEL Yamagata University
Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

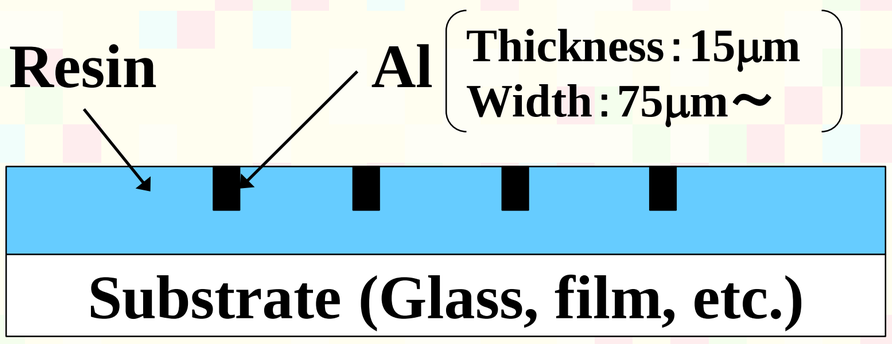
Non-ITO Transparent Electrode with Implanted Al-mesh Structure

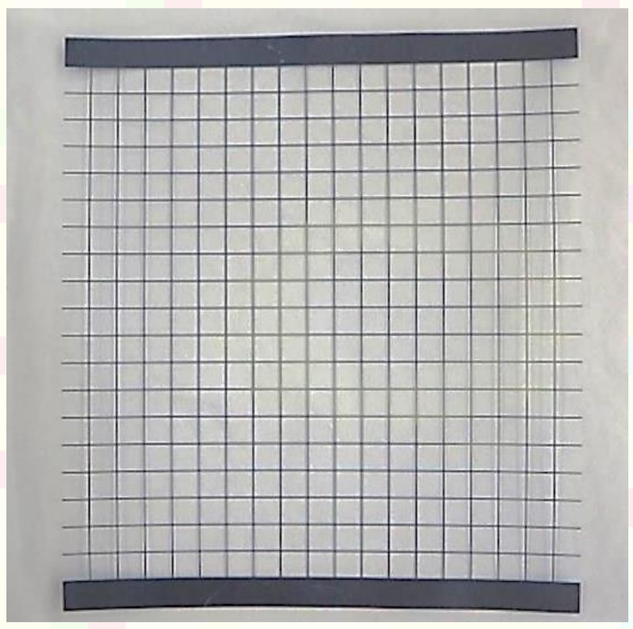
ITO (Indium Tin Oxide), which is the most common transparent electrode in LCDs and OLEDs, has issues in cost, productivity, etc.
We develop OLED devices using a non-ITO transparent electrode with novel implanted Al-mesh structure fabricated by Toyo Aluminium.

Technological features

■ **Non-ITO transparent electrode with novel implanted Al-mesh structure fabricated by Toyo Aluminium K.K.**
- **High conductivity led by Al-mesh**
- **Smeeth surface due to the implanted Al-mesh electrode into resin**
- **Applicable to OLED, OPV, etc.**
- **Applicable to flexible devices**

	Surface resistance
ITO (on glass)	～10Ω/□
ITO (on film)	～40Ω/□
Al-mesh developed by Toyo Aluminium	0.05～1Ω/□

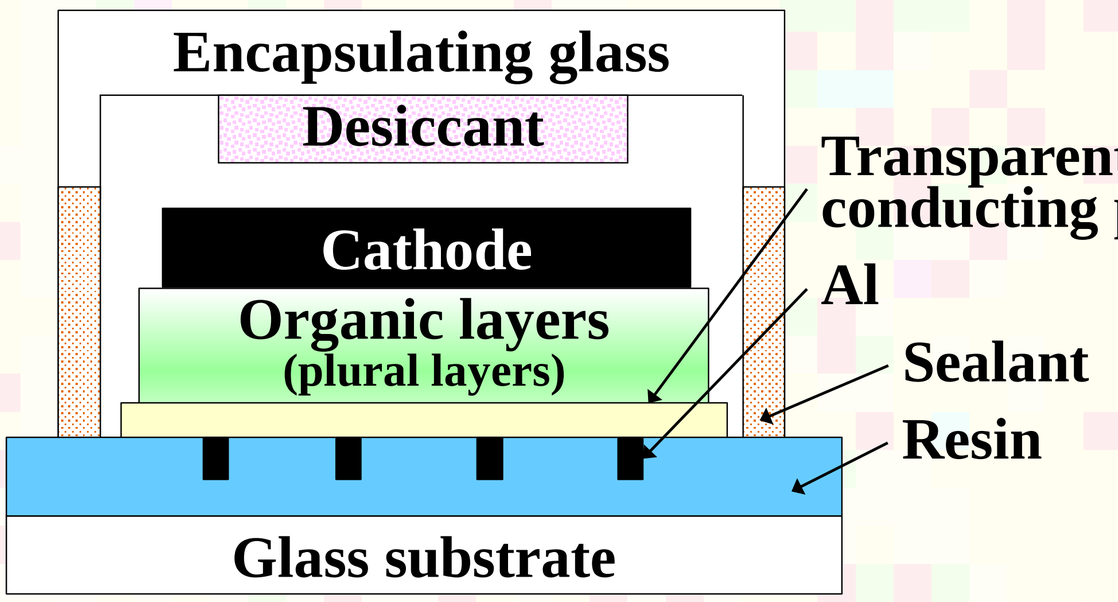




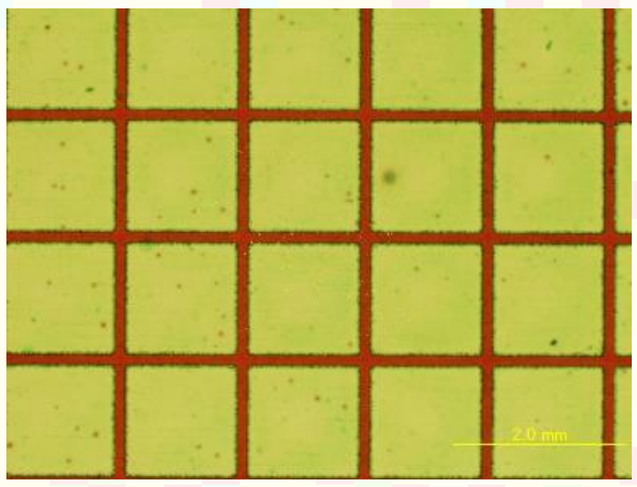
Al-mesh substrate

Developed technologies

■ **OLED devices using non-ITO transparent electrode with implanted Al-mesh electrode substrate fabricated by Toyo Aluminium K.K.**



Device structure of OLED



Emission of OLED devices

Collaboration Toyo Aluminium K.K., Prof. Takeshi Sano (INOEL, Yamagata University)

Related program

- **JST: Program on Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA) [FY2018～FY2022]**

Publication

- **Toyo Aluminium; "48th INTERNEPCON Japan" (Jan. 2018).**

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

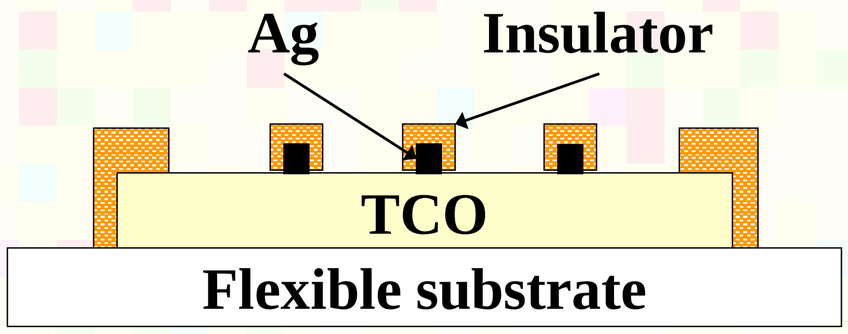
Roll-to-roll (R2R) Fabrication of Flexible Substrates with Electrode

We develop roll-to-roll (R2R) fabrication technologies of flexible substrates with electrode, aiming at large size OLED lighting.

※Collaboration with German companies and institutes in Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC)

Technological features

■ **Roll-to-roll (R2R) fabrication of electrodes on flexible substrates by photolithography-free processes. (low cost, high productivity)**



（TCO: Transparent Conducting Oxide）

R2R sputtering of TCO layer

↓

R2R screen printing of etching paste

↓

R2R wet cleaning for TCO patterning

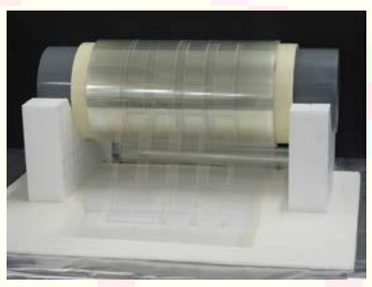
↓

R2R screen printing of Ag electrode

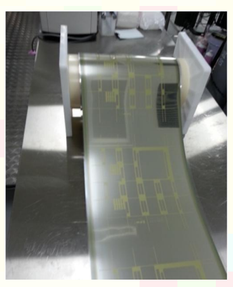
↓

R2R screen printing of insulator

Key technologies

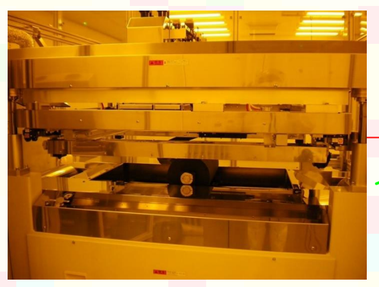


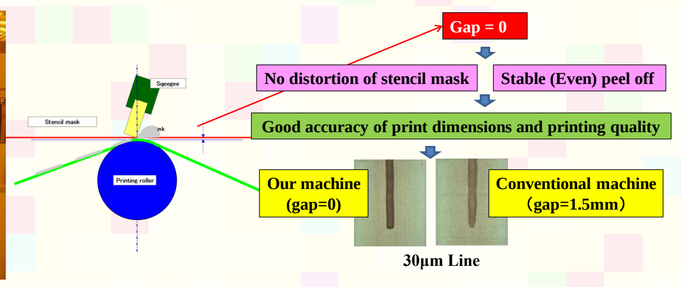
Ultra-thin glass
(Nippon Electric Glass)



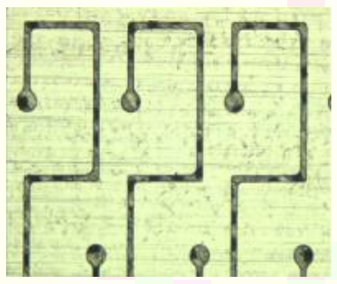
Stainless steel foil
(NIPPON STEEL Chemical & Material Co., Ltd.)

Plastic film
(TEUJIN)

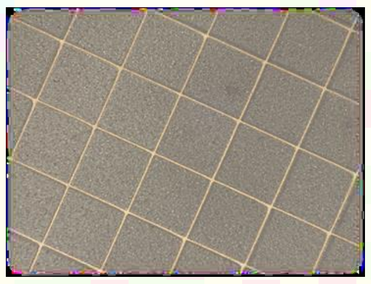




Screen printing equipment
(SERIA ENGINEERING)

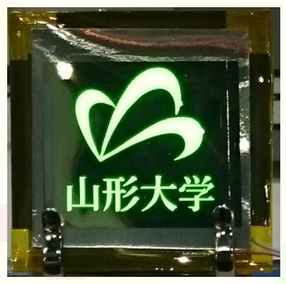


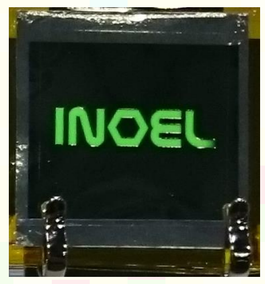
Screen mask
(Tokyo Process Service)



Conducting ink
(FUJIKURA KASEI)

Cutting
(Mitsuboshi Diamond Industrial)





Flexible OLED device
(Yamagata University)
Barrier resin: tesa

Collaboration

Nippon Electric Glass, NIPPON STEEL Chemical & Material, TEIJIN, SERIA ENGINEERING, Tokyo Process Service, FUJIKURA KASEI, Mitsuboshi Diamond Industrial

Related program

- **Yamagata University Flexible Organic Electronics Practical Key Technology Consortium (YU-FOC) [Apr. 2016～Mar. 2019]**
- **Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2021]**
- **JST: Program on Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA) [FY2016～FY2020]**
- **MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]**
- **MEXT: Regional Innovation Eco-system Program [FY2018～FY2022]**

Publication

- **Nippon Electric Glass; “LED JAPAN 2018” (Oct. 2018), “FINETECH JAPAN 2018” (Dec. 2018).**
- **Mitsuboshi Diamond Industrial; “FINETECH JAPAN 2018” (Dec. 2018).**
- **T. Furukawa, N. Kawamura, T. Noda, Y. Hasegawa, D. Kobayashi, M. Koden, *IDW’17*, FLX6-2 (2017). “Novel Roll-to-Roll Fabrication Processes of Transparent Electrodes on Ultra-Thin Glass”**
- **T. Furukawa, M. Koden, *IEICE Trans. Electron*, E100-C, 949-954 (2017). “Novel roll-to-roll deposition and patterning of ITO on ultra-thin glass for flexible OLEDs”**

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

TFE (Thin Film Encapsulation) Technologies for OLEDs

We develop TFE (Thin Film Encapsulation) technologies for OLED devices, using organic resins developed by TOYO INK SC HOLDINGS.

Technological features

■ To apply “Non-solvent UV-IJ resin ink” developed by TOYO INK SC HOLDINGS

＜Advantages of “Non-solvent UV-IJ resin ink” developed by TOYO INK SC HOLDINGS” ＞

- ▪To support SiNx barrier layer
- ▪UV cure type (non-solvent)
- ▪Applicable to ink-jet

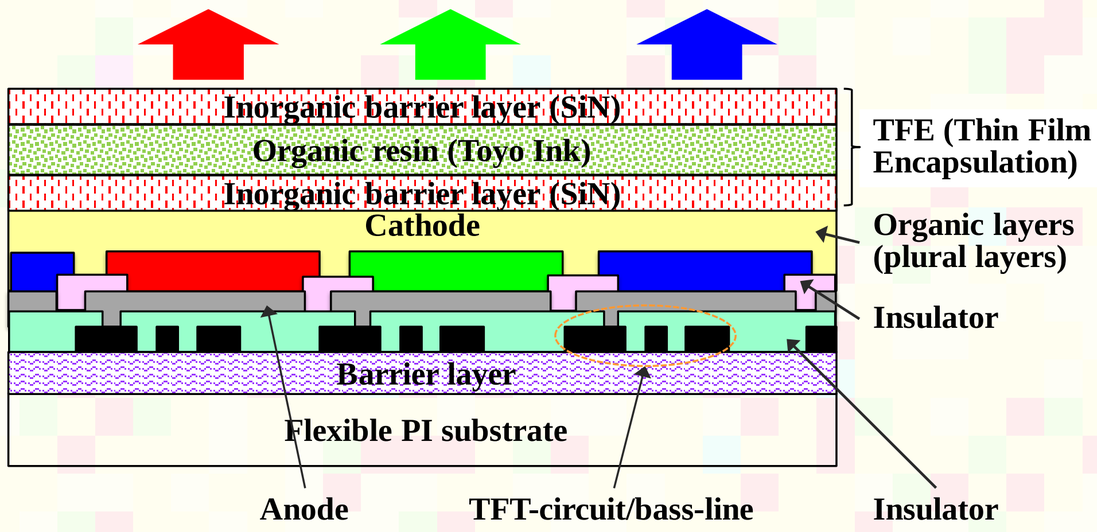
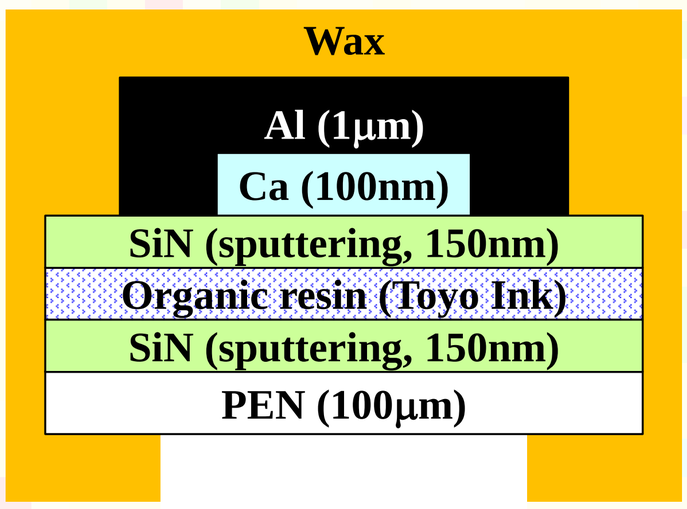


Image of OLED with TFE

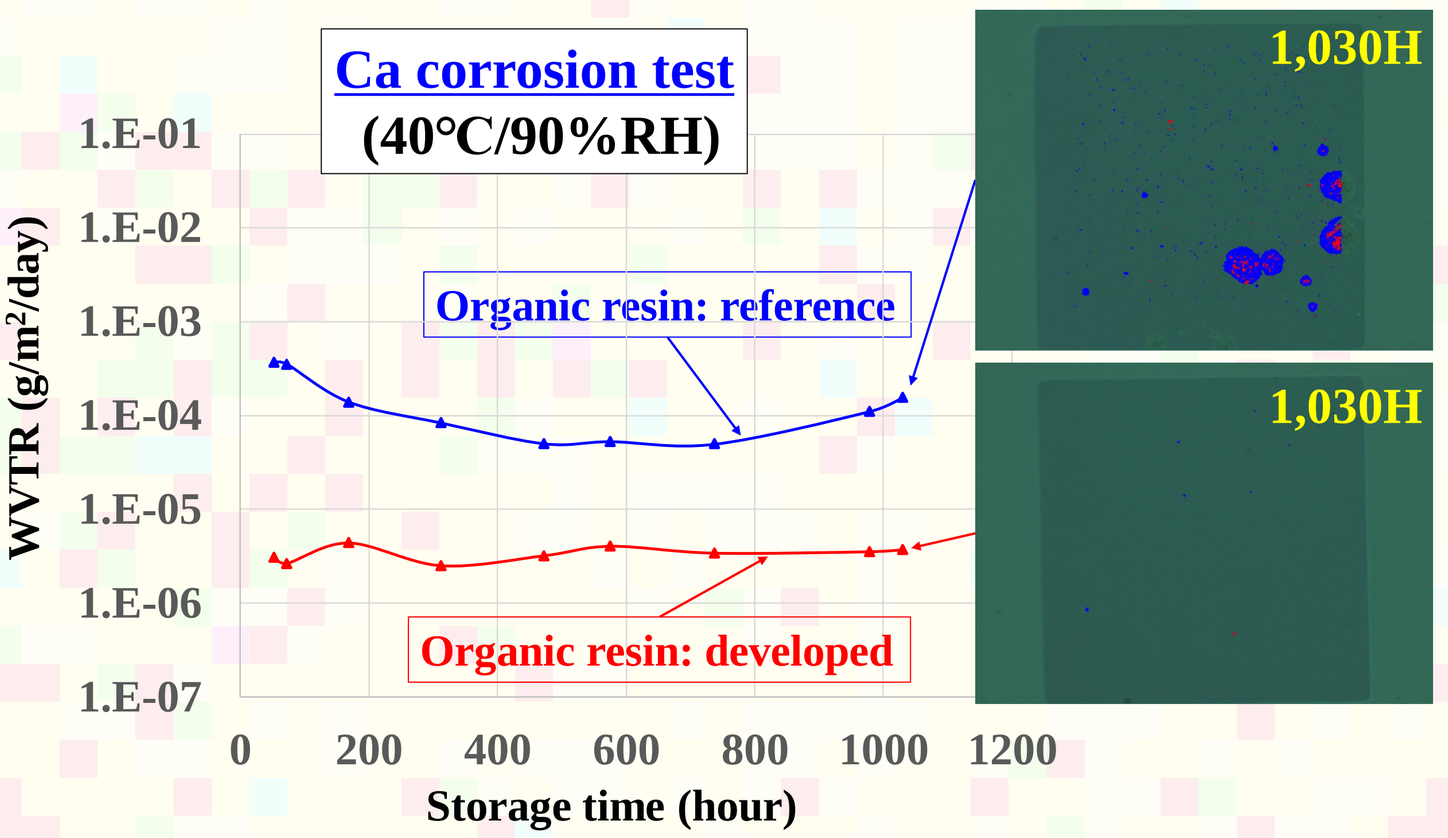
Developed technologies

■ TFE structure with high gas barrier property

- ▪ “Non-solvent UV-IJ resin ink” developed by TOYO INK SC HOLDINGS is sandwiched by SiN barrier layers
- ▪High gas barrier property：
  - * No actual damage after storage test of 1,000 hours under 40℃/90%RH
  - * WVTR (Water Vapor Transmission Rate): order of 10^{-6}g/m^2/day (40℃/90%RH)



Device structure of Ca corrosion test



Collaboration

TOYO INK SC HOLDINGS CO., LTD.

Related program

- Yamagata University Flexible Organic Electronics Practical Key Technology Consortium (YU-FOC) [Apr. 2016～Mar. 2019]
- NEDO: Strategic technological innovation program for energy saving “Development of high efficient OLED materials” (Collaboration with CEREBA) [Aug. 2017～Mar. 2019].

Publication

- TOYO INK SC HOLDINGS CO., LTD.; News Release (13 Feb. 2018). http://schd.toyoinkgroup.com/ja/release/2018/18021301.html

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)

Developed technologies

Laminating Encapsulation for OLEDs

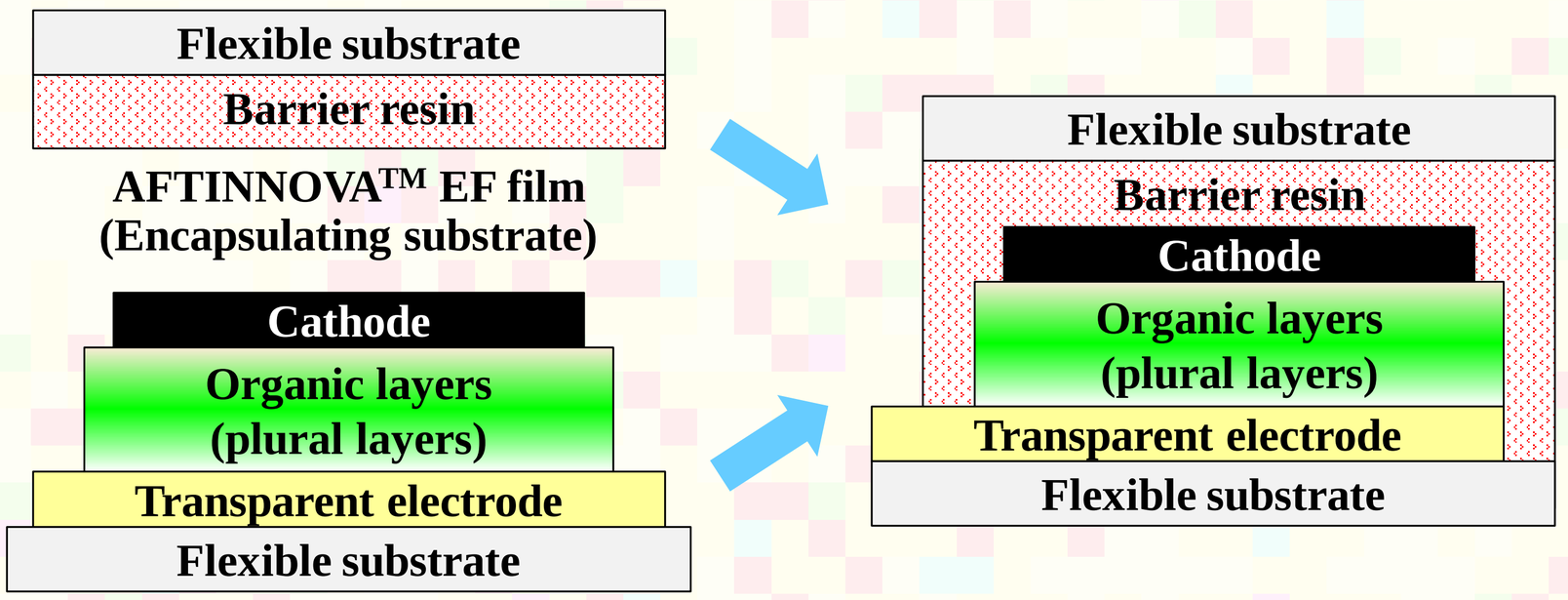
We develop flexible OLED devices, using laminating encapsulating film AFTINNOVA™ EF developed by Ajinomoto Co., Inc. / Ajinomoto Fine-Techno Co., Inc.

Technological features

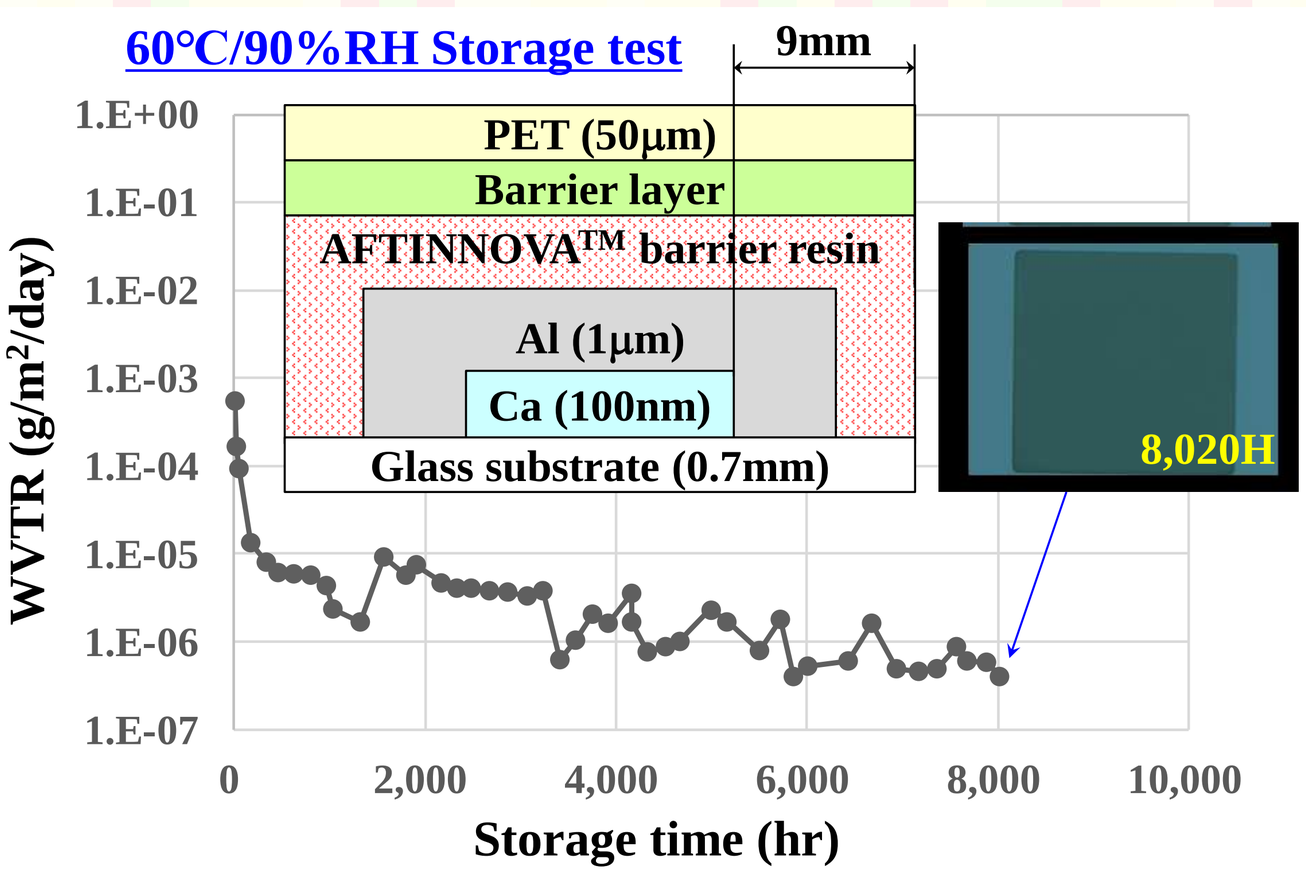
- AFTINNOVA™ EF substrate protecting water penetration from side of OLED device
- Simple device architecture and simple fabrication process
- Reduction of defect occurrence by stress release effect of AFTINNOVA™ EF

Developed technologies

AFTINNOVA™ EF
（Ajinomoto)



- High gas barrier property:
  - * No actual damage after storage test of 8,000 hours under 60°C/90%RH
  - * WVTR (Water Vapor Transmission Rate): order of 10^{-6}g/m^2/day (60°C/90%RH)
- Flexible OLED devices



Flexible OLED device with AFTINNOVA™ EF

Collaboration Ajinomoto Co., Inc. / Ajinomoto Fine-Techno Co., Inc.

Related program

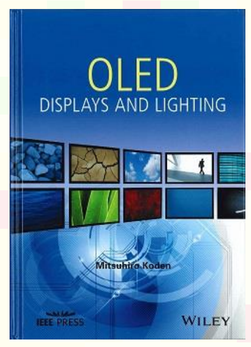
- Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) [Jan. 2018～Mar. 2023]
- NEDO: Strategic technological innovation program for energy saving “Development of high efficient OLED materials” (Collaboration with CEREBA) [Aug. 2017～Mar. 2019].
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022]

Topics / Publications

Award

- H. Nakada, M. Koden, "Award from Minister of State for Science and Technology Policy", Cabinet Office, Government of Japan, (2017).

Book



- M. Koden, "*OLED Displays and Lighting*" (Wiley, IEEE Press) (2017).

Paper

- T. Furukawa, M. Koden, *IEICE Trans. Electron*, E100-C, 949-954 (2017).
  "Novel roll-to-roll deposition and patterning of ITO on ultra-thin glass for flexible OLEDs"

International Conference

- K. Taira, Taiga Suzuki, W. Konno, H Chiba, H. Itoh, M. Koden, T. Takahashi, T. Furukawa, *IDW'18*, FLX2-4L (2018). "Development of High Gas Barrier Film Using Novel Precursor by Roll to Roll PECVD"
- T. Suzuki, W. Konno, K. Taira, H Chiba, H. Itoh, M. Koden, T. Takahashi, T. Furukawa, *IDW'18*, FLXp1-10L (2018). "High Gas Barrier Films with Heterogeneous Multilayer"
- T. Furukawa, *Advanced Materials-2018 (WCAM2018)* (2018). [Invited]
  "Substrates for Organic Electronics - Ultra-thin Glass, Stainless Steel Foil and High Gas Barrier Plastic Film"
- M. Koden, T. Furukawa, T. Yuki, H. Nakada, *LS16* (2018). [Invited]
  "Roll-to-roll and printing technologies for electrodes of flexible OLED lighting"
- T. Furukawa, N. Kawamura, T. Noda, Y. Hasegawa, D. Kobayashi, M. Koden, *IDW'17*, FLX6-2 (2017).
  "Novel Roll-to-Roll Fabrication Processes of Transparent Electrodes on Ultra-Thin Glass"
- K. Taira, T. Furukawa, N. Kawamura, M. Koden, T. Takahashi, *IDW'17*, FLXp1-8L (2017).
  "High gas barrier film for OLED"
- T. Furukawa, N. Kawamura, M. Koden, H. Itoh, H. Kuroiwa, K. Nagai, *LOPEC* (2017).
  "Gas barrier film for OLED devices"
- M. Koden, T. Furukawa, T. Yuki, H. Kobayashi, H. Nakada, *IDW/AD'16*, FLX3-1 (2016). [Invited]
  "Substrates and Non-ITO Electrodes for Flexible OLEDs"
- T. Furukawa, *IWFPE2016* (2016). [Invited]
  "Flexible Substrates and Printed Transparent Electrode for OLED Lighting"

Exhibitions

- "JFlex2019" (Jan. 2019).
- "LOPEC" (March 2018, Germany).
- "Printable Electronics 2018" (Feb. 2018).
- "LED & OLED EXPO 2017" (June 2017, Korea)
- "Printable electronics 2017" (Feb. 2017).
- "G7 Exhibition" (May. 2016).
- "Printable electronics 2016" (Jan. 2016).
- "International Photonics Exhibition 2015" (Korea)(Oct. 2015).
- "National Museum of Nature and Science (Japan)" (May 2015).

Printable Electronics 2017 Award
"Originality Award" to INOEL

- "Printable electronics 2015" (Jan. 2015).

"Printable electronics 2016"
(Jan. 2016)

"Printable electronics 2017"
(Feb. 2017)

"Printable electronics 2018"
(Feb. 2018)

Members

Professor, Deputy Director
Hitoshi Nakada
nakada@yz.yamagata-u.ac.jp

Field: Organic electronics devices

1981 Graduated at Tohoku University
1981～2013 Pioneer Corporation
1988～ R&D of OLED display and OLED lighting
2013～ INOEL, Yamagata University (current position)

(Award)
- Award from Minister of State for Science and Technology Policy", Cabinet Office, Government of Japan (2017).
- Optoelectronics Industry and Technology Development Association, 19th Kenjiro-Sakurai Memorial Award (2003).
- 47th Okochi Memorial Award (2000).

(Development)
- World's first OLED product (passive-matrix OLED display) (1997).
- World's first phosphorescent OLED product (2003).
- Passive-matrix full-color flexible OLED display prototype (2003).

Professor
Dr. Mitsuhiro Koden
koden@yz.yamagata-u.ac.jp
http://www.asahi-net.or.jp/~ar3t-kudn/technology.html

Field: LCD, Display, OLED, Chemistry

1983 Graduated at Osaka University (PhD)
1983～2012 Sharp Corporation
(Liquid crystal materials, LCD, OLED display, etc.)
1998～2011 Guest prof. of Nara Institute of Science and Technology
2012～ INOEL, Yamagata University (current position)

(Award)
- Award from Minister of State for Science and Technology Policy", Cabinet Office, Government of Japan (2017).
- Award from The Japanese Liquid Crystal Society (2005).

(Development)
- 17" Ferroelectric liquid crystal display (FLCD) prototype (1999).
- 3.6" Polymer OLED display with world's highest resolution (2006).

(Book)
- M. Koden, "OLED Displays and Lighting" (Wiley; IEEE Press) (2017).
- K. Takatoh, M. Hasegawa, M. Koden, N. Itoh, R. Hasegawa, M. Sakamoto, "Alignment Technologies and Applications of Liquid Crystal Devices" Taylor & Francis (2005).

Associate Professor
Tadahiro Furukawa
ta-furukawa@yz.yamagata-u.ac.jp

Field: Fine patterning technology, Printing, Roll-to-roll technology

1984 Graduated at Saitama University (Master degree)
1984～2011 Kyoto Printing Co., Ltd.
R&D and production of Color filter (CF)
R&D of flexible CF and LCD
2011～ INOEL, Yamagata University (current position)

(International conference)
- T. Furukawa, *WCAM2018* (2018). [China, Invited]
- T. Furukawa, et al., *IDW'17*, FLX6-2 (2017).
- T. Furukawa, *LED & OLED EXPO 2017* (2017). [Korea]
- T. Furukawa, et al., *LOPEC* (2017). [Germany]
- T. Furukawa, et al., *IDW/AD'16*, FLX3-3 (2016).
- T. Furukawa, *IWFPE2016* (2016). [Korea, Invited]
- T. Furukawa, et al., *ICFPE 2016*, O15-6 (2016).

Associate Professor
Dr. Toshinao Yuki
t-yuki@yz.yamagata-u.ac.jp

Field: OLED (Display, Lighting, Device),

1993～1996 Teijin Limited
1996～1999 Graduated at Yamagata University (PhD).
1999～2015 Tohoku Pioneer Corporation
(PMOLED, AMOLED, Tiling OLED, OLED lighting, etc.)
2015～ INOEL, Yamagata University (current position)

(Award)
- The 4th Japan OLED Forum Outstanding Achievement Awards (2011).

(Development)
- World's first phosphorescent OLED product (2003).
- World's first large size tiling OLED display product (2010).
- World's first color-tunable OLED lighting product (2013).

January 2019 (revised in Feb. 2019)
Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden Group)
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