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)

2022

Professor
Hitoshi Nakada

Associate Professor
Tadahiro Furukawa

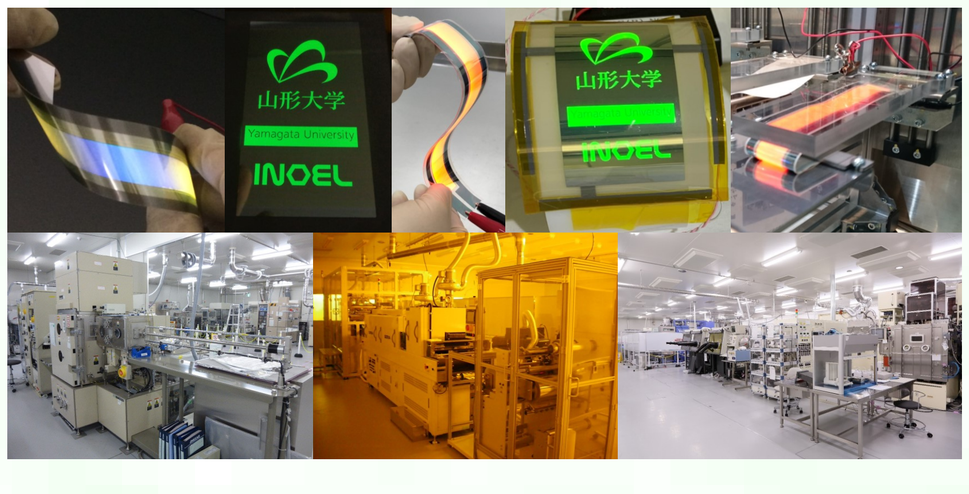
Associate Professor
Dr. Toshinao Yuki

Professor
Dr. Mitsuhiro Koden

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

Printable Electronics 2017 Award

JFlex Award (2019, 2020)



Homepage： https://inoel.yz.yamagata-u.ac.jp/F-consortium/home-e.html

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Activity

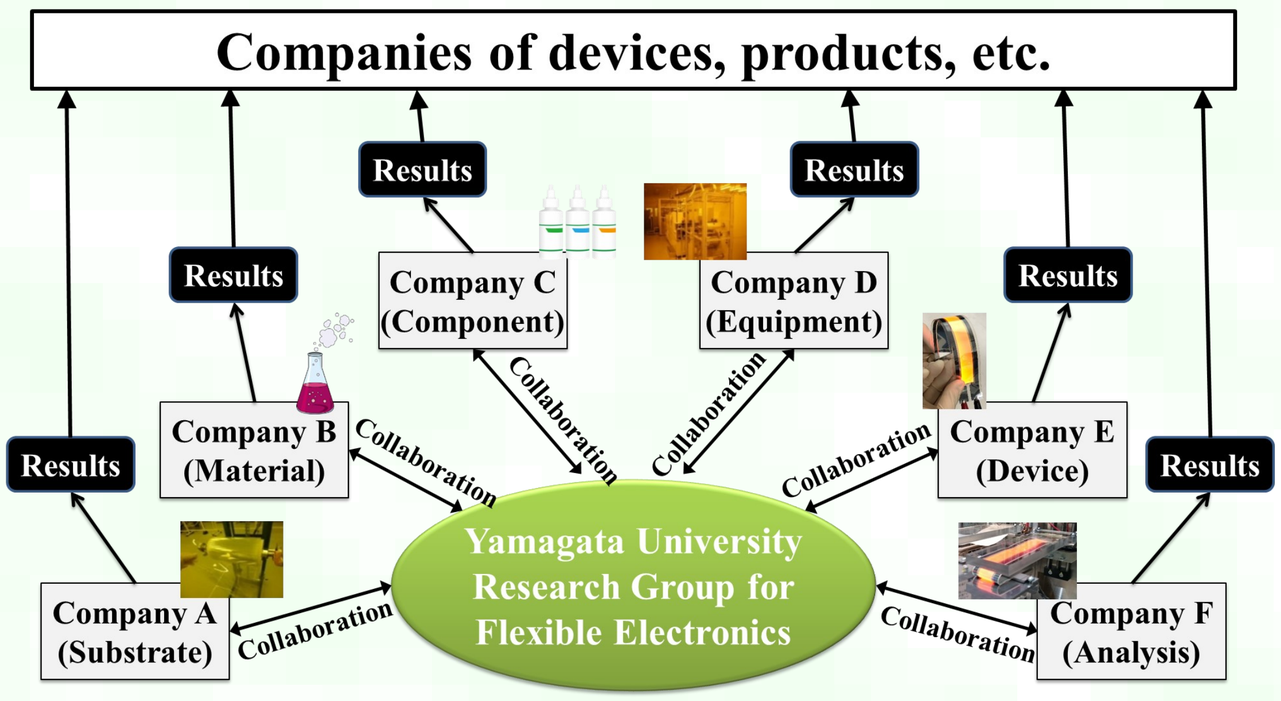
Academia-Industry Collaboration "Needs First!"

In flexible organic electronics technologies, we offer academia-industry collaboration with "Needs First", in which needs and requests from collaborating companies are first priority.
We contribute R&Ds of collaborating companies, aiming at practical technologies and 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)

- Devices and processes of organic electronics (OLED, OPV, OTFT, etc.)
- Materials and components for flexible organic electronics
- Barrier technologies / Barrier evaluation and analysis / Flexible encapsulation
- Printing and roll-to-roll (R2R) technologies for flexible organic electronics



Collaboration scheme

Discussion
↓
Planning
↓
Contract
↓
Experiment, evaluation, etc.
↓
Feedback

Unique points

- "Needs First" (Business First)
  Company's needs are first priority.
- Merits in IPs
- Self-supporting accounting system
  An unique model based on collaboration with industry

Collaborations

- Device fabrication with collaborating company's technologies and feedback of all results to the company
- Data for proofing potential of the technologies of collaborating company.
- Prototype samples
- Coordination of plural companies
- Individual collaboration / Consortium / International collaboration

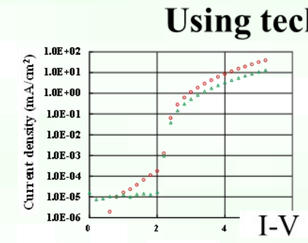
Skills of members

- Substantial experience in the practical development at previous companies.
- Rich knowledge on organic electronics (OLEDs etc.), displays, flexible, R2R, printing, etc.
- Rich information about trends of technologies and businesses.
- Rich human network in academic society and industrial fields.

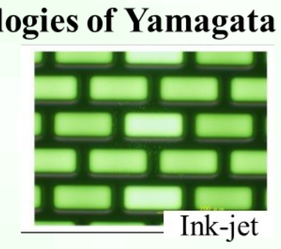
Evaluation / Developmental support

Company's technologies → Devices &evaluation → Feedback

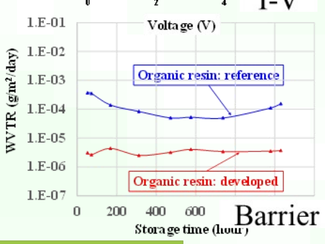
Using technologies of Yamagata Univ.



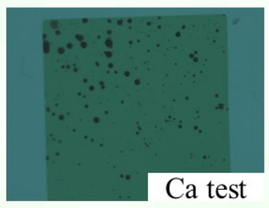
I-V

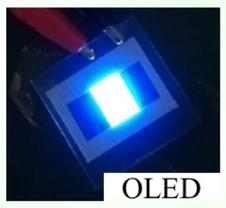

Ink-jet


Bending test



Barrier

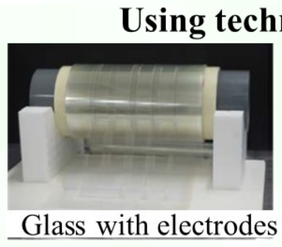

Ca test

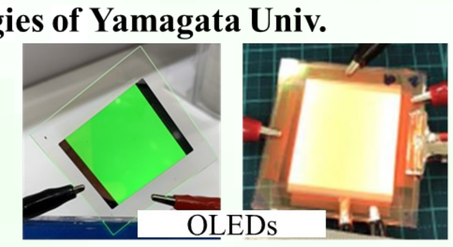

OLED

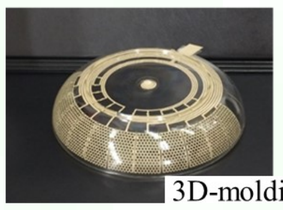
Prototype / Lab. sample

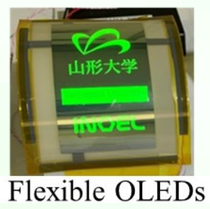
Company's technologies → Lab. samples → Utilizations in company

Using technologies of Yamagata Univ.


Glass with electrodes


OLEDs


3D-molding



Flexible OLEDs

Activities

- Academia-Industry Cooperation Consortium (p.3～p.5)
- National Project (p.3)
- Individual Collaboration
- Evaluation support (p.8) : WVTR (Water Vapor Transmission Rate) evaluation with MORESCO

Activity

Consortium / National Projects

Based on the concept of "Needs First", we promote academia-industry collaboration consortiums and participate various national projects.

Academia-Industry Collaboration Consortium

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

Prof. Koden

Yamagata University Organic Thin Film Device Consortium

21 companies
Dexerials, DIC, DNP, FEBACS, JNC, Kaneka, KOBELCO, Koito Manufacturing, Komori Machinery, Merck Performance Materials Manufacturing, Mitsubishi Materials, Mitsubishi Plastics, NEC Lighting, Nippon Electric Glass NIPPON STEEL & SUMITOMO METAL / NIPPON STEEL & SUMIKIN MATERIALS, Okura Industrial, SERIA, Shin-Etsu Chemical, Taiyo Kikai, Teijin, ZEON

Supported by MITI

Profs. Nakada & Koden

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

10 companies
FEBACS, Kaneka, The Japan Steel Works, NEC Lighting, Nippon Electric Glass, Nippon Steel & Sumitomo Metal / Nippon Steel & Sumikin Materials, SERIA, Shin-Etsu Chemical, TOYO INK, Teijin

Mr. Furukawa

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

9 companies

Dr. Yuki

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

17 companies

Supported by MEXT

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: OPERA Program Grant Number JPMOP1614

JST: OPERA Program Grant Number JPMOP1844

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

NEDO: Development of high efficient OLED materials

NEDO Project

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山形大学 Yamagata University

Consortium

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

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 2023

Participants 9 Companies (Jan. 2022)

Subjects

- Innovative roll-to-roll fabrication of OLED lighting on flexible substrates
- Application of organic electronics technologies to interactive advertisement
- Fabrication technologies for three dimensional print circuit boat (3DPCB)

Leaders

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



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

- ✓Mutual visits between Germany and Japan.
- ✓Frequent remote meeting between Germany and Japan.
- ✓Demonstrations of collaborated results at conferences and exhibitions.

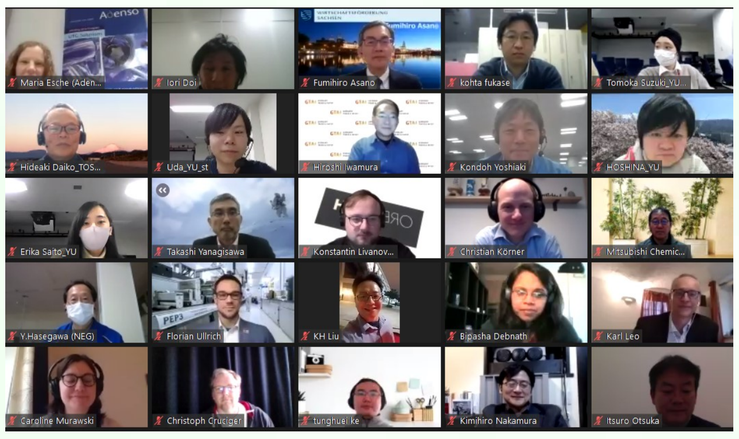
LOPEC/Germany (Mar. 2019)

Flex Japan 2019 (May 2019)

Germany (Sep. 2019)

Japan (Jan. 2020)

JFlex (Jan. 2020)



The 9th Germany-Japan Joint Workshop (Online) “Flexible, Printed Electronics and Sensors”, 26 February (2021).

Related program

- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].
- JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2021].

Web page

- Home page: https://inoel.yz.yamagata-u.ac.jp/yu-fic-en/
- You Tube: https://www.youtube.com/watch?v=Zu9DZH4Nq6c

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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 collaborations with individual companies, promoting practical development based on the concept of "Needs First". We would appreciate it if you are interested in YU-FLEC.

Mission and Subjects

Practical R&D in flexible electronics

- Flexible substrates
- Gas barrier and flexible encapsulation
- process technologies for flexible devices
- Novel electrodes (Non-ITO electrode)
- Next-generation materials and devices
- Equipment

Leaders



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

Activities

- Application of flexible substrates to OLEDs
  - Stainless steel foil
  - Barrier film
- Gas barrier technologies
  - Evaluation of gas barrier properties
  - Fabrication technologies of gas barrier layers
- Flexible encapsulation
  - TFE (Thin Film Encapsulation)
  - PSA encapsulating technology
  - Laminating encapsulation
- Non-ITO transparent electrode
  - Metal mesh electrode
- OLED devices and processes
  - OnDemand patterning of OLED
- Novel materials for emission devices
  - Evaporation materials
  - Solution materials
- Novel emission devices
  - QLED
  - Novel TFT technologies
- Novel components for organic electronics
- Equipment for organic electronics
  - Evaporation equipment
  - Deposition of barrier layers
  - Ink-jet

Project term

January 2018 ～ March 2023

Participants (total)

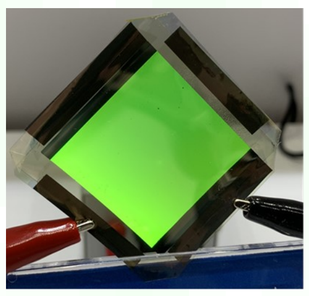
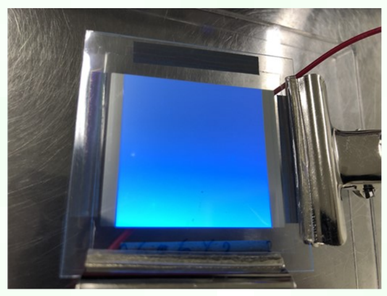
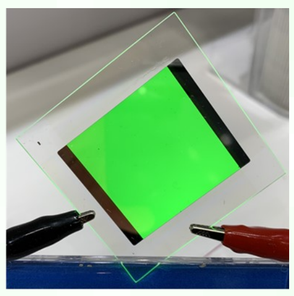
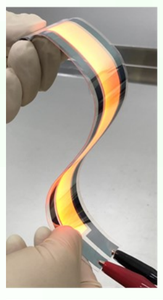
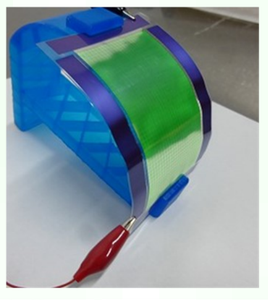
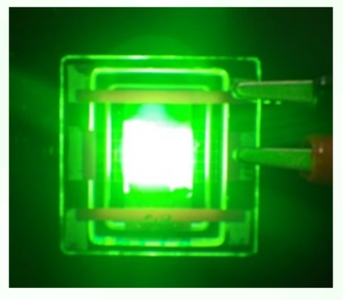
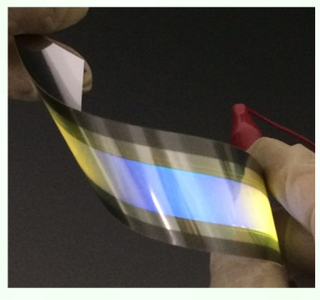
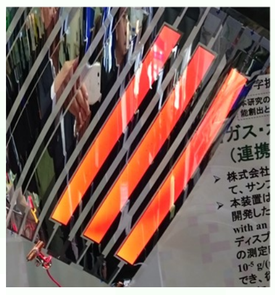
17 Companies (January 2022)

Unique points

- Academia-industry collaboration led by scientists having rich experience in actual businesses
- Large size equipment for various prototypes
- Creation of business competitiveness

Main applications

- Small flexible OLED displays (mobile, etc.)
- Large size OLED displays (TV, etc.)
- Flexible OLED lighting


Related program

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

Seminar

- Monthly report for YU-FLEC members by Prof. H. Nakada "Trend of organic electronics"
- Bimonthly report for YU-FLEC members by Prof. M. Koden "Trend of organic electronics - OPV"
- 1st YU-FLEC seminar (Aug. 2019 Tokyo).

Web page

- Home page: https://inoel.yz.yamagata-u.ac.jp/yu-flec-en/

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Background technologies

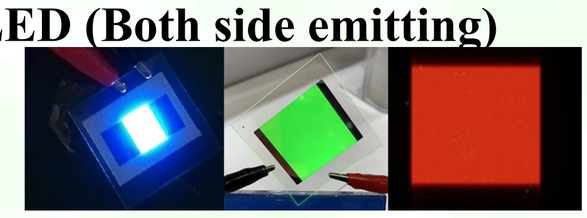
OLED & OPV Device Fabrications

Various types of OLED & OPV devices are able to be fabricated. The fabricated OLED & OPV devices are utilized for technological evaluations, prototype samples, etc.

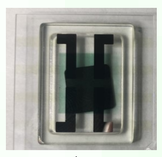
OLED (Organic Light Emitting Diode)

■ Materials
- Small molecular and polymer materials
- Fluorescent, phosphorescent and TADF
- Quantum dot (QD) materials

■ Devices
- Bottom emitting & Top-emitting
- Transparent OLED (Both side emitting)
- Multi-photon
- White emitting



OPV (Organic Photovoltaic)



■ Materials
- Vacuum & Coating
- Quantum dot (QD)

■ Devices
- Normal structure
- Inverted structure

Processes for organic layers

- Dry process: Vacuum evaporation
- Solution process: Spin-coat, Ink-jet, Spray, etc.

Vacuum evaporation

Ink-jet

Spin-coat

Spray

Wet cleaning

Plasma cleaner

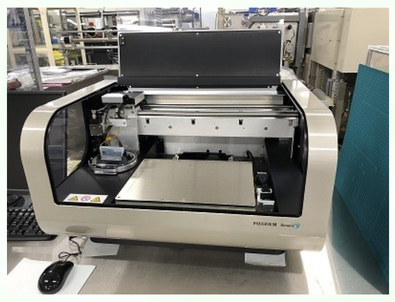
Barrier layers

- Inorganic barrier layer: CVD, Sputtering, ALD
- Inorganic/organic alternatingly stacked barrier layer

R2R sputtering & CVD

ALD (Atomic Layer Deposition)

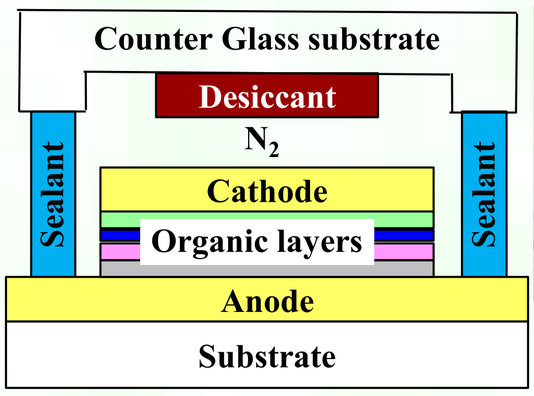
Sputtering

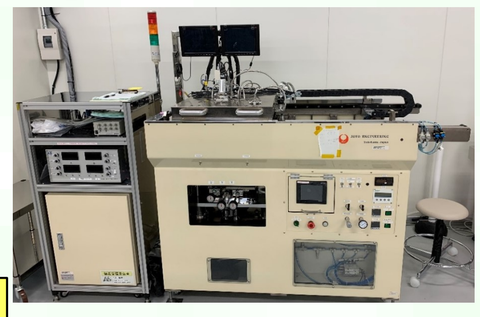


Ink-jet

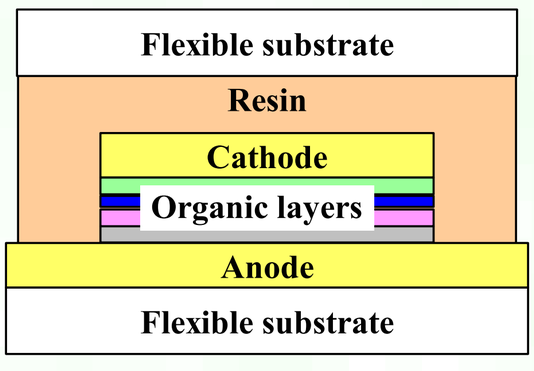
Encapsulations

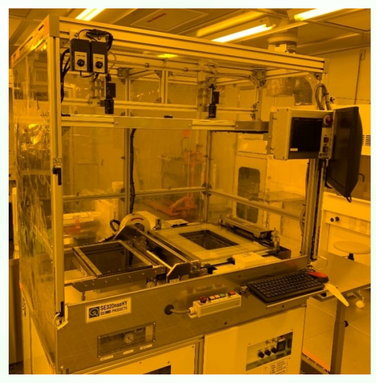
Various encapsulating technologies are applied.
- Common encapsulation with desiccant
- Flexible all-solid type encapsulation





Sheet-type lamination



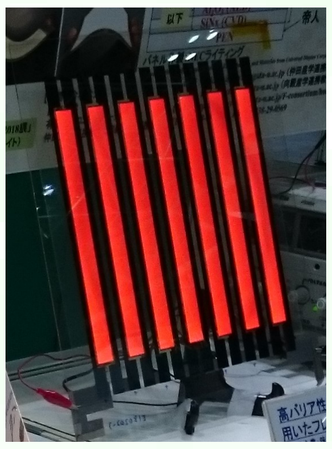


Roll-type lamination

Large size OLEDs

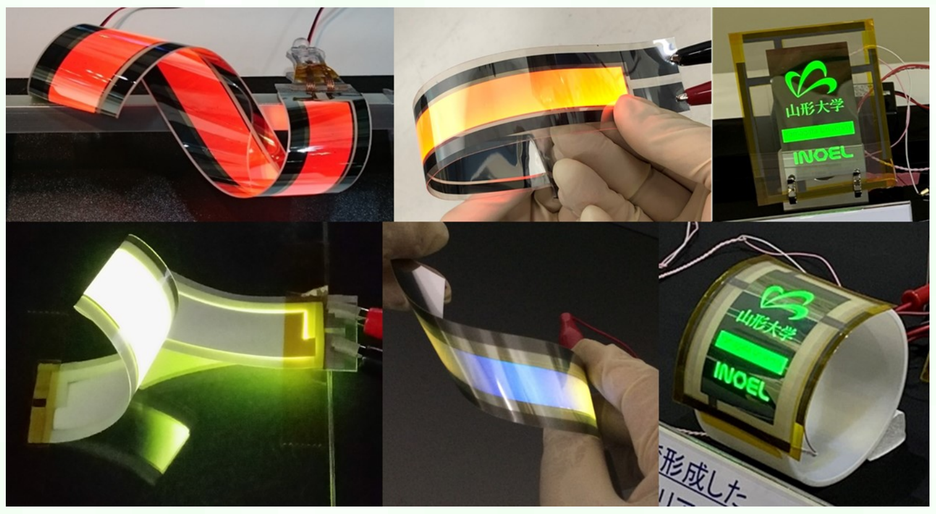
Large size OLED devices can be fabricated.
The maximum substrate size: 30cm × 30cm

OLED vacuum evaporation equipment “ELVESS” (Tokki)



Flexible OLEDs

Flexible OLED devices with various designs can be fabricated.



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山形大学 Yamagata University

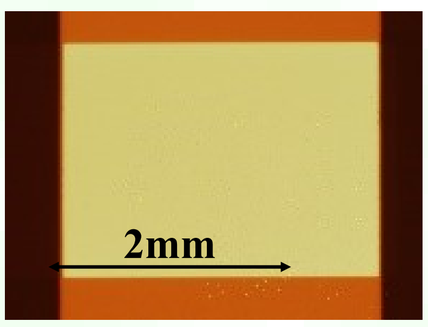
Background technologies

Evaluation of OLED & OPV

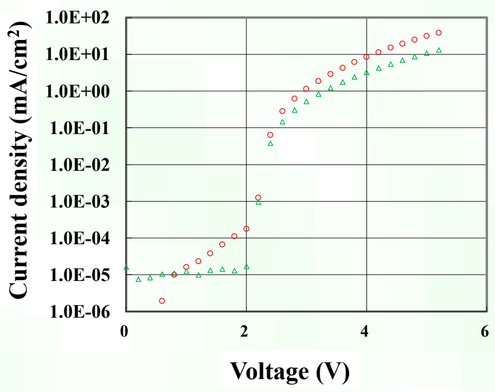
OLED and OPV devices with various technologies (materials, components, device architectures, processes, equipment, etc.) of collaborating companies are fabricated and evaluated from practical points of view. All evaluating results are feedbacked to the collaborating company for not only the next development but also demonstrations etc.

Evaluations of OLEDS

Various characteristics of OLEDs are evaluated.
- **Emission quality such as uniformity, defects, etc.**
- **I-V, L-I characteristics**
- **Emission spectrum, etc.**



Uniform emission

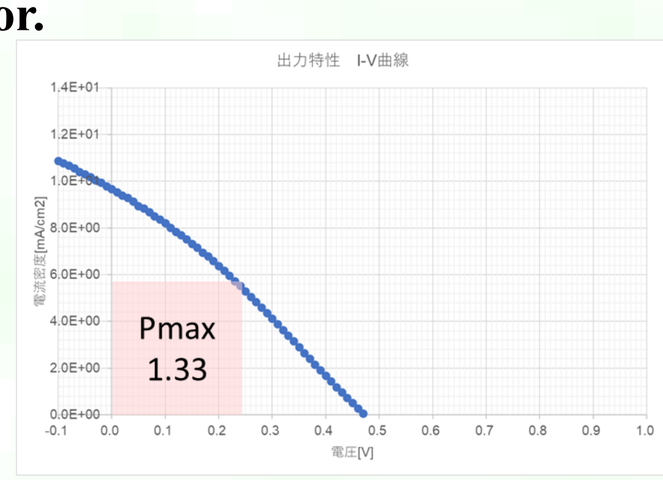


I-V characteristics

Evaluaitons of OPVs

Power generations of OPV devices are evaluated, using solar simulator.

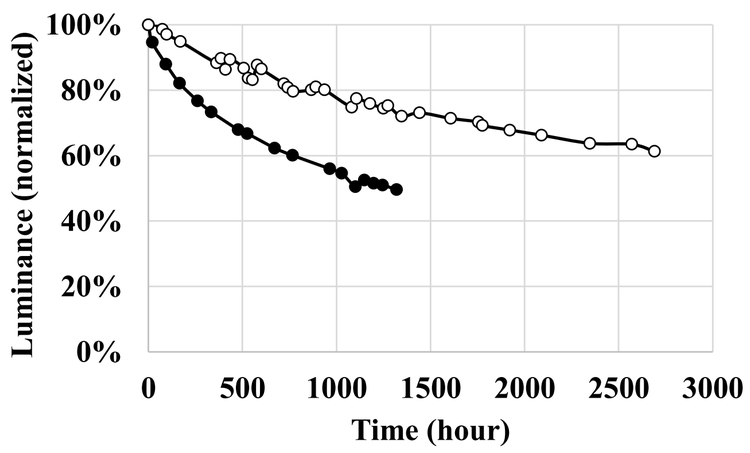
Solar simulator
Newport MODEL 66902



1SUN(1000W/m²)
AM1.5 room temperature
～100,000 LUX

Driving lifetime

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

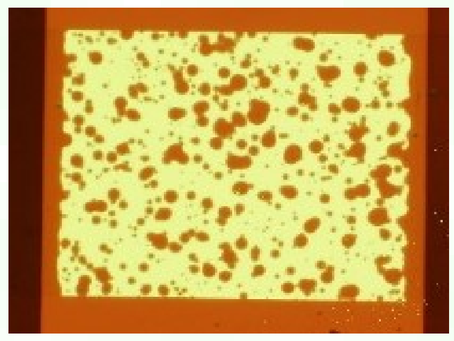


Driving lifetime

Storage lifetime

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

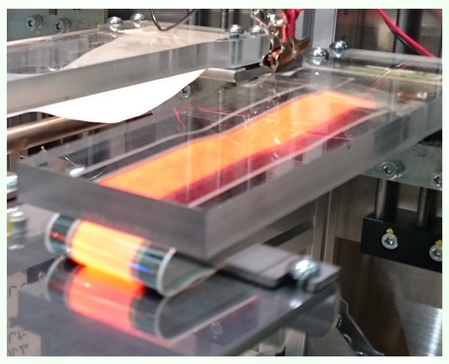
Initial emission (No defect)



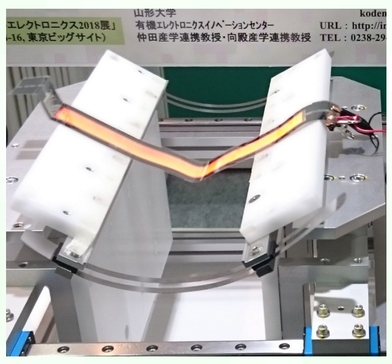
Emission after storage test (Dark spot)

Bending tests

The influences of various bending stress on device characteristics, barrier properties, etc. are evaluated using three types of bending equipment.



U-shape sliding

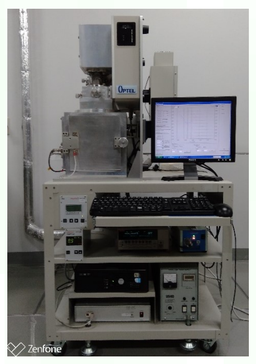


Folding

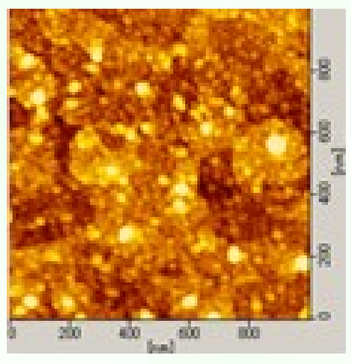
Both-side bending

Others

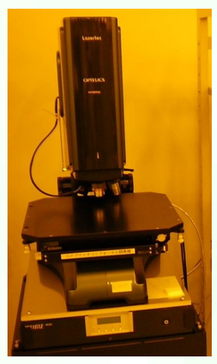
Other evaluations can be used, based on the request from collaborating companies.
(Example)
- **Ionization potential**
- **Defect analysis**
- **SEM, AFM**
- **3D profile**



Ionization potential



AFM



Hybrid confocal microscopy

INOEL Yamagata University
Innovation Center for Organic Electronics
Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)
山形大学 Yamagata University

Background technologies

Roll-to-roll (R2R) and Printing Technologies

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

Roll-to-roll (R2R)

Three 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 and slit-coating (SERIA)

R2R wet cleaning (FEBACS)

Printing / Coating

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

Screen printing

Flexography and gravure offset printing

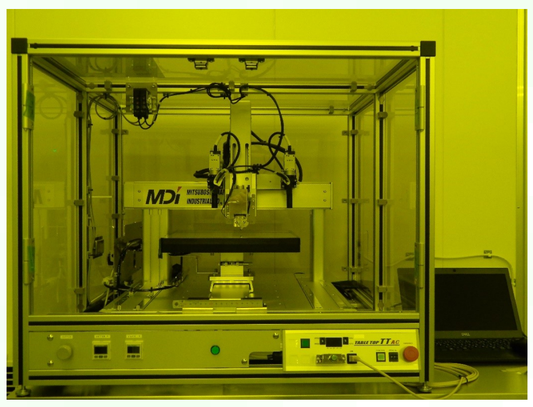
Ink-jet

Spray

Spin-coating

Process technologies

Various equipment for process technologies can be used.



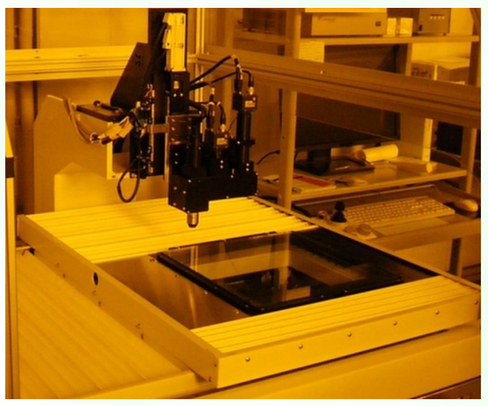
Cutting machine for ultra-thin glass

3D thermoforming

Evaluation

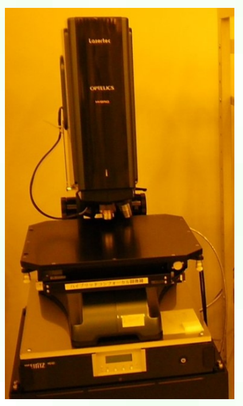
Various evaluation equipment are used for R&D of printing and roll-to-roll (R2R) technologies.

Contact angle measurement



Precise position detector

Viscoelasticity measurement



Hybrid confocal microscopy

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

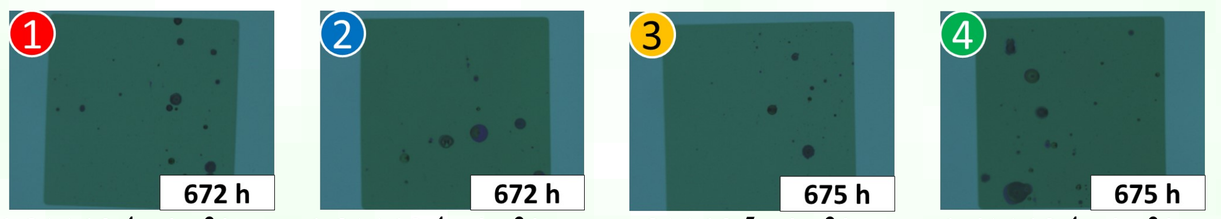
Background technologies

Evaluation of Gas Barrier / International Standardization

Evaluation of gas barrier properties is very important in flexible organic electronics technologies. We provide two evaluation methods which are "Calcium corrosion method" and "MA method (Modified differential pressure method with an Attached support)". In addition, we contribute to SEMI international standardizations of gas barrier films.

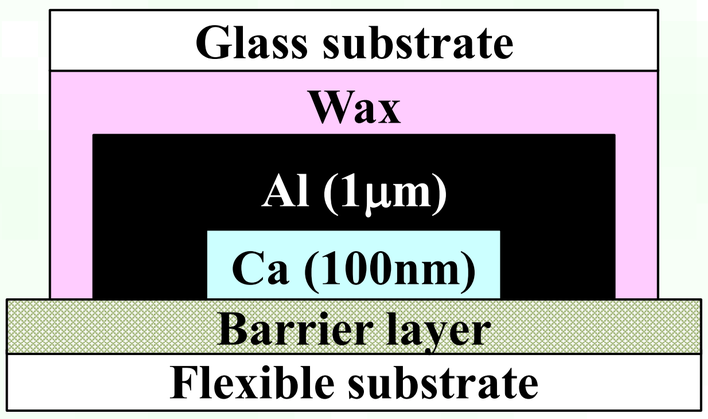
Ca corrosion method

- ✓ **Ca corrosion method evaluates the optical change in Ca reflectivity which changes by the reaction of Ca and H_2O, giving WVTR (Water Vapor Transmission Rate) valuers.**
  This method is useful for the evaluation of defects in barrier layer.
  ・$Ca+2H_2O \rightarrow Ca(OH)_2+H_2$
- ✓ **SEMI D78 - Test Method of Water Vapor Barrier Property for Plastic Films with High Barrier for Electronic Devices**

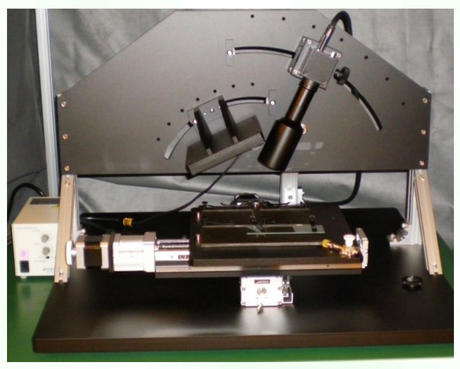


1.2×10^{-4} g/m^2/day　1.3×10^{-4} g/m^2/day　7.3×10^{-5} g/m^2/day　1.4×10^{-4} g/m^2/day

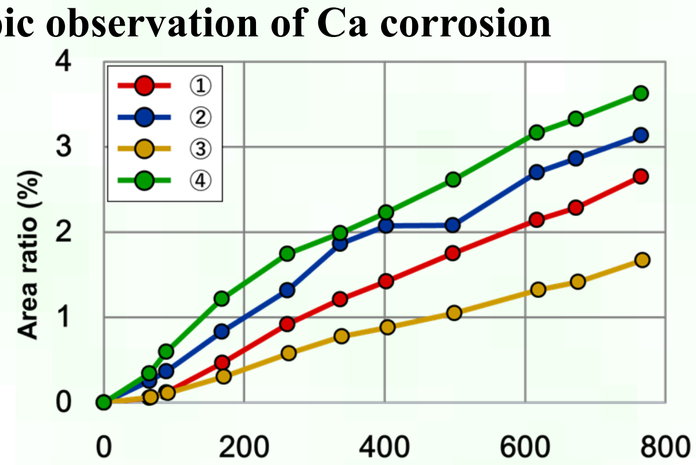
Microscopic observation of Ca corrosion



Structure of Ca corrosion device



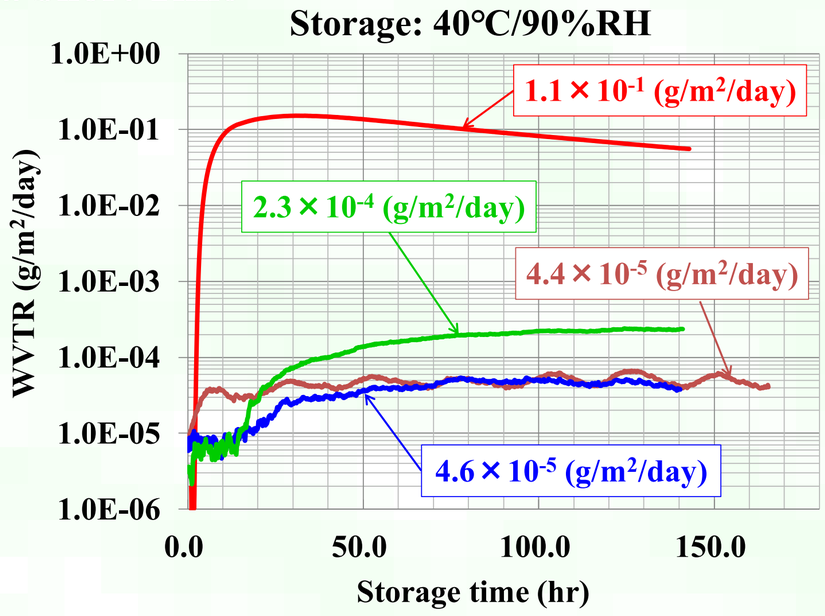
Evaluation equipment



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).**
- ➢ **SEMI D80 - Test Method for Measurement of Water Vapor Transmission Rate for High Gas Barrier Plastic Film in a Short Time**



WVTR equipment (MA method)

Evaluation of film substrate

- ✓ **SEMI D74 - Guide for Measuring Dimensions of Plastic Films/Substrates**

Collaboration　TEIJIN LIMITED, MORESCO Corporation

Related program

- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].
- JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2021].

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

YU-FIC

Flexible OLEDs on Ultra-thin Glass

We develop flexible OLED lighting devices on ultra-thin glass with electrodes fabricated by roll-to-roll (R2R) technologies.

Technological features

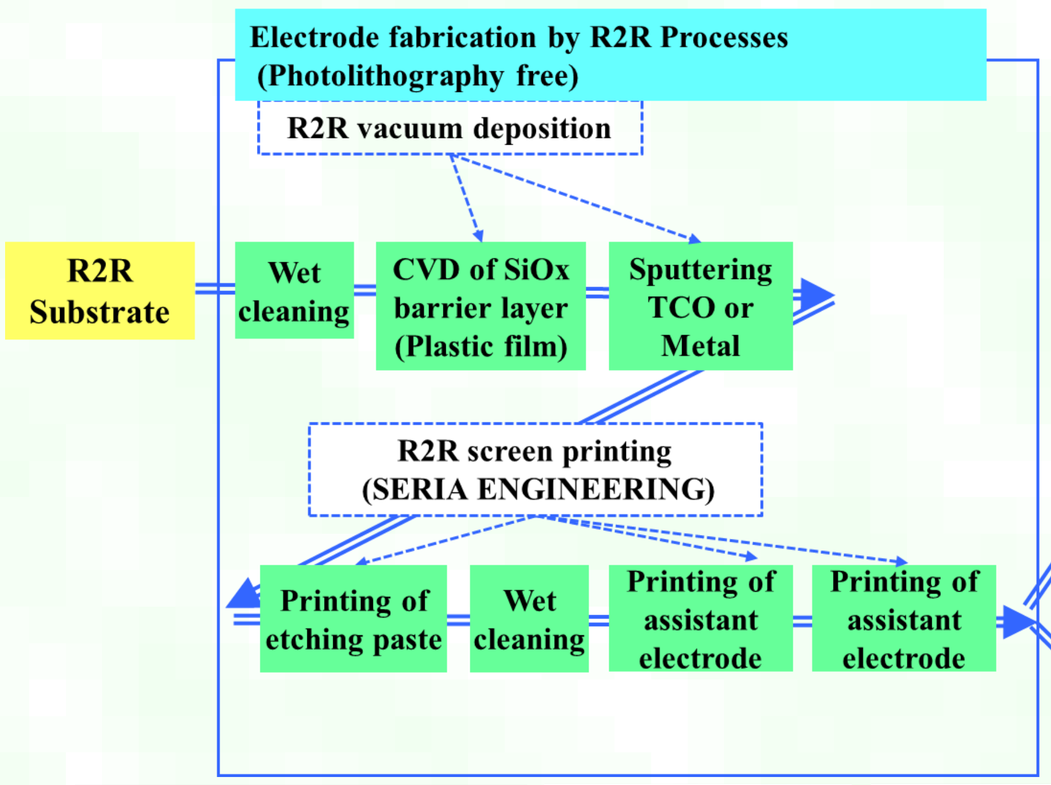
■ **Advantages of ultra-thing glass G-Leaf® of Nippon Electric Glass**

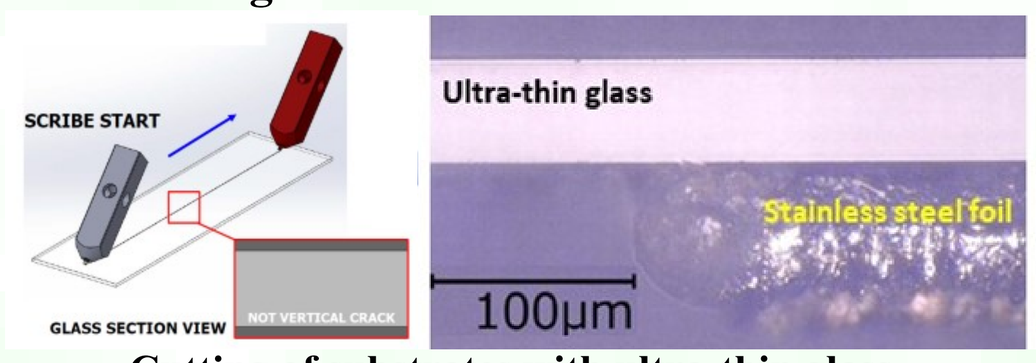
- **Flexibility due to the thickness of 50μm; Applicability to Roll-to-roll (R2R) fabrication**
- **Intrinsic advantages of glass**
  (High gas barrier, surface smoothness, temperature stability, chemical stability, size stability, etc.)

Developed technologies

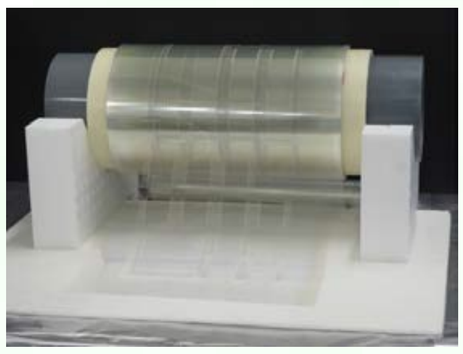
■ **Flexible OLED devices on ultra-thin glass with the thickness of 50μm.**

- **Roll-to-roll (R2R) photolithography-free fabrication of electrodes**
- **Unique glass cutting technology giving no damage to OLED devices with ultra-thin glass**
- **Flexible laminating encapsulation matching with ultra-thin glass**

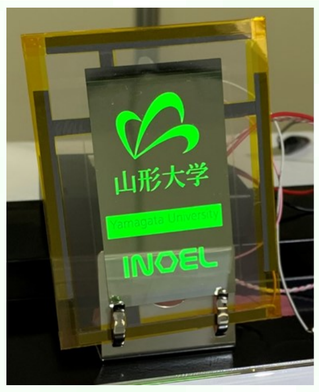


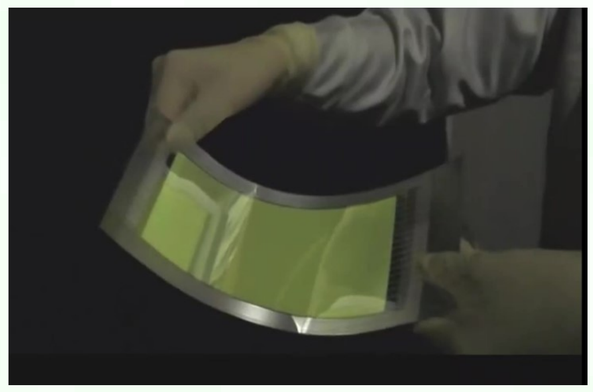


Cutting of substrates with ultra-thin glass (Mitsuboshi Diamond Industrial)



Ultra-thin glass with patterned electrodes (Nippon Electric Glass)





Collaboration

Fraunhofer FEP, Nippon Electric Glass Co., Ltd., SERIA ENGINEERING,INC., FEBACS CO., LTD., Mitsuboshi Diamond Industrial Co., Ltd., NIPPON STEEL Chemical & Material Co., Ltd., FUJIKURA KASEI CO., LTD., Taica Corporation, tesa tape K.K.

Related program

- **Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2023].**
- **JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2020].**
- **MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].**

Publication

- **T. Furukawa, M. Koden, IEICE Trans. Electron, E100-C, 949 (2017). "Novel roll-to-roll deposition and patterning of ITO on ultra-thin glass for flexible OLEDs"**
- **T. Furukawa, J. Hauptmann, T. Nakagaki, R. Ikeuchi, M. Sagawa, D. Nagata, J. Nakatsuka, IDW'21, FLX5/FMC6-1 (2021). "Roll-to-Roll Fabrication for OLED Lighting Using Ultra-Thin Glass Substrate and Encapsulating Stainless Steel Foil"**
- **T. Nakagaki, T. Kawabata, H. Takimoto, T. Furukawa, IDW'19, FLXp1-9L (2019). "Scribing Tool and Cutting Method for Ultra-thin Glass"**
- **T. Furukawa, K. Mitsugi, S, Akiyama, H, Itoh, D, Kobayashi, T. Suzuki, H,kuroiwa, M, Sakakibara, K,Tanaka, M, Kawamura, M, Koden, IDW'14, FLX3-4 (2014). "Patterned ITO Film by Roll-to-Roll Process on Ultra-thin Glass"**

INOEL Yamagata University
Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

YU-FIC

Improved Mechanical Strength of Flexible OLEDs on Ultra-thin Glass

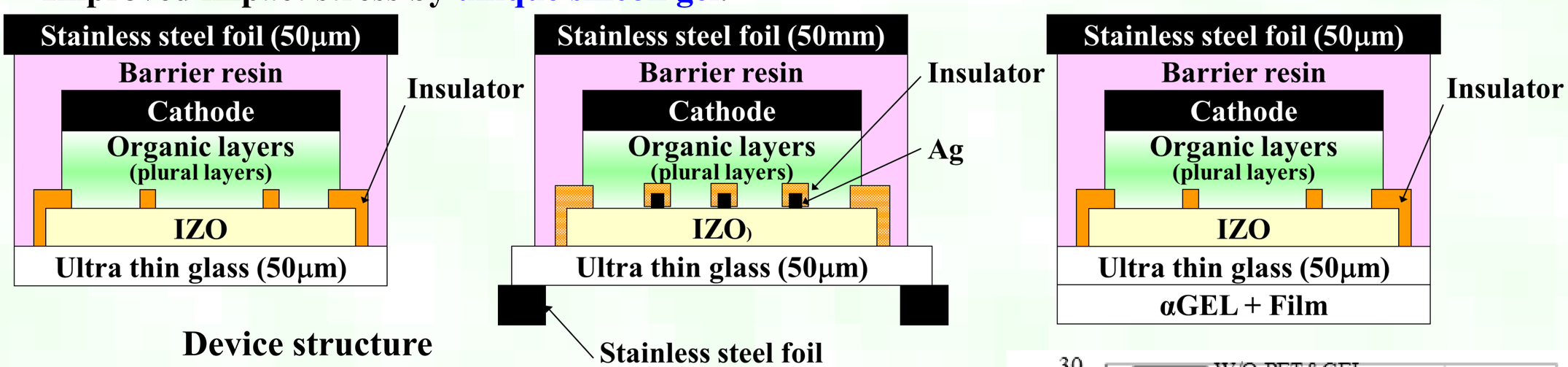
We develop technologies for improvement of mechanical strength of flexible OLED devices fabricated on ultra-thin glass.

Technological features

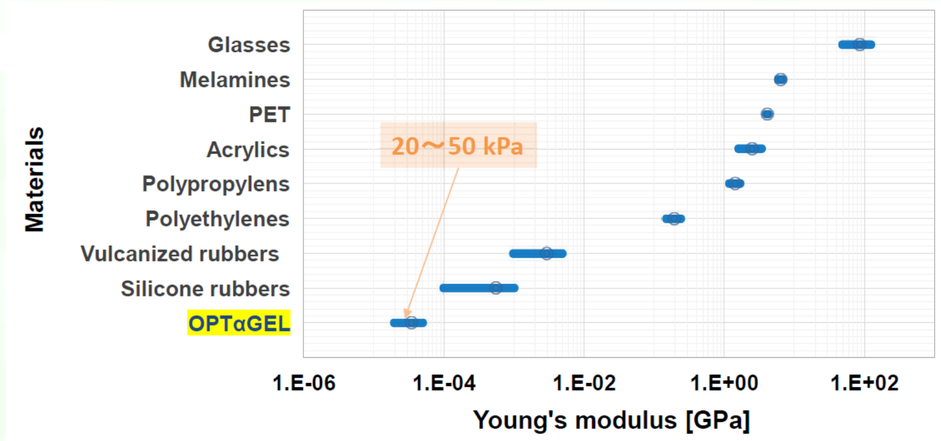
- **Improved mechanical strength of flexible OLED devices ultra-thin glass with the thickness of 50μm.**

Developed technologies

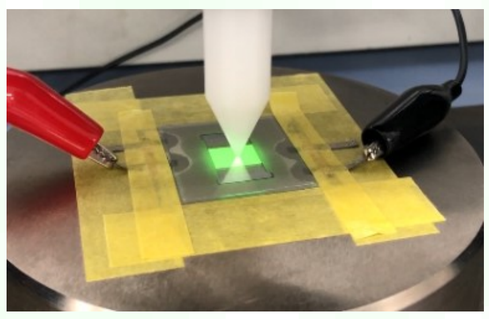
- **Improved mechanical strength by encapsulation with stainless steel foil.**
- **Reduced side edge crack under glass cutting.**
- **Improved impact stress by unique silicon gel.**

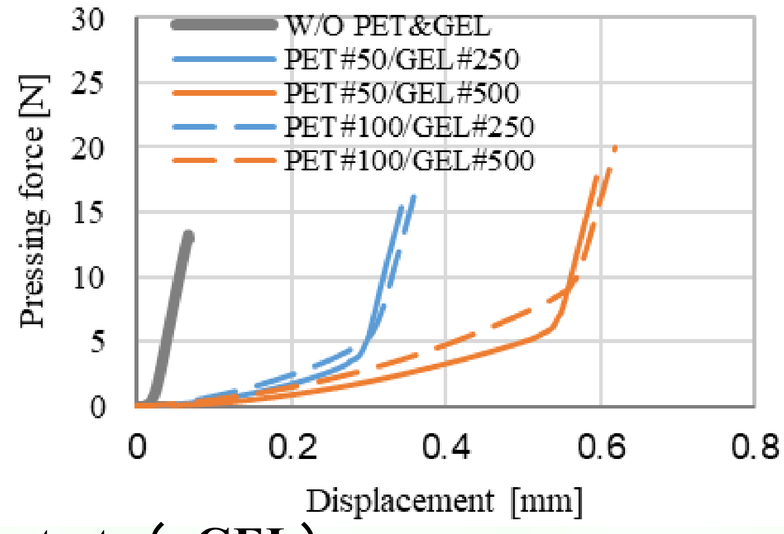


Device structure



Young's modulus of various materials





Pressure stress test （αGEL）

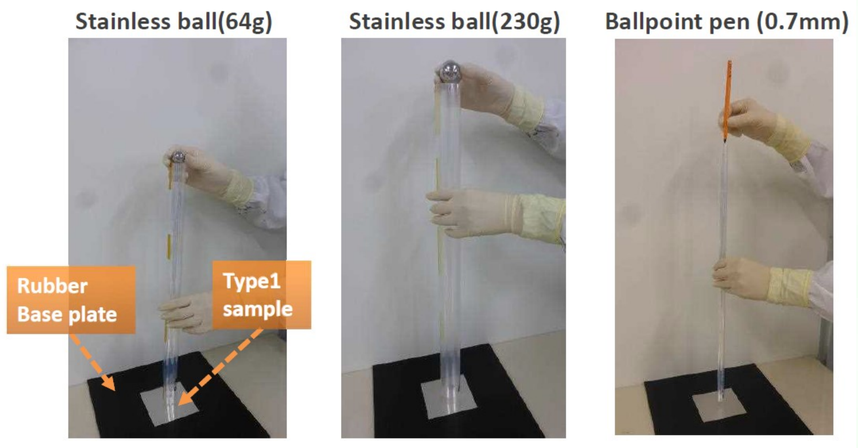


Table Drop impact test result

Protection layer			Height when glass cracked [cm]		
Cover film / Thickness [μm]	OPTαGEL t250μm Needle penetration [1/10mm]		Stainless ball drop 64 [g]	230 [g]	Ballpoint pen drop
-	-		60~80	20~40	10
PET / 100	-		90~100	60~80	20~50
PC / 200	-		50~60	> 100	50~70
PET / 100	130	Soft	> 100	70	50~60
PC / 200	130		> 100	90	50~70
PC / 200	90		> 100	> 100	80
PC / 200	50		> 100	100	50~60
PC / 200	25	Hard	> 100	80~90	60

Drop Impact test（αGEL）

Collaboration

Nippon Electric Glass Co., Ltd., Mitsuboshi Diamond Industrial Co., Ltd., NIPPON STEEL Chemical & Material Co., Ltd., Taica Corporation, tesa tape K.K.

Related program

- **Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2023].**
- **JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2020].**
- **MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].**

Publication

- **T. Furukawa, J. Hauptmann, T. Nakagaki, R. Ikeuchi, M. Sagawa, D. Nagata, J. Nakatsuka, IDW'21, FLX5/FMC6-1 (2021). "Roll-to-Roll Fabrication for OLED Lighting Using Ultra-Thin Glass Substrate and Encapsulating Stainless Steel Foil"**
- **M. Natsuka, Y. Ono, H. Mataki, S. Usui, H. Suzuki, M. Abe, T. Furukawa, IDW'21, FLX5/FMC6-2 (2021). "Protection of OLED Lighting with Ultra-Thin Glass by Special Silicone Gel"**

INOEL Yamagata University
Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

YU-FIC

Flexible OLEDs on Stainless Steel Foil or Barrier Film

We develop flexible OLED devices on stainless steel foil of NIPPON STEEL CORPORATION GROUP or PEN film of Teijin.

Technological features

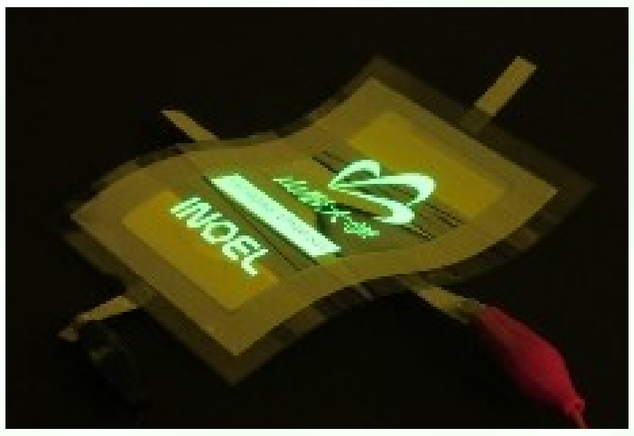
■ **Stainless steel foils of NIPPON STEEL CORPORATION GROUP**
- Thickness: 50μm or 30μm
- Excellent surface smoothness（Ra～0.6nm）
- Excellent temperature and process resistances
- High gas barrier ability

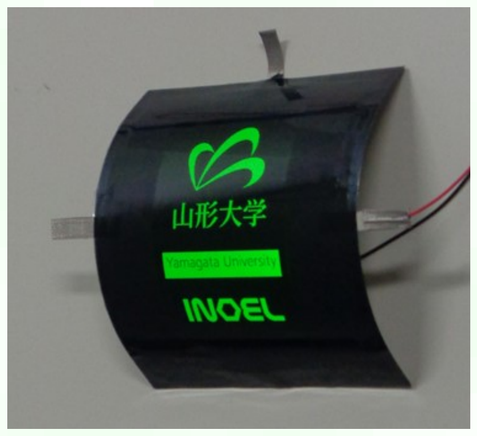
■ **PEN or PET film**
- Roll-to-roll (R2R) CVD for barrier layer
- High gas barrier: WVTR～10^{-6}g/m^2/day
  （WVTR: Water Vapor Transmission Rate）

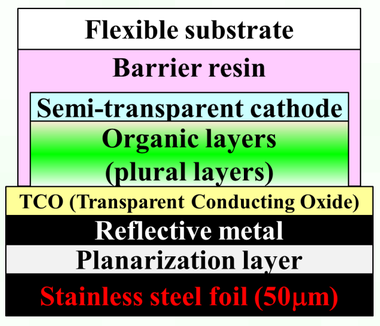
Developed technologies

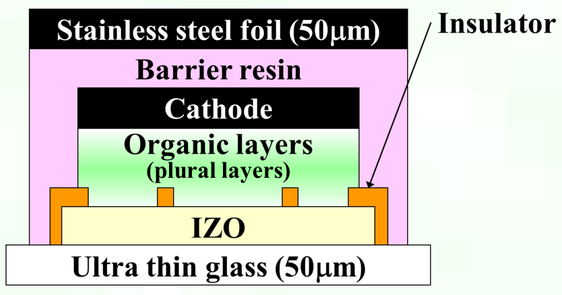
■ **Stainless steel foil**
- Reflective electrode fabrication by Roll-to-roll (R2R) photolithography-free processes
- Prototype flexible OLEDs on stainless steel foil
- Laminating encapsulation with stainless steel foil for improving mechanical strength of flexible OLED devices on ultra-thin glass

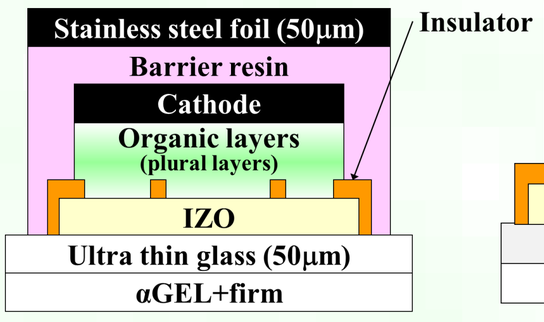
■ **Barrier film**
- Roll-to-roll (R2R) fabrication of single layer barrier and transparent electrode on flexible film
- Prototype flexible OLEDs on barrier film

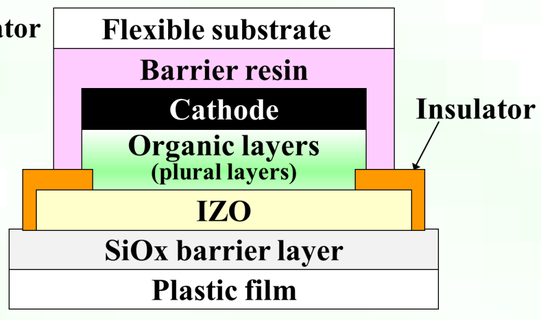












Collaboration

TEIJIN LIMITED, NIPPON STEEL Chemical & Material Co., Ltd., Nippon Electric Glass Co., Ltd., Mitsuboshi Diamond Industrial Co., Ltd., FUJIKURA KASEI CO., LTD., tesa tape K.K.

Related program

- Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2023].
- 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"
- T. Furukawa, N. Kawamura, M. Koden, H. Itoh, H. Kuroiwa, K. Nagai, LOPEC (2017). "Gas barrier film for OLED devices"
- 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

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

山形大学 Yamagata University

Developed technology

YU-FIC

Roll-to-Roll (R2R) Fabrication of Barrier Film with Transparent Electrode

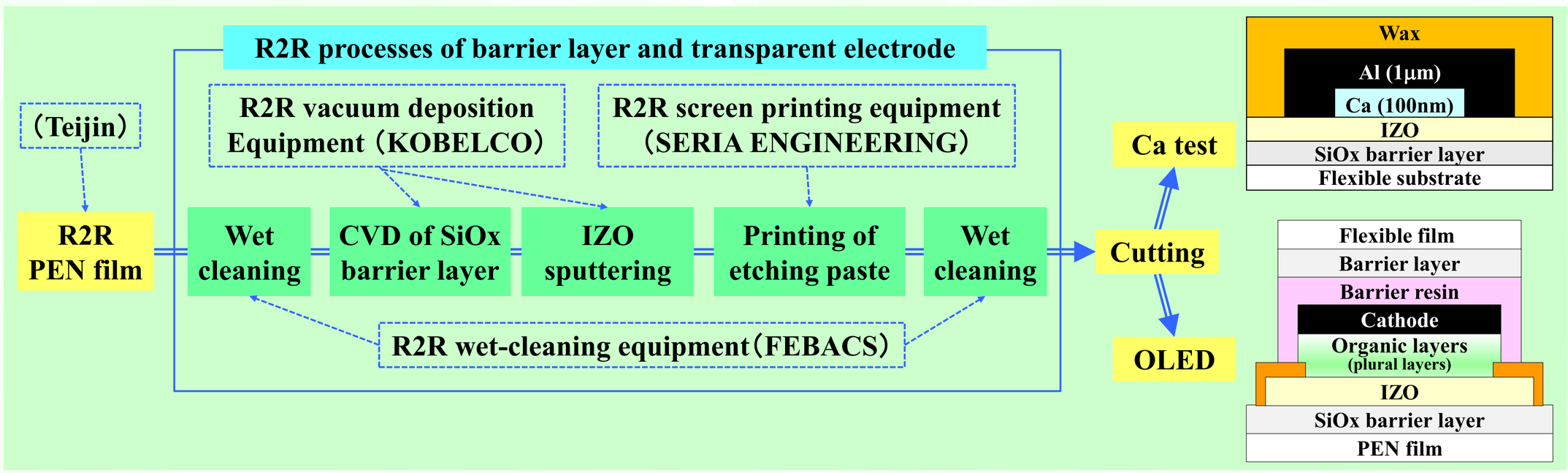
We develop fabrication technologies of gas barrier layer and transparent electrode on flexible films, using roll-to-roll (R2R) depositions, which are PE-CVD (Plasma Enhanced Chemical Vapor Deposition) and sputtering.

Technological features

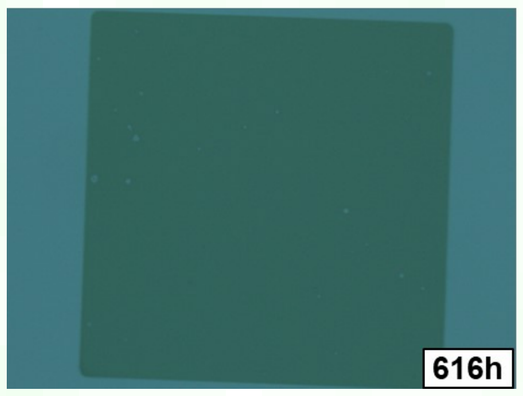
- Roll-to-roll (R2R) PE-CVD deposition of gas barrier layer on flexible films
- High barrier ability with WVTR (Water Vapor Transmission Rate) of the order of 10^{-6}g/m^2/day
- High gas barrier films with transparent electrode

Developed technologies

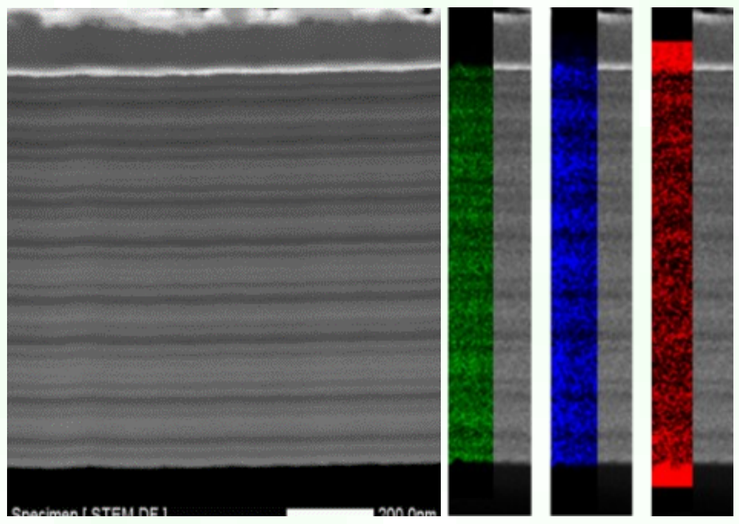
- Roll-to-roll (R2R) photolithography-free fabrication of barrier layer and transparent electrode on flexible films



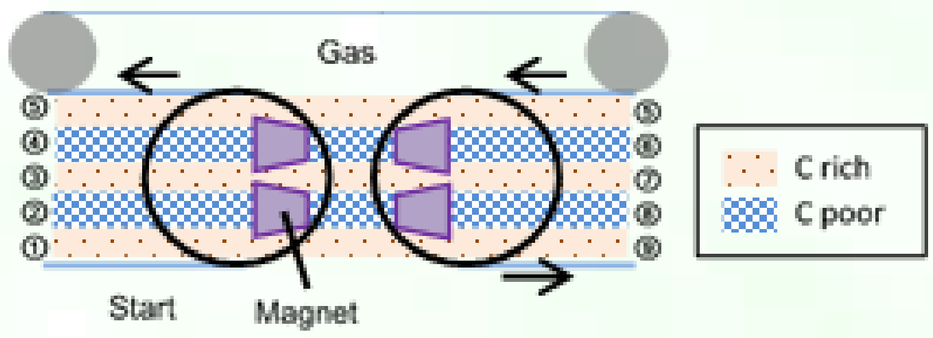
- High gas barrier property: WVTR = 6.3×10^{-6}g/m^2/day



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



Cross section of barrier layer



CVD deposition mechanism

Collaboration

TEIJIN LIMITED, Tosoh Corporation, MORESCO Corporation

Related program

- Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2023].
- 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 (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"
- 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"

INOEL Yamagata University Innovation Center for Organic Electronics

山形大学 Yamagata University

Developed technology

YU-FIC

In-Mold Electronics (IME) Technology

We develop novel in-mold electronics (IME) technologies, molding functional components, printed electrodes on flexible substrates.

Technological features

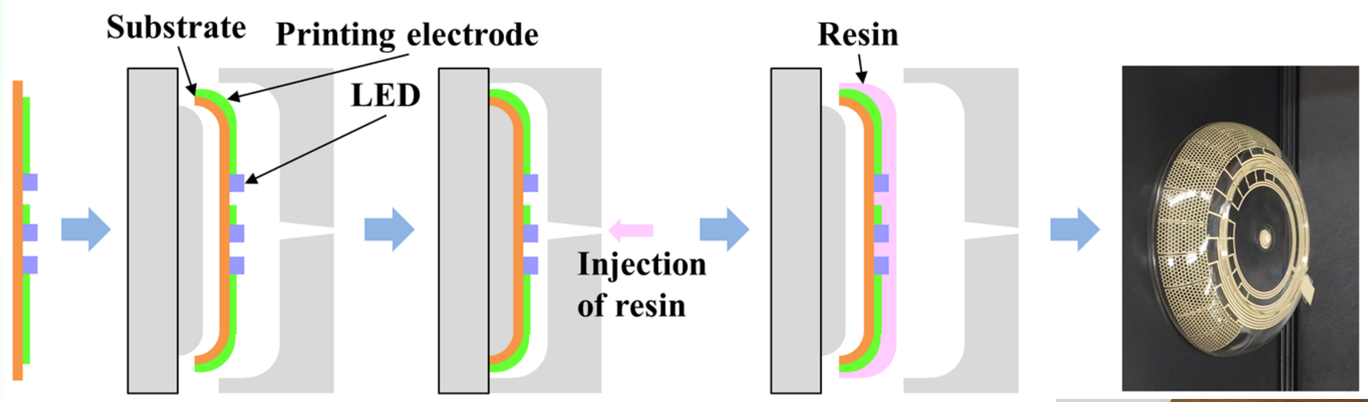
- **3D-molding technologies with electrodes**
- **Process simplification in fabrication of circuit board by printing technologies**

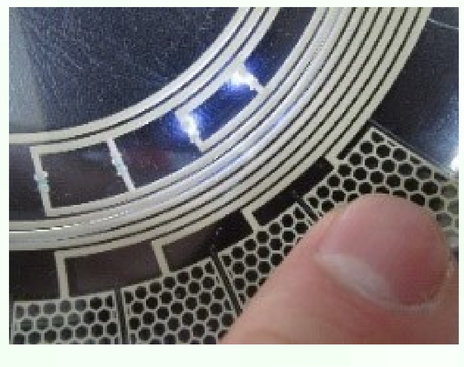
Applications

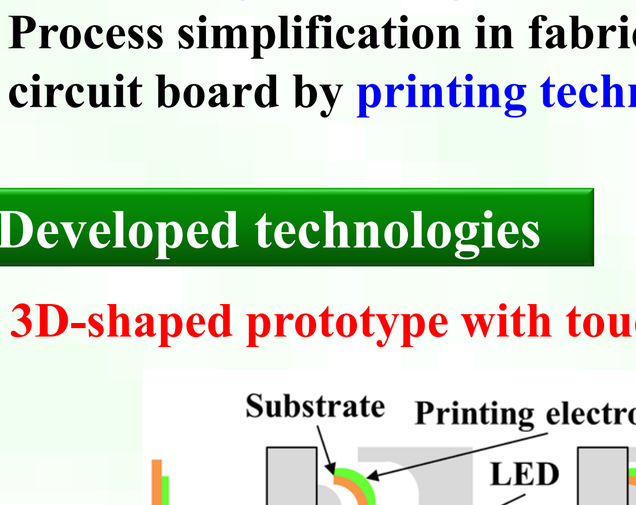
- **Sensors (agricultural sensors, in-water sensors, etc.)**
- **Automotive interiors (lighting, controller, etc. of instrument panels and consoles)**
- **Thin IoT devices**

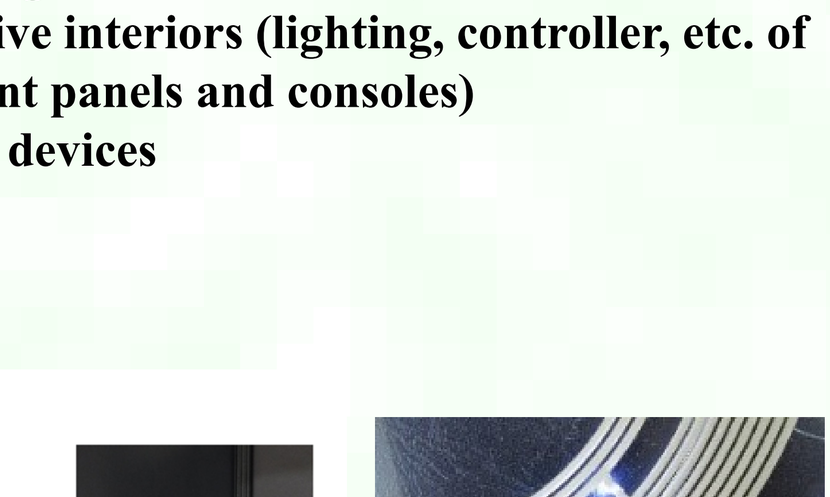
Developed technologies

- **3D-shaped prototype with touch screen and LEDs**



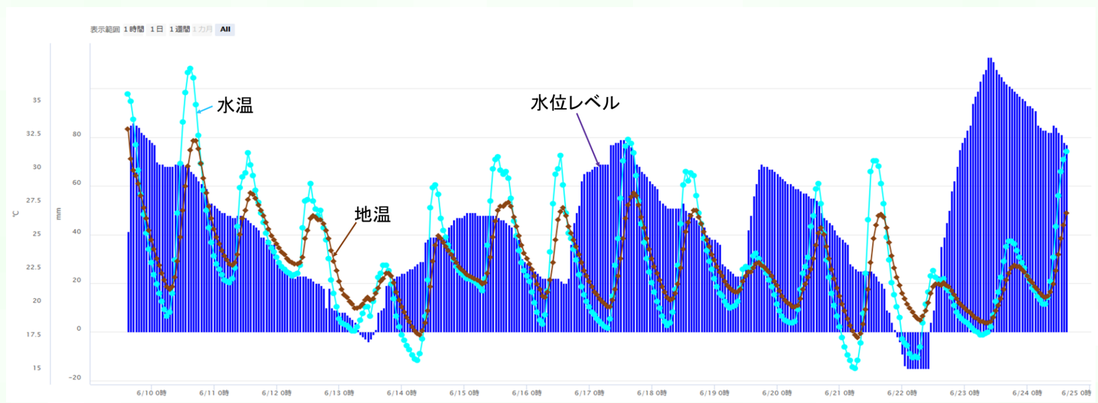


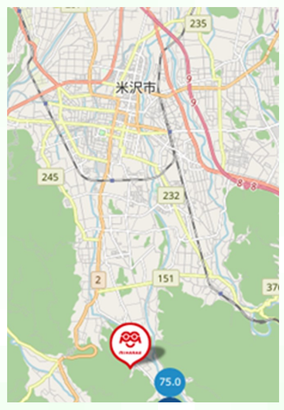


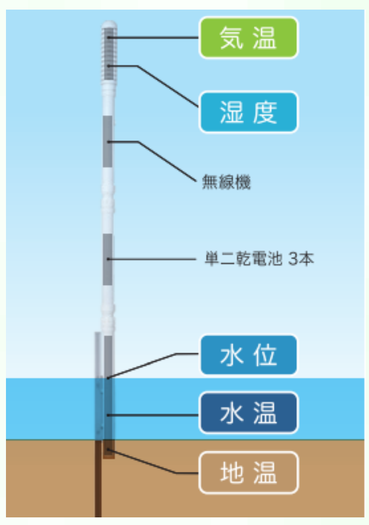


JPCA Show 2021
(Tokyo)

- **Agricultural sensor / Verification test**
  - **Applied to agricultural sensors of Nishimu Electronics Industries**
  - **Verification test in Paddy fields of Yonezawa city and Tome city.**







Collaboration

Aiwa Lite Corporation, The Japan Steel Works, LTD., TEIJIN LIMITED, FUJIKURA KASEI CO., LTD., Nishimu Electronics Industries Co., Ltd.

Related program

- **Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2023].**
- **MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].**

Publication

- **Y. Kawamura, T. Takahashi, T. Furukawa, ICFPE 2021, 2Rm401-08-02 (2021). "Student Oral Presentation Award" "Improvement of printed electrodes disconnection after 3D thermoforming by optimizing print process on PC film"**
- **Y. Kawamura, T. Takahashi, K. Wakabayashi, H. Hirose, Y. Azakami, H. Itoh, T. Furukawa, IDW'20, FLX3-04L (2020). "Effect of Pressure Forming Conditions on PC Sheet integrating Electric Wiring for 3D Electronics Technology"**
- **山形大学;「有機デバイス総合展」(2021.10 / 東京ビッグサイト).**
- **山形大学;「JFlex2020展」(2020.1 / 東京ビッグサイト),「JFlex2021展」(2020.12 / オンライン).**

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

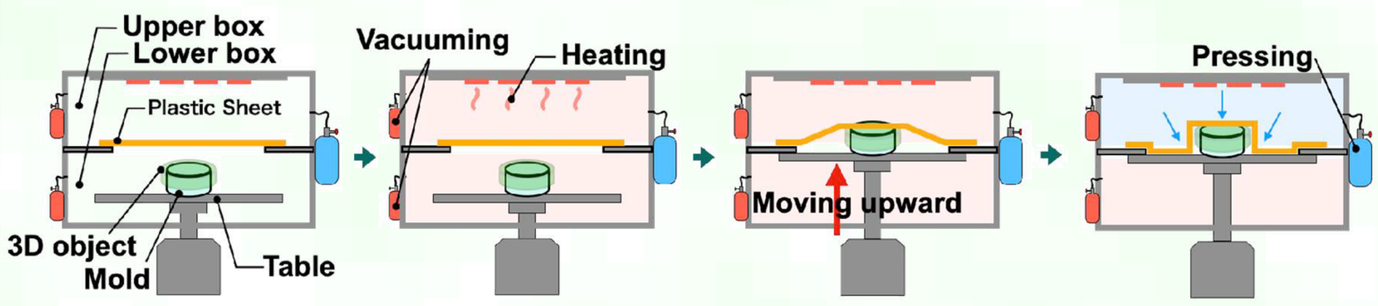
Mechanism analysis of electrode disconnection in 3D thermoforming

We study on https://sid.onlinelibrary.wiley.com/toc/21680159/2008/39/1processes.

Processes

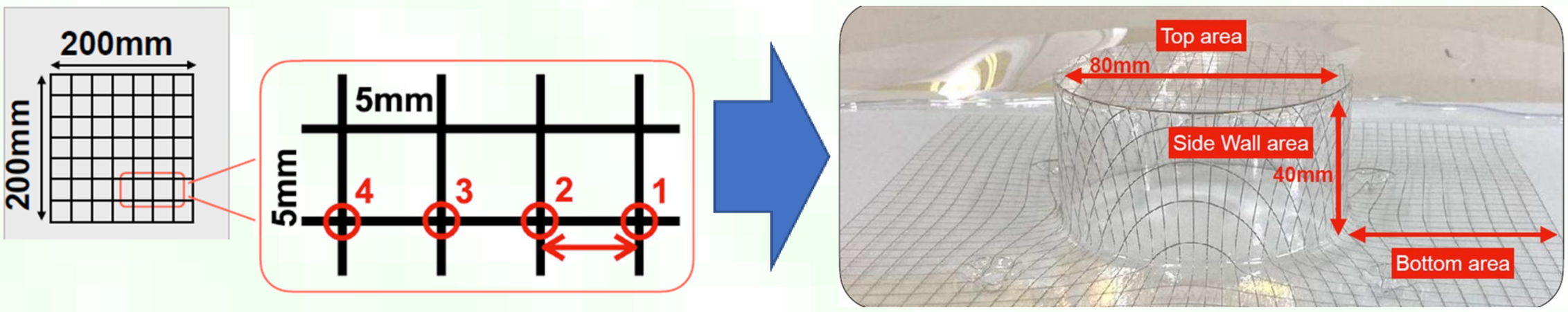
Screen printing equipment

3D thermoforming equipment



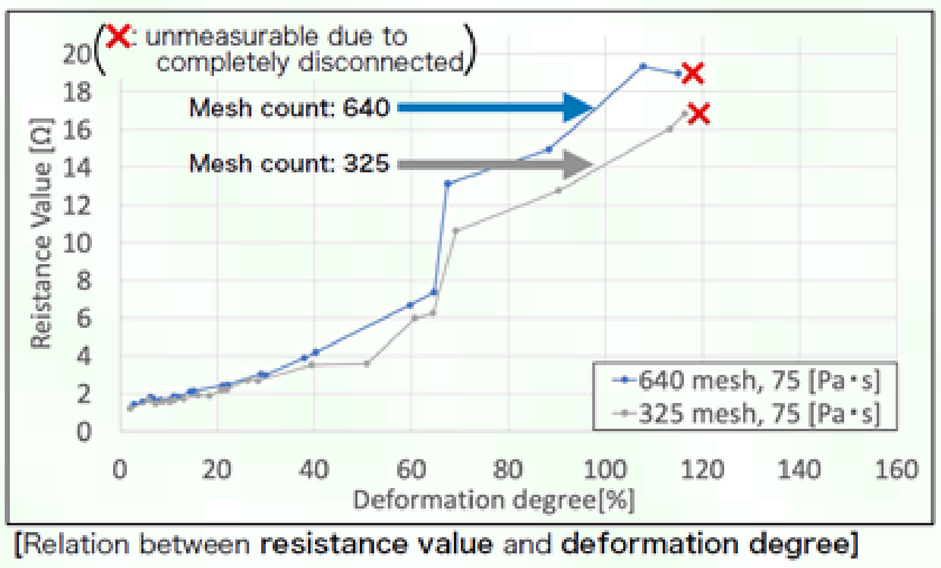
3D thermoforming process

Thermoforming experiments



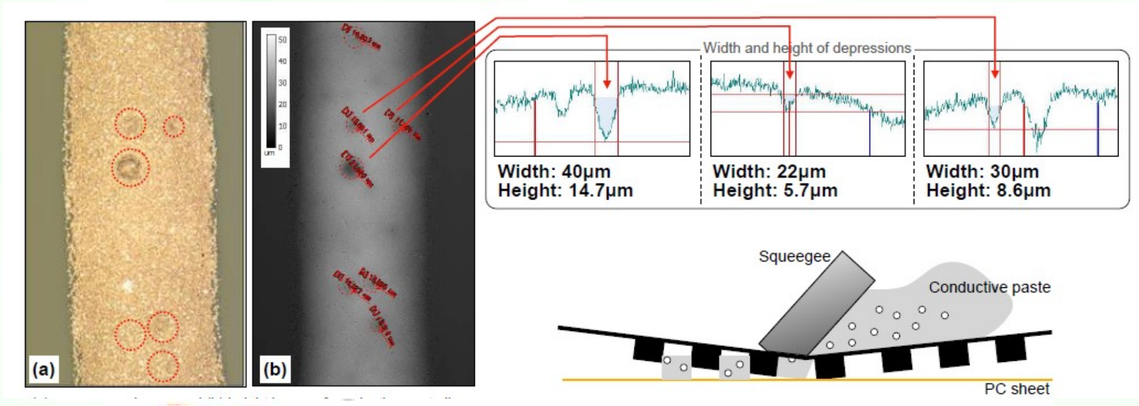
Printing of conducting paste on plastic sheet

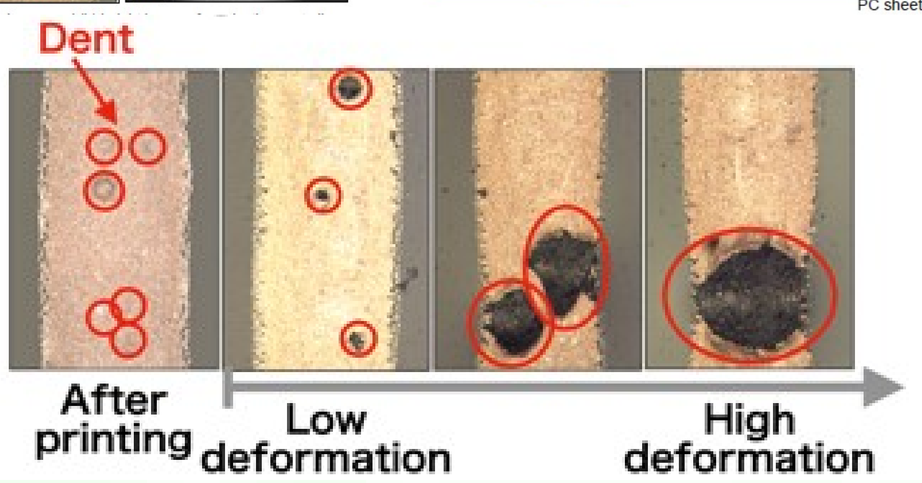
Thermoforming



[Relation between resistance value and deformation degree]

Relationship between deformation degree of substrate and electrical resistance





Mechanism of electrode disconnection

Collaboration TEIJIN LIMITED, FUJIKURA KASEI CO., LTD.

Related program

- Yamagata University Flexible Electronics Japan-Germany International Collaborative Practical Utilization Consortium (YU-FIC) [Oct. 2017～Mar. 2021].
- JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2020].
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].

Publication

- Y. Kawamura, T. Takahashi, T. Furukawa, ICFPE 2021, 2Rm401-08-02 (2021). “Student Oral Presentation Award” “Improvement of printed electrodes disconnection after 3D thermoforming by optimizing print process on PC film”
- Y. Kawamura, T. Takahashi, K. Wakabayashi, H. Hirose, Y. Azakami, H. Itoh, T. Furukawa, IDW’20, FLX3-04L (2020). “Effect of Pressure Forming Conditions on PC Sheet integrating Electric Wiring for 3D Electronics Technology”

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

YU-FIC

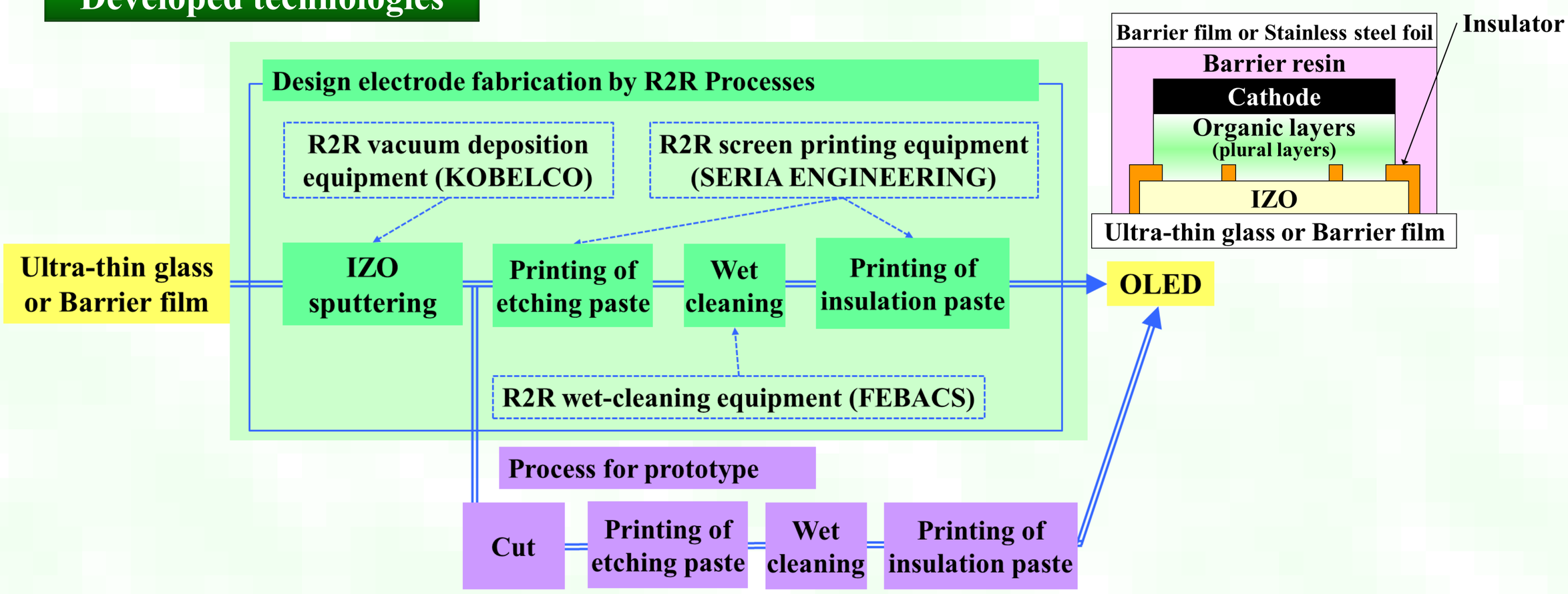
Application of organic electronics technologies to interactive advertisement

We develop flexible OLED devices for packages, etc., aiming at the application of organic electronics products to advertisement.

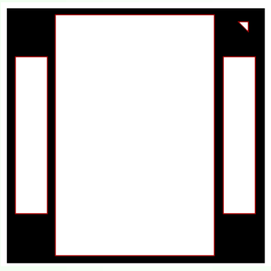
Technological features

- Flexible OLED packages for various applications
- Applied to package, advertisement, souvenir, name plate, bookmark, etc.

Developed technologies

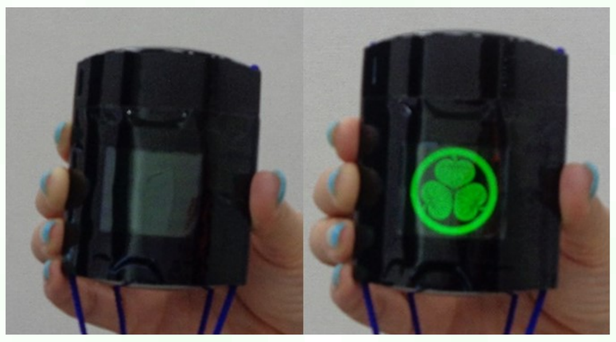


Etching of transparent electrode (common pattern)



Printing of certain design

Bookmark



Medicine case

Pencil case

Nameplate

Souvenir

Amulet

Collaboration KOMORI Corporation, TAKEDA PRINTING CO., LTD., Taica Corporation

Related program

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

INOEL Yamagata University
Innovation Center for Organic Electronics
Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)
山形大学 Yamagata University

Developed technology

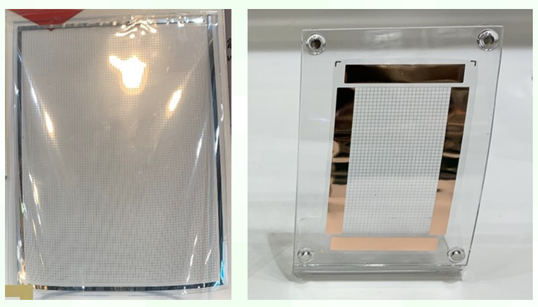
YU-FLEC

Non-ITO Transparent Electrode with Implanted Metal-mesh Structure

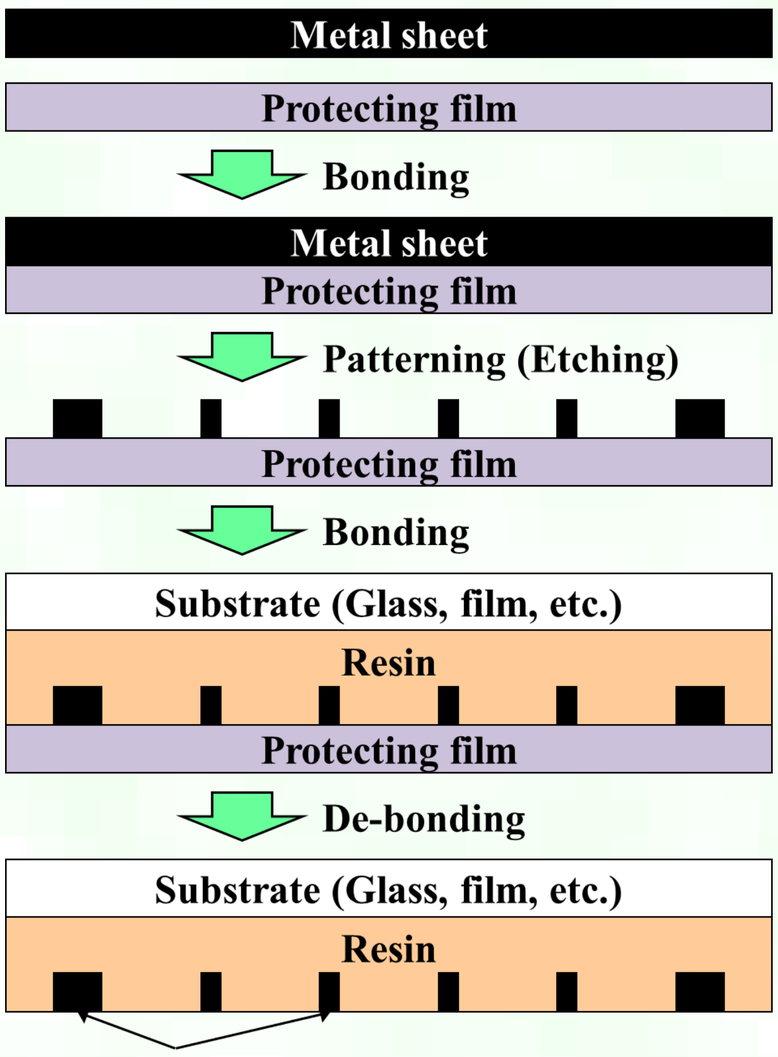
ITO (Indium Tin Oxide), which is the most common transparent electrode in LCDs and OLEDs, has issues in cost, productivity, etc.
We develop OLED devices using a non-ITO transparent electrode with novel implanted metal-mesh structure fabricated by Toyo Aluminium.

Technological features

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



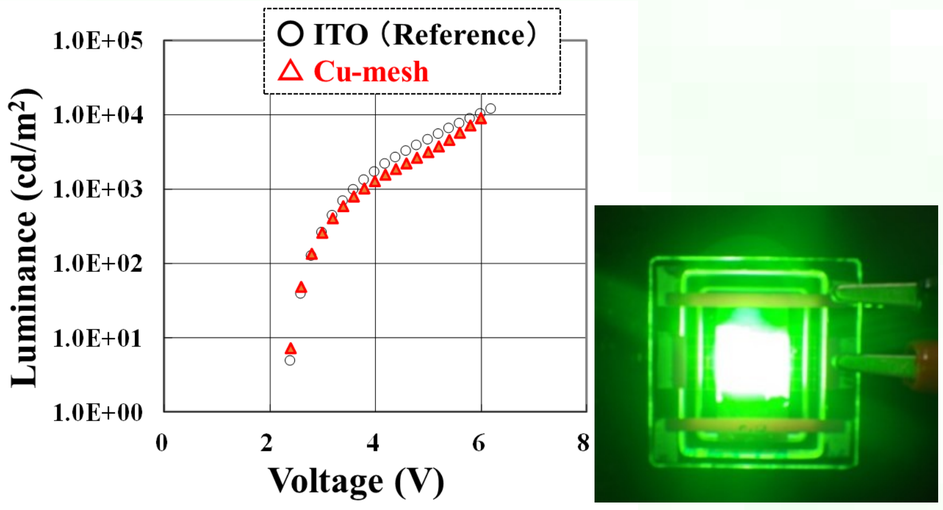
	Sheet resistance
ITO（on glass）	～10Ω/□
ITO（on film）	～40Ω/□
Al mesh (thickness: 15μm)	0.036Ω/□
Cu mesh (thickness: 15μm)	0.023Ω/□



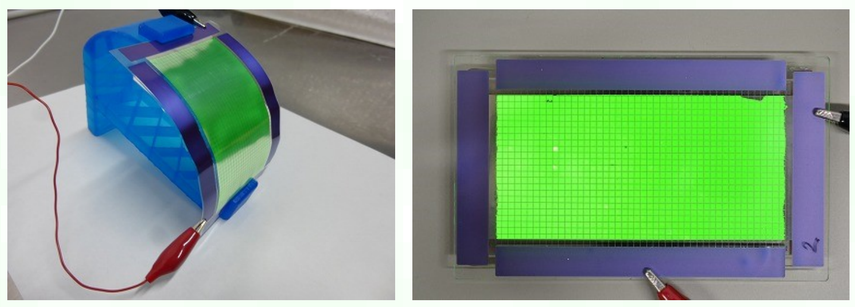
Fabrication process of metal-mesh substrate

Developed technologies

- **OLED devices using non-ITO transparent electrode with implanted metal-mesh electrode**
  - **Comparative performance with normal ITO electrode**



- **OLED device samples with implanted metal-mesh electrode**



Metal mesh (Thickness: 15μm, width: 75μm)

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

Related program

- Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) [Jan. 2018～Mar. 2023].
- JST: OPERA Program Grant Number JPMOP1844 [FY2018～FY2022].
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].

Publication

- M. Koden, N. Kawamura, T. Yuki, H. Nakada, R. Waguri, K. Den, R. Nakao, H. Minamiyama, The 31th Meeting of Japan OLED Forum, S7-2 (2020).
- R. Waguri, K. Den, R. Nakao, H. Minamiyama, MES2020, 1B1-2 (2020).
- Yamagata University; “JFlex2020” (Jan. 2020 / Tokyo), “TCTJAPAN” (Jan. 2020 / Tokyo, “JFlex2019” (Jan. 2019 / Tokyo).
- Toyo Aluminium; Japan Chemical Daily (20 Jan. 2020), Japan Metal Daily (18 Mar. 2020).
- R. Waguri, Toyal Technical Report (2019).
- Toyo Aluminium; “INTERNEPCON Japan” (Jan. 2020, Jan. 2019 / Tokyo).

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

YU-FLEC

TFE (Thin Film Encapsulation) Technologies for OLEDs

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

Technological features

■ **Advantages of "Non-solvent UV-IJ resin ink" developed by TOYOCHEM"**
- To support SiNx barrier layer
- UV cure type (non-solvent)
- Applicable to ink-jet

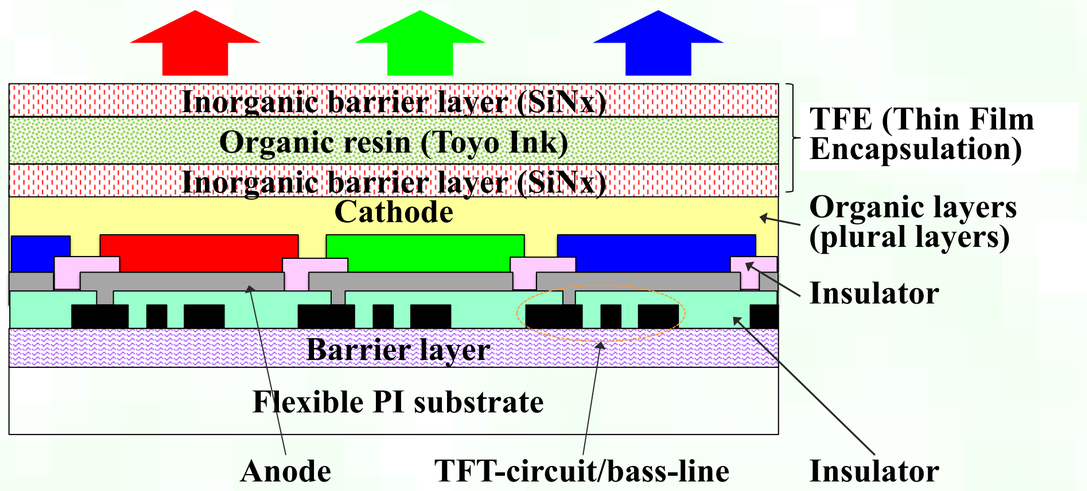
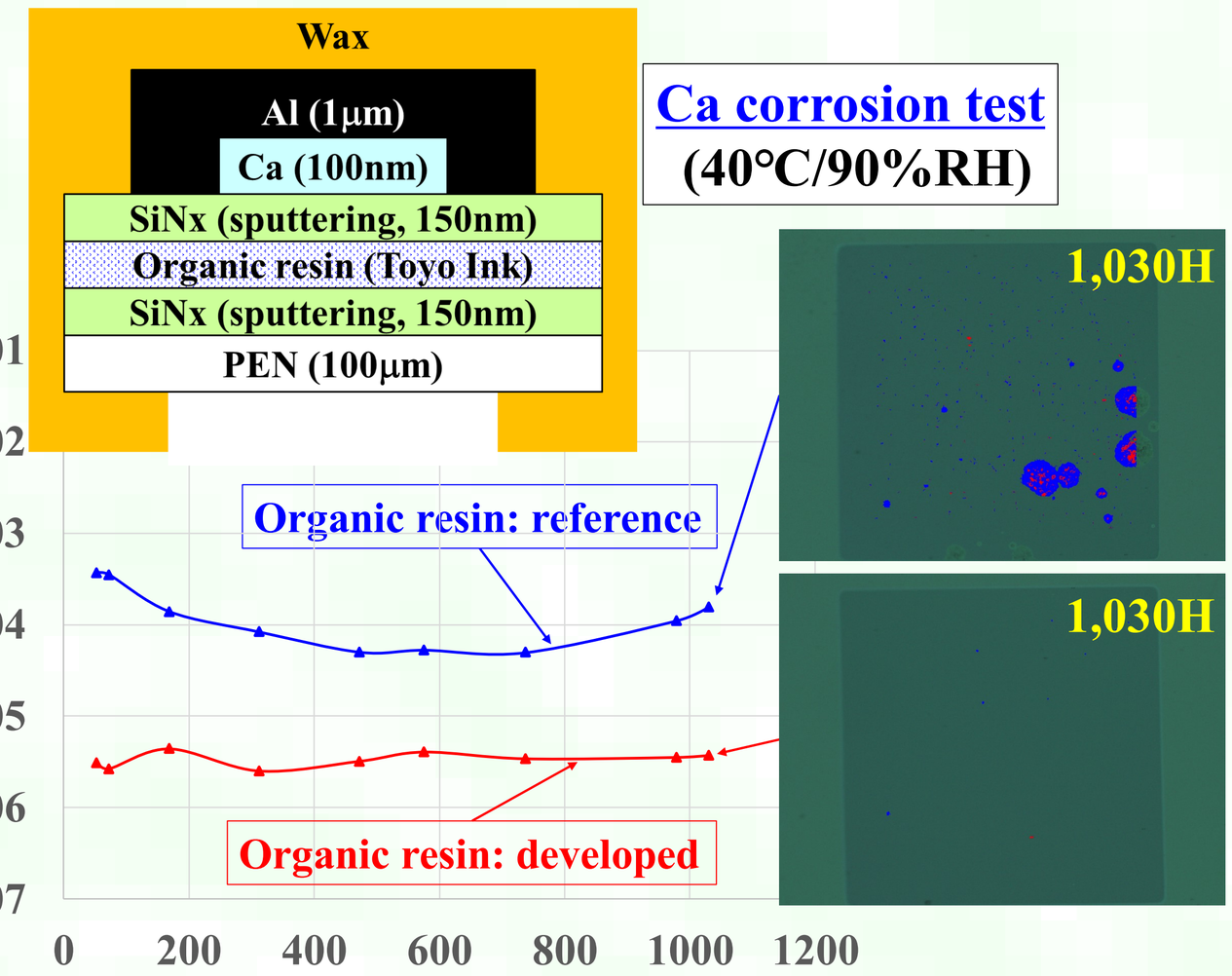


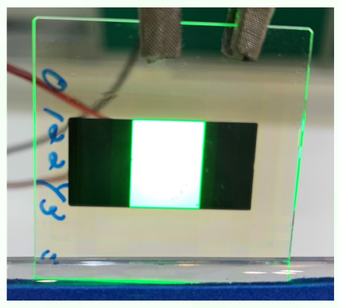
Image of OLED with TFE

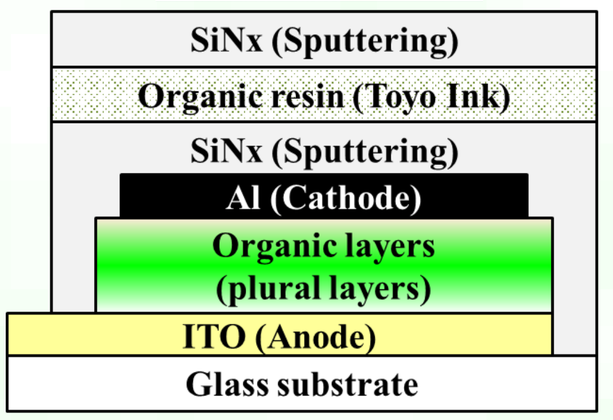
Developed technologies

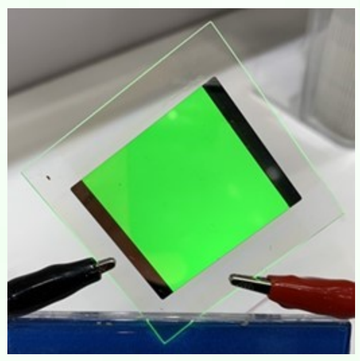
■ **TFE structure with high gas barrier property**
- TEF with "Non-solvent UV-IJ resin ink" developed by TOYOCHEM
- No actual damage after storage test of 1,000 hours under 40℃/90%RH
- WVTR (Water Vapor Transmission Rate): order of 10^{-6}g/m^2/day (40℃/90%RH)

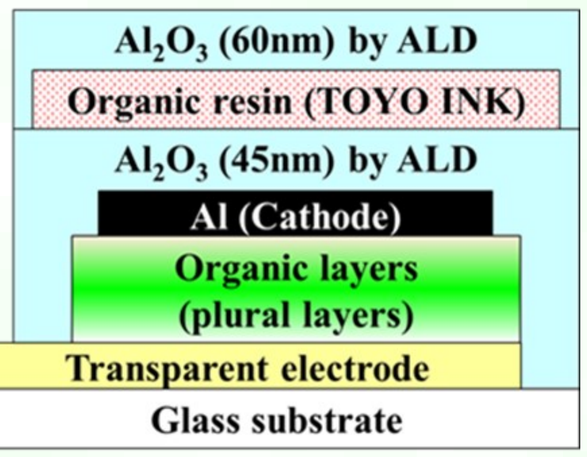


■ **OLED device with the developed TFE structure**









Collaboration

TOYOCHEM CO., 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 / Commercialization

- Yamagata University; "JFlex2020" (Jan. 2020 / Tokyo); "JFlex2019" (Jan. 2019 / Tokyo).
- The developed results have been applied to LIORESIT™ NSP 800 series (UV Curing/ IJ printing) of TOYOCHEM CO., LTD.

INOEL Yamagata University Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

YU-FLEC

OnDemand Patterning of OLEDs by Ink-jet Printed Insulators

OnDemand patterning of OLEDs was developed by on-demand pattens of insulators fabricated by ink-jet printing. The developed technology can be applied to small lot OLED productions with various designs, inducing novel applications.

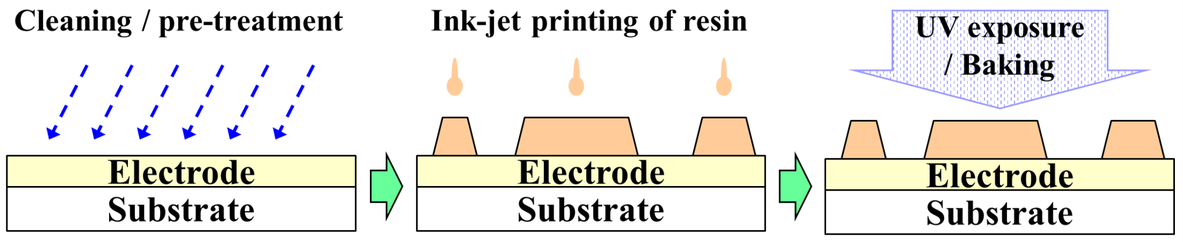
Technological features

■ **Ink-jet printing of insulators**
- simple and inexpensive processes
- On-Demand design (small lot with various designs)
- Eco-friendly (small volume of waste liquid)
- Suppression of contamination (Non-contact between substrates and masks)

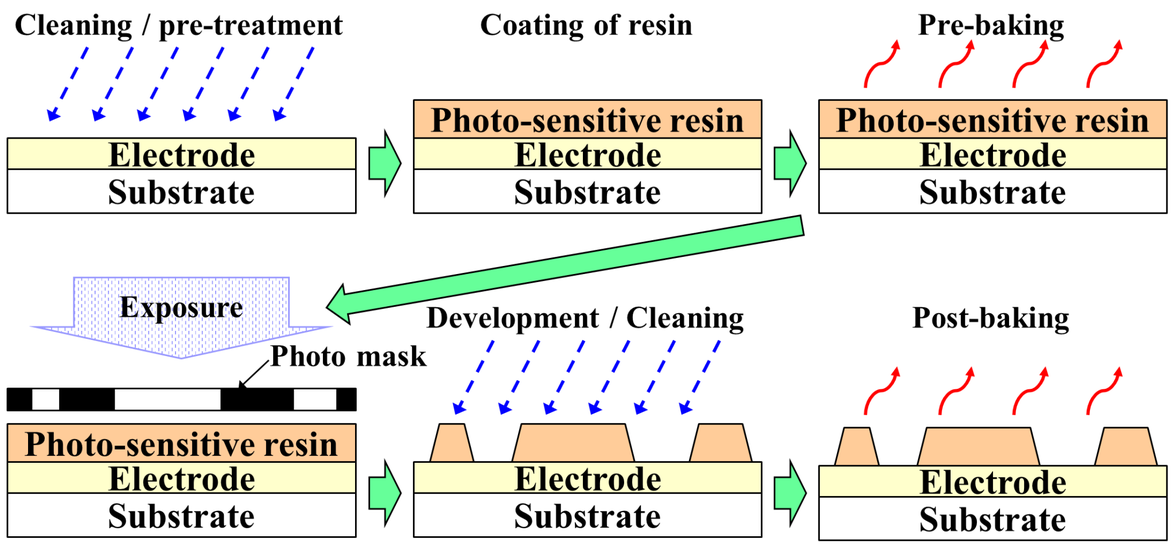
■ **LIORESIT™ NSP 800 of TOYOCHEM CO., LTD.**
- UV curing transparent insulation material
- Printable with IJ printer
- Curable with 365～395nm UV light
- No solvent included

[*] TOYOCHEM CO., LTD. is a wholly owned subsidiary company of Toyo Ink SC Holdings Co., Ltd.

＜OnDemand ink-jet patterning of insulators＞

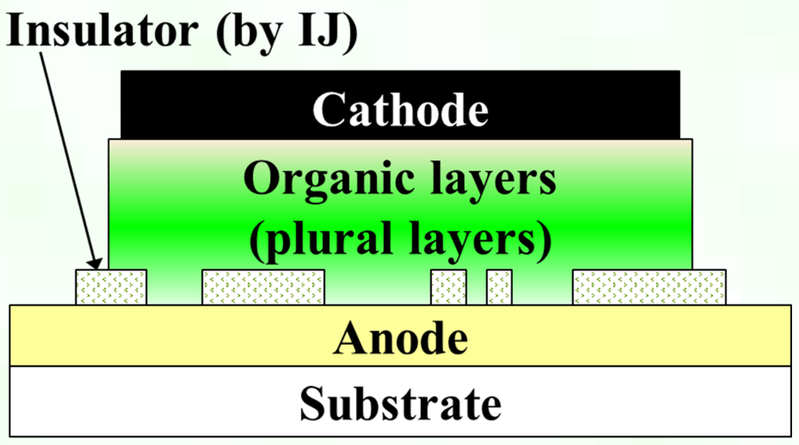


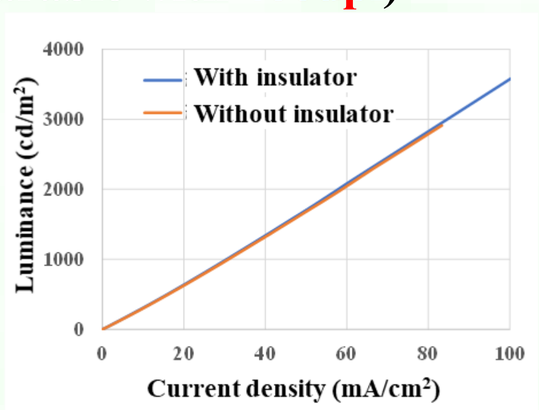
＜Current method with photosensitive resists＞
- High resolution but complicated (expensive)
- Inadequate for on-demand production because of photomasks

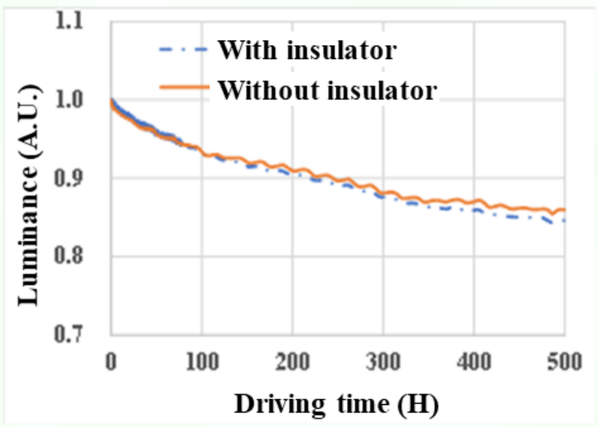


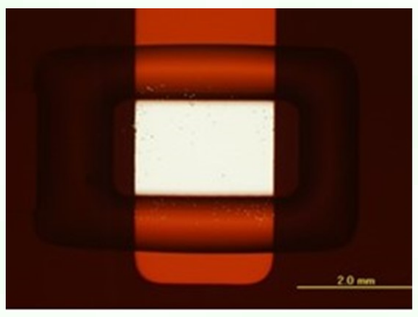
Developed technologies

■ **OLED devices with On-Demand patterns of insulators printed by ink-jet**
- Uniform emission including with edges of insulators
- Comparable characteristics and lifetime with OLEDs without the insulators
- Resolution: L/S=61/62μm (almost comparable with 400dpi)

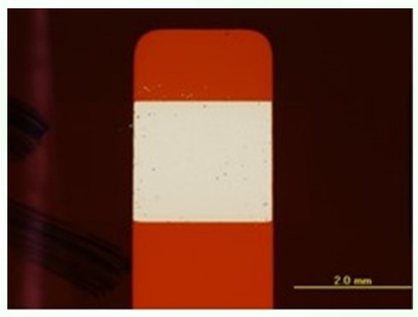






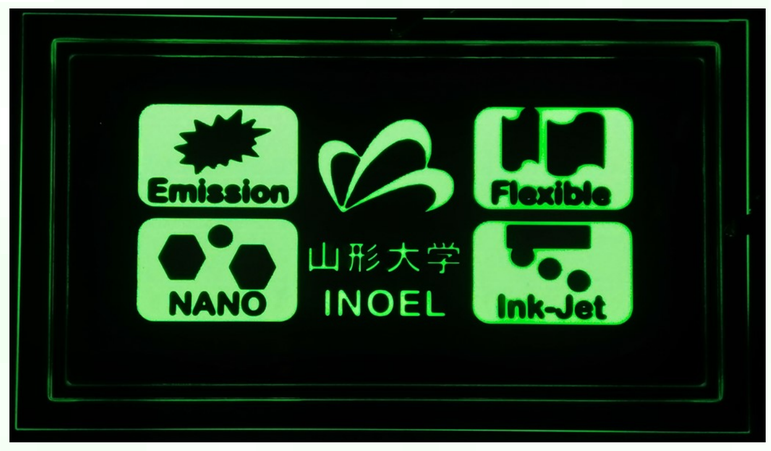


With insulator



Without insulator

Substrate size : 50mm × 50mm



Substrate size : 60mm × 100mm

Collaboration TOYOCHEM CO., 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
- M. Sugimoto, Y. Fukuchi, H. Tsuruta, M. Koden, H. Nakada, T. Yuki, A-COE 2021, PA-17 (2021). “OLEDs with on-demand patterns drown by ink-jet printing”

INOEL Yamagata University
Innovation Center for Organic Electronics

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

山形大学 Yamagata University

Developed technology

Barrier layer by ALD (Atomic Layer Deposition)

ALD (Atomic Layer Deposition) can fabricate barrier layers with excellent surface coverage and can be applied flexible electronics devices.
We provide high gas barrier layers using ALD method for applying various collaborations on flexible organic electronics.

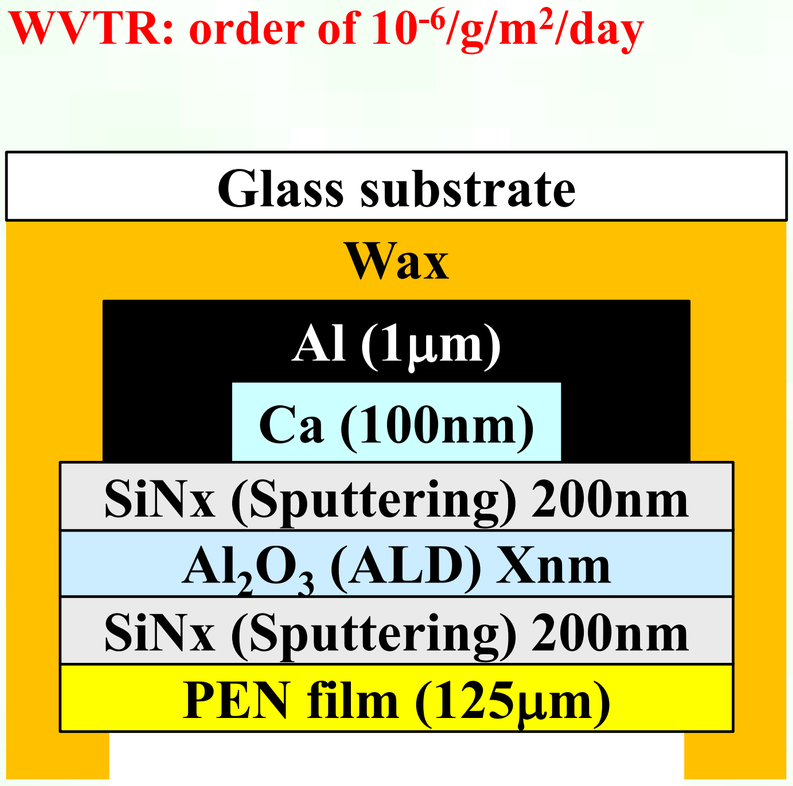
Technological features

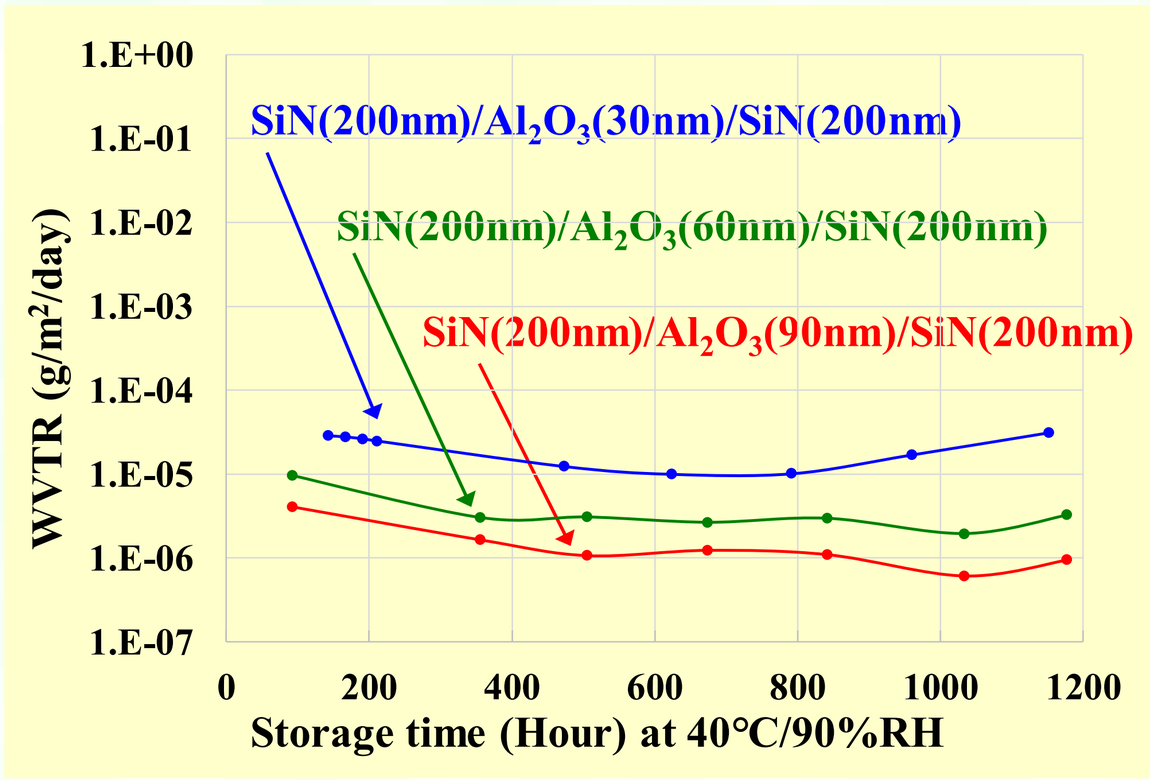
- Excellent surface coverage by ALD
- High gas barrier property by multi-layer structure with SiNx.
  WVTR: order of 10^{-6}/g/m^2/day
  (WVTR: Water Vapor Transmission Rate)
- Equipment：ALD of SUGA CO., Ltd.
  (Maximum substrate size: 10cm × 10cm)

ALD equipment (SUGA CO., Ltd.)

Developed technologies

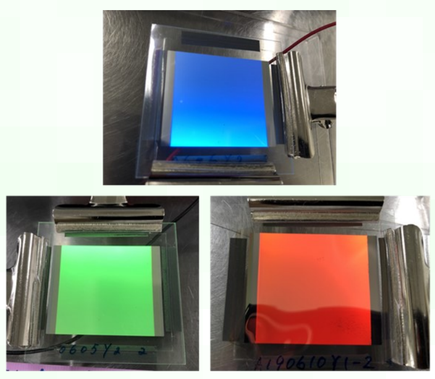
- Multi-layered barrier with Al_2O_3(ALD) and SiNx (Sputtering) layers
  WVTR: order of 10^{-6}/g/m^2/day



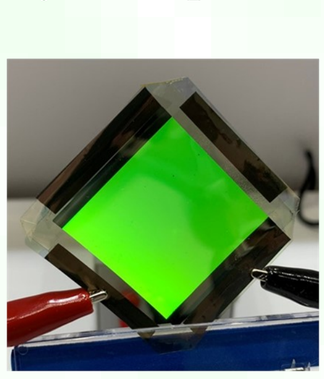


WVTR (Water Vapor Transmission Rate) measurement by Ca corrosion method

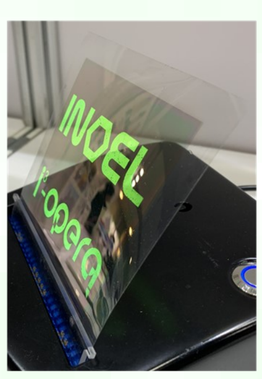
- OLED devices with Al_2O_3 layers deposited by ALD



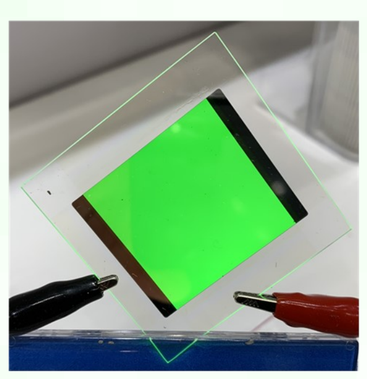
Flexible substrate
Barrier layer
PSA barrier resin (MORESCO)
Al_2O_3 (60nm) by ALD
Cathode
Organic layers (plural layers)
ITO
Barrier layer
Flexible substrate



EXPEEK film (KURABO)
Si_3N_4 (100nm) by sputtering
Al_2O_3 (90nm) by ALD
Si_3N_4 (100nm) by sputtering
Barrier resin
Al (100nm)
Organic layers (plural layer)
IZO (120nm)
Si_3N_4 (100nm) by sputtering
Al_2O_3 (90nm) by ALD
Si_3N_4 (100nm) by sputtering
EXPEEK film (KURABO)



SiN (200nm) by CVD (i^3-opera)
Al_2O_3 by ALD
SiN (200nm) by CVD (i^3-opera)
Cathode
Organic layers (plural layers)
Transparent electrode
SiN (200nm) by CVD (i^3-opera)
Flexible substrate (PEN)



Al_2O_3 (60nm) by ALD
Organic resin (TOYO INK)
Al_2O_3 (45nm) by ALD
Al (Cathode)
Organic layers (plural layers)
Transparent electrode
Glass substrate

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].

INOEL Yamagata University Innovation Center for Organic Electronics

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

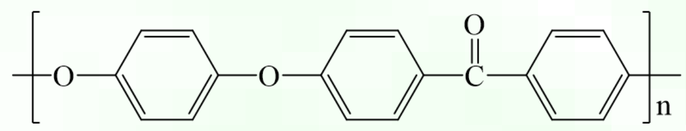
山形大学 Yamagata University

Developed technology

YU-FLEC

High Temperature Tolerant Barrier Films for Flexible OLEDs

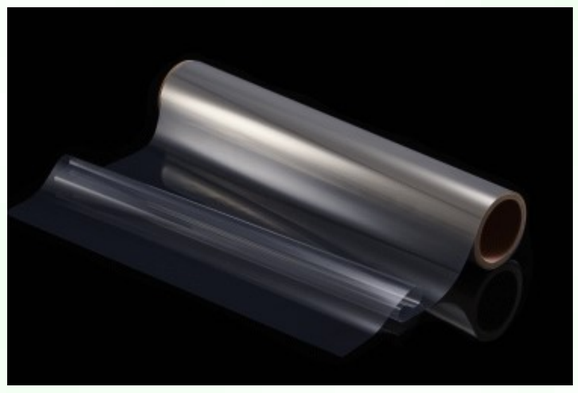
OLED fabrication often requires high temperature processes (higher than 200℃). From this point of view, we develop high temperature tolerant barrier films for flexible OLEDs, using EXPEEK® film developed by KURABO.



Fundamental moiety of PEEK

Technological features

- Advantages of high temperature tolerant film EXPEEK (KURABO INDUSTRIES LTD.)
  - ・Biaxially stretched PEEK (polyetheretherketone) film
  - ・Similar temperature tolerance to polyimide (Tg：320℃)
  - ・Excellent solvent tolerance
  - ・Excellent transparency
  - ・Low thermal shrinkage
- Application of EXPEEK with gas barrier layer to flexible OLED devices



EXPEEK
(KURABO INDUSTRIES)

Developed technologies

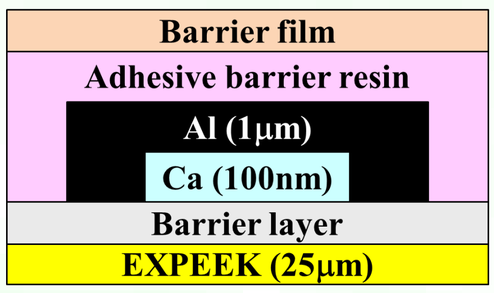
- High gas barrier property:

WVTR with order of 10^{-5}～10^{-6}g/m^2/day

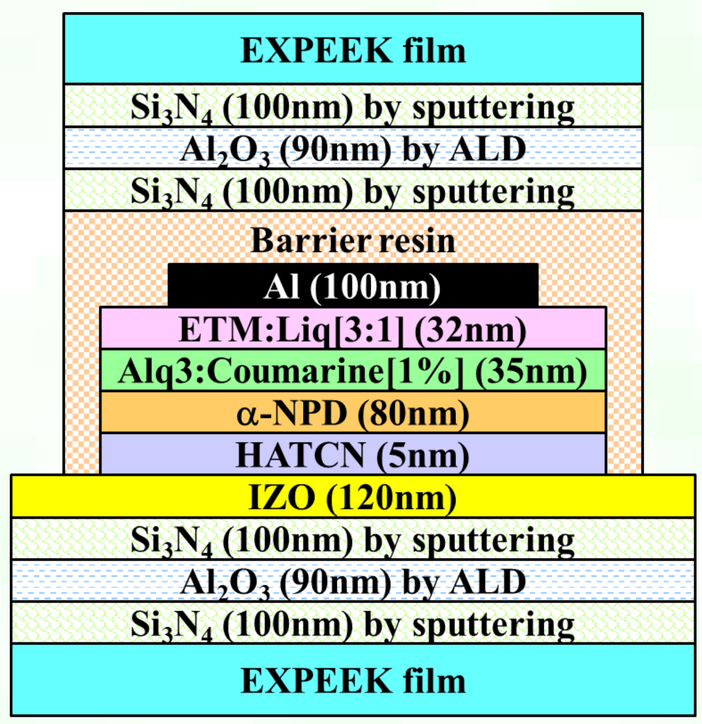
WVTR (Water Vapor Transmission Rate) measurement by Ca corrosion method

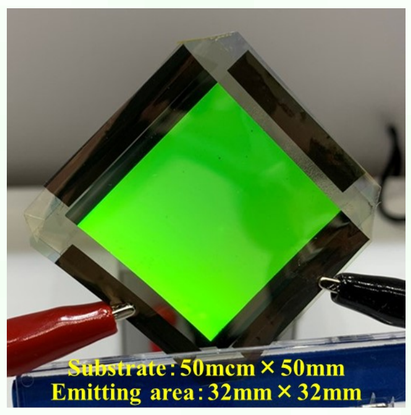
Structure of barrier film	Highest process Temperature	Typical WVTR
EXPEEK/SiNx(100nm)	<100℃	2×10^{-3}
EXPEEK/Al_2O_3(90nm)	100℃	2×10^{-2}
EXPEEK/Al_2O_3(10nm)	300℃	2×10^{-6}
EXPEEK/SiNx(100nm)/Al_2O_3(90nm)/SiNx(100nm)	100℃	2×10^{-5}
EXPEEK/Resin/SiNx(100nm)	100℃	4×10^{-4}
EXPEEK/SiNx(100nm)/Resin/SiNx(100nm)	100℃	3×10^{-6}

WVTR (Water Vapor Transmission Rate): Evaluated by Ca corrosion method under 40℃/90%RH
SiNx: Deposited by sputtering
Al_2O_3: Deposited by ALD (Atomic Layer Deposition)
Resin: NSP811 (Toyo Ink) coated by ink-jet (thickness:10～15μm)



- Flexible OLED devices





"JFlex2020"
(Oct. 2020 / Tokyo)

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

- T. Yuki, T. Nishikawa, M. Sugimoto, H. Nakada, M. Koden, ITE Trans. on MTA Vol. 9, No. 4, pp. 216-221 (2021). "High Temperature Tolerant Barrier Films with Stacking Barrier Layers by Sputtering and ALD"
- T. Yuki, T. Nishikawa, M. Sugimoto, H. Nakada, M. Koden, IDW'20, FLX2-3 (2020). "High Temperature Tolerant Barrier Film with Stacking Barrier Layers by Sputtering and ALD"
- Yamagata University；"JFlex2020" (Jan. 2020 / Tokyo); "JFlex2019" (Jan. 2019 / Tokyo).
- KURABO; "7th Fine Plastic Exhibition" (Dec. 2018 / Tokyo), "SEMICON Japan 2018" (Dec. 2018 / Tokyo).

INOEL Yamagata University
Innovation Center for Organic Electronics
Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)
山形大学 Yamagata University

Developed technology

Printed Flexible Organic Photovoltaic (OPV) Fabricated by Roll-to-roll Processes

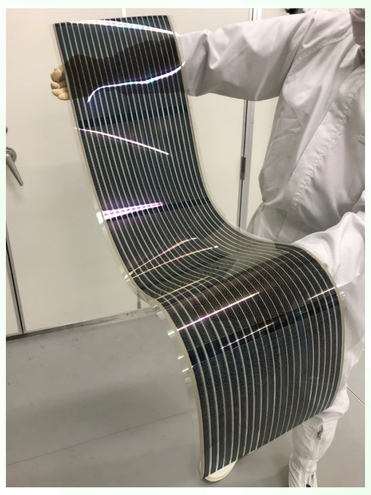
By the collaboration with MORESCO Corporation, we developed a roll-to-roll (R2R) process technology for printing-type flexible Organic Photovoltaics (OPVs).
The develop devices are being evaluated by the verification test of the technology.

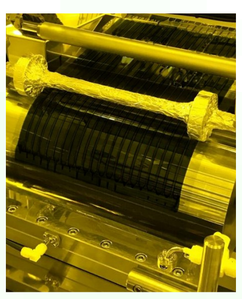
Features of flexible OPV

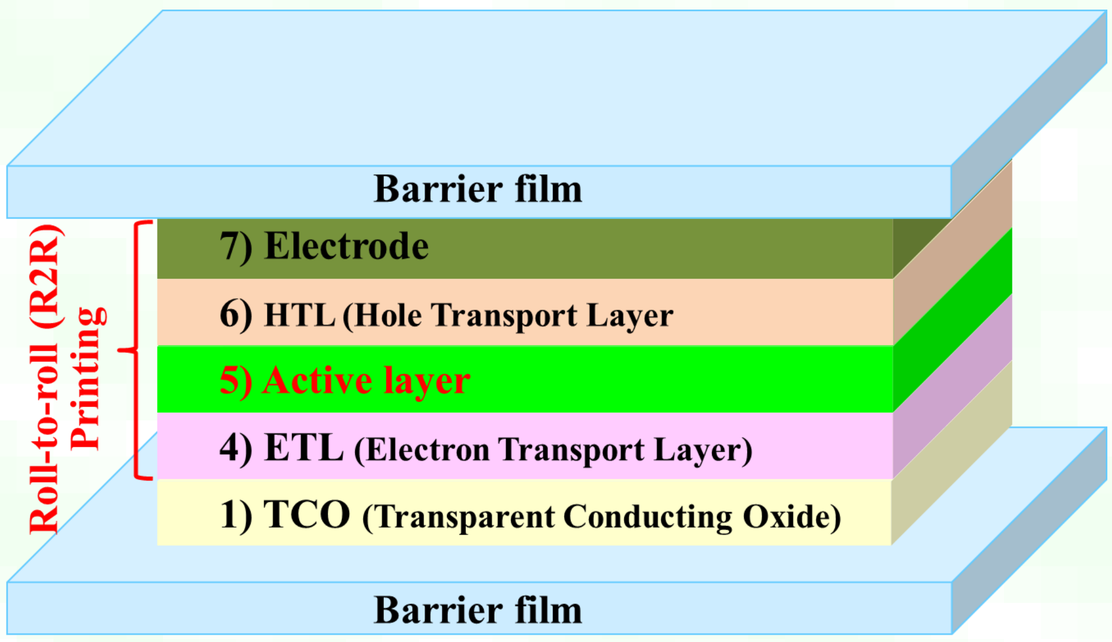
- can be applied to windows etc. due to the transparent feature.
- thin, light weight and un-breakable due to flexible and film
- applied to various places such as windows, walls, etc. by double-sided tape etc.

Technological features

- Fabricated by roll-to-roll (R2R) printing
- Width:30cm、Length>1m
- Fabrication processes
  1) Transparent electrode (TCO) deposition
  2) TCO patterning
  3) Cleaning of substrate
  4) Printing of ETL（R2R）
  5) Printing of active layer（R2R）
  6) Printing of HTL（R2R）
  7) Printing of electrode（R2R）
  8) Current collection
  9) Encapsulation







Structure of flexible OPV

Developed technologies

- Roll-to-roll (R2R) printing technologies of flexible OPV
- Verification test:
  1) Laminate flexible OPVs on windows of 2nd flour
  2) Measure and transmit the data of voltage, current, temperature and sunshine by using the generated power.
  3) Display the measured data on a monitor of 1st flour.

Verification test at INOEL of Yamagata University

OPVs of MORESCO

Shopping street (March 2018)

“OPTree” at KOBE ANIMAL KINGDOM(Oct. 2020)

JR East TokyoYard Building (Sep.2021）

“Tapestry”（designing by printing on OPV）

Collaboration MORESCO Corporation

Related program

- JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2020].
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].

Publication

- Yamagata University；“JFlex2020” (Jan. 2020 / Tokyo).
- Yamagata University; “PVEXPO 2021” (March 2021 / Tokyo & Online).
- Yamagata University； Press Release (6 Nov. 2019).
- MORESCO； Press Release (6 Nov. 2019).

INOEL Yamagata University
Innovation Center for Organic Electronics
Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)
山形大学 Yamagata University

Developed technology

YU-FLEC

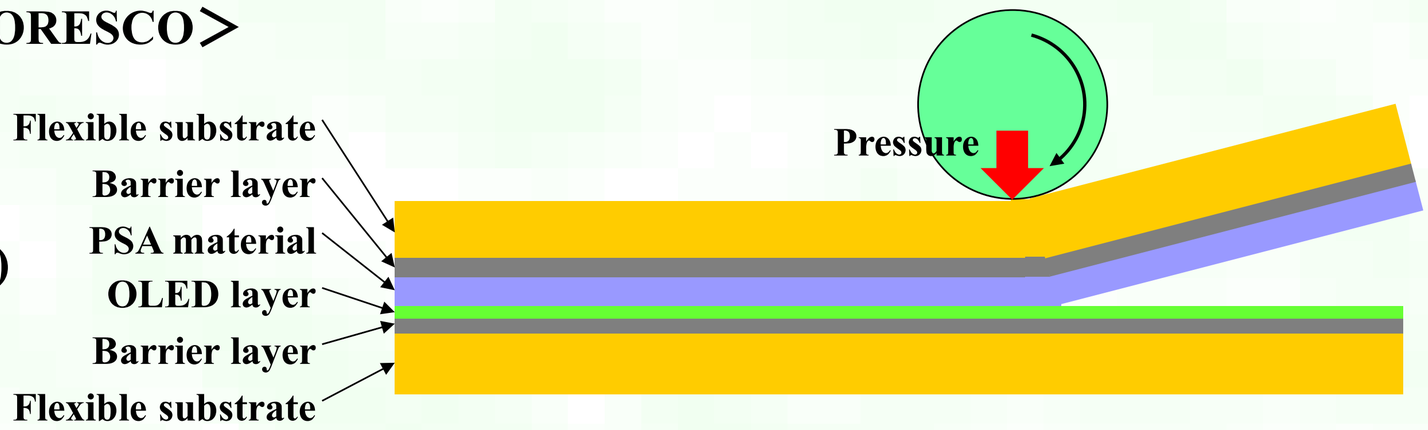
PSA Encapsulating Technologies for OLEDs

We collaborate with MORESCO Corporation, aiming at the development of flexible OLED devices with their PSA (Pressure Sensitive Adhesive) film.

Technological features

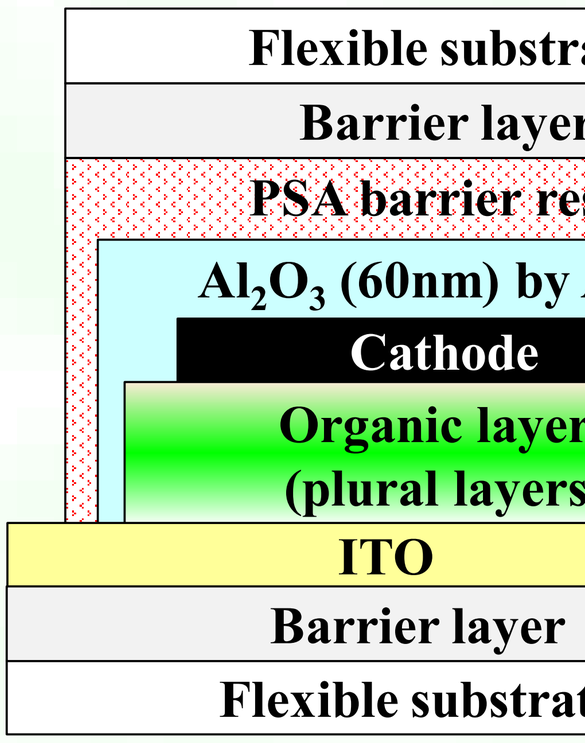
＜Unique features of PSA film of MORESCO＞

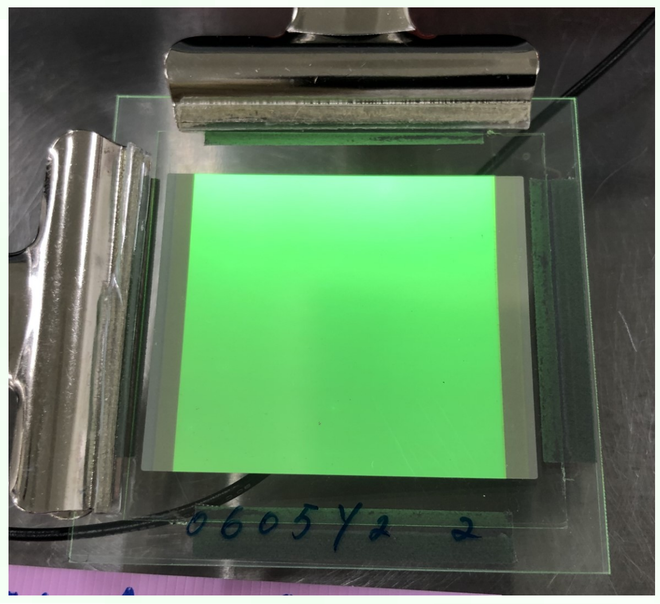
- Hot-melt type
- Simple encapsulation process
- Excellent flexibility
- Excellent adhesion (barrier layer)
- High gas barrier
- Solvent free

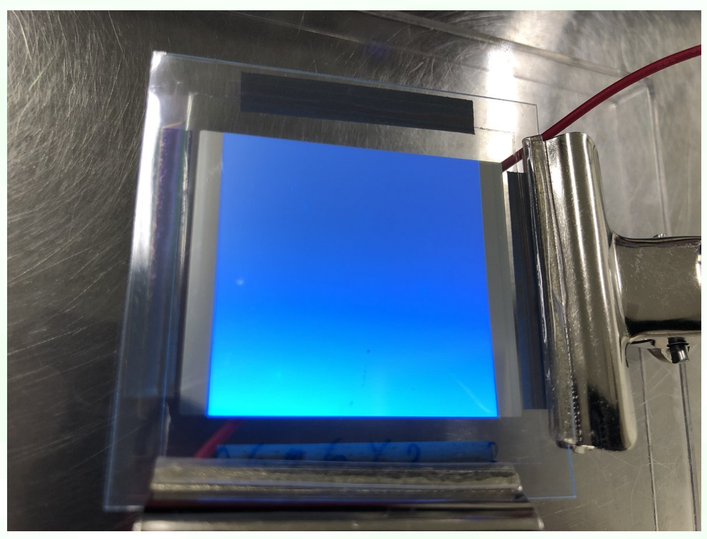


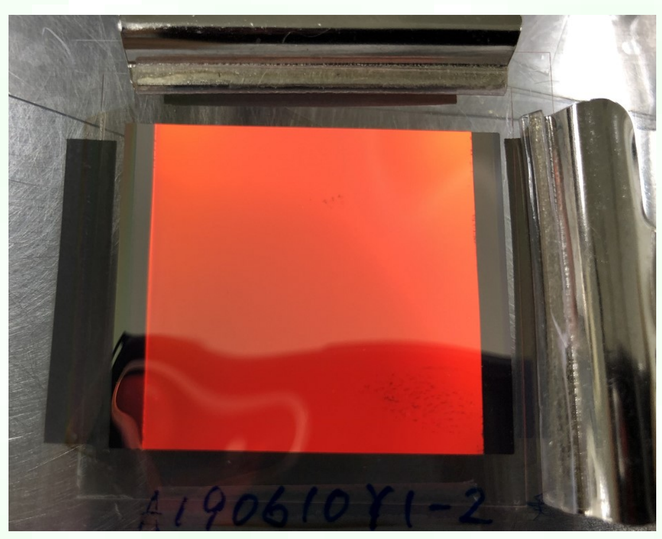
Developed technologies

- Flexible OLED devices with PSA encapsulation









Collaboration

MORESCO Corporation

Related program

- Yamagata University Flexible Electronics Consortium for Academia-Industry Cooperation (YU-FLEC) [Jan. 2018～Mar. 2023].
- JST: OPERA Program Grant Number JPMOP1614 [FY2016～FY2020].
- MEXT: Construction Program of Open Innovation Organization [FY2018～FY2022].

Publication

- Yamagata University；“JFlex2020” (Jan. 2020 / Tokyo).

技術成果

Spray Coating

Spray coating technology for organic electronics devices are developed. OLED devices fabricated by spray coating gave uniform emission and comparable characteristics with those fabricated by spin coating.

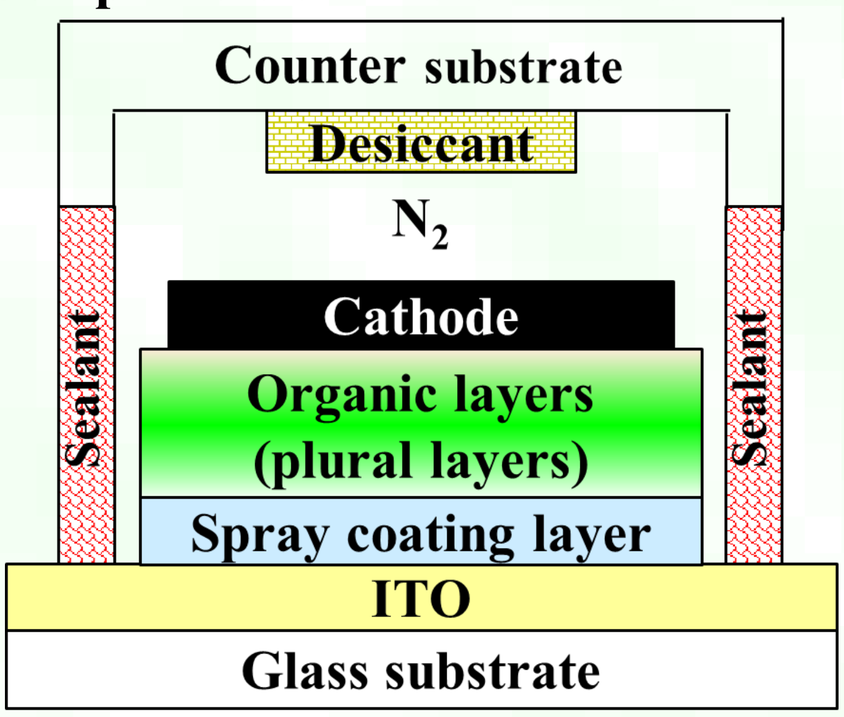
Spray equipment

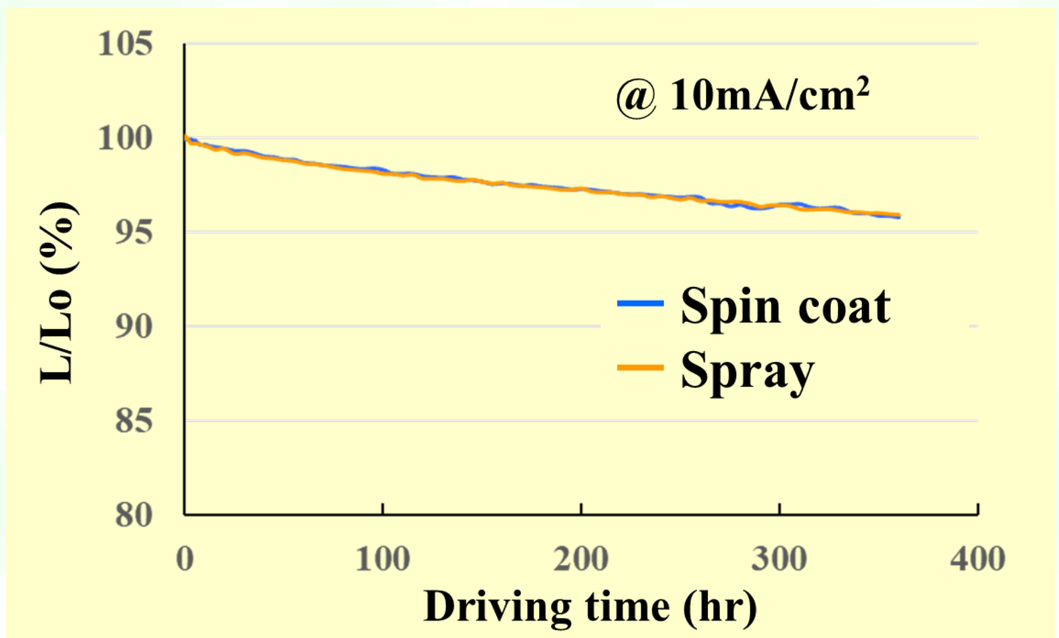
Technological features

■ Uniform coating on large substrates

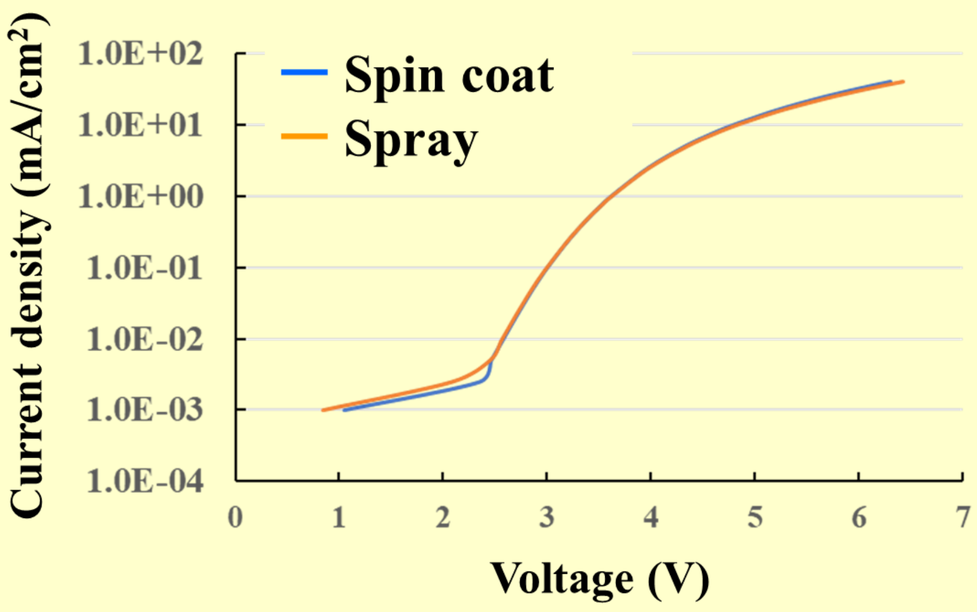
Developed technologies

■ Applied to OLED devices
- Uniform emission
- Comparable characteristics with those fabricated by spin coating

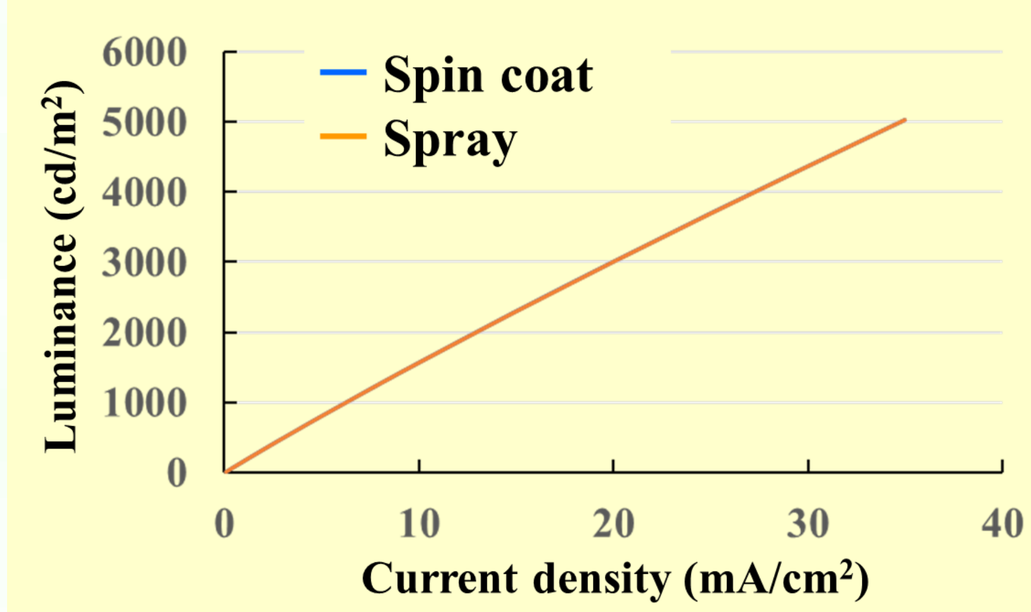




Lifetime



I-V characteristics



L-I characteristics

OLED devices fabricated using spray coating

技術成果

Optical simulation

Optical simulation is very useful in device architecture of OLED devices.
We develope optical simulation technologies for practical OLED devices.

Technological features

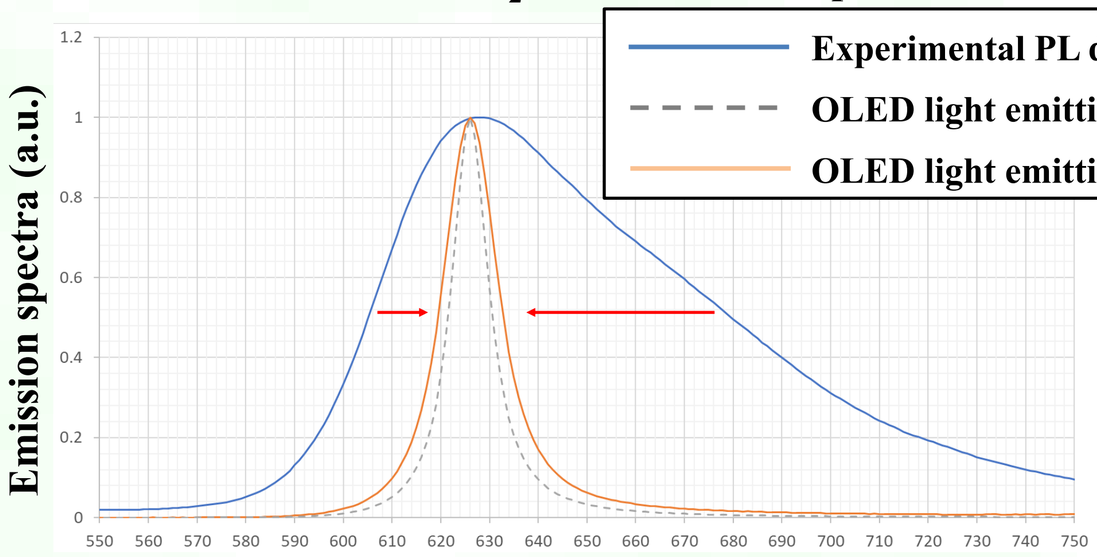
■ **The developed optical simulation technologies of OLED devices can contribute to accuracy and efficiency of R&D in conjunction with our rich experiences on actual OLED devices.**

■ **Software; Fluxim Setfos (Cyber Net Inc.), etc.**

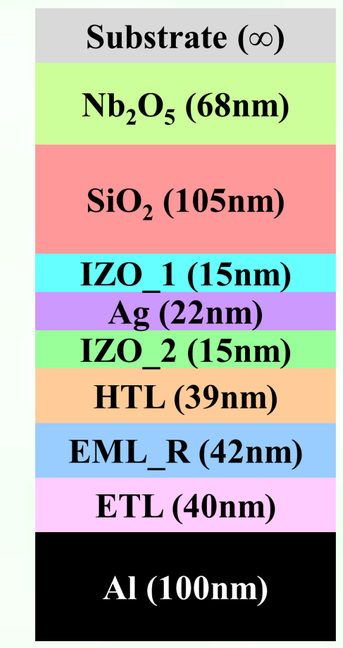
Developed technologies

■ **Optical simulation of OLED device architecture with a mirror plane and a micro-cavity layer with faint-reflecting Ag anode**

- **Optical simulation of optimized light emitting profile of OLED devices with a dielectric mirror with high reflective index and a micro-cavity layer with faint-reflecting Ag anode**
- **Application of a Nb_2O_5 layer as high reflective index layer**
- **The thicknesses of SiO_2 and HTL were optimized for maximizing light emitting energy.**



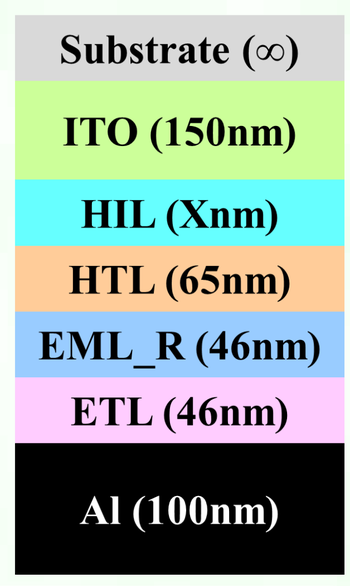
An example of comparison of an actual device and a simulation of one layer of dielectric mirror with high reflective index and a micro-cavity layer with faint-reflecting Ag anode.

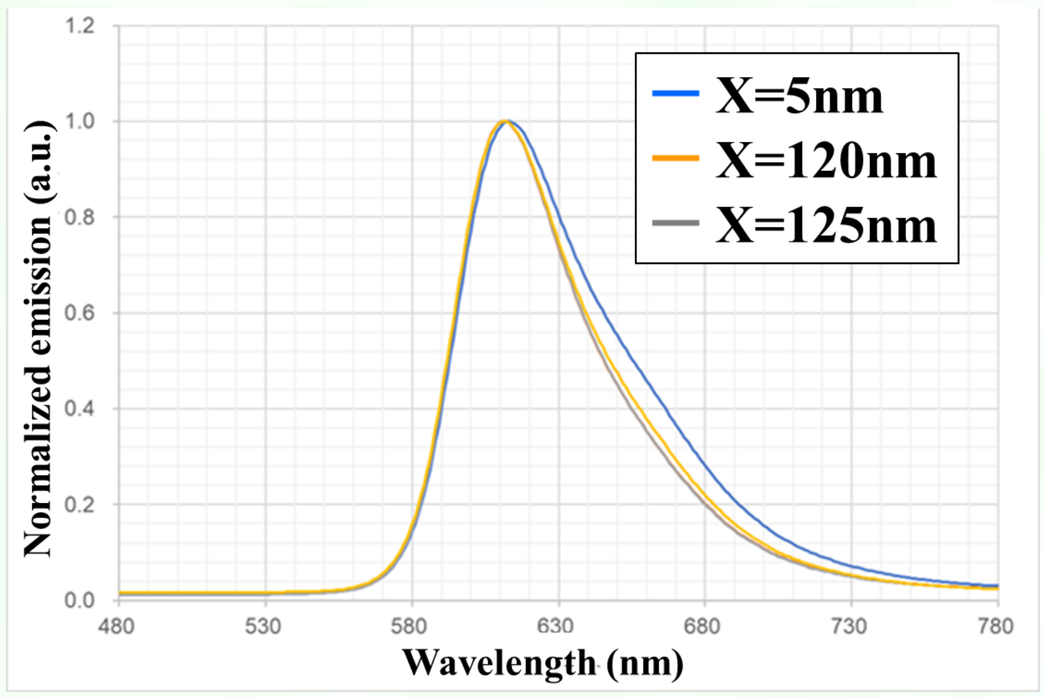


1) **Measure PL (photo luminescent) intensity of a dilute solution with a low concentration of emitting material.**
2) **Estimate optimized device architecture of OLED devices with a dielectric mirror by using the device simulation with obtained PL spectrum.**
3) **Compare the simulated results with the characteristics of actual devices for contributing accuracy and efficiency of research.**

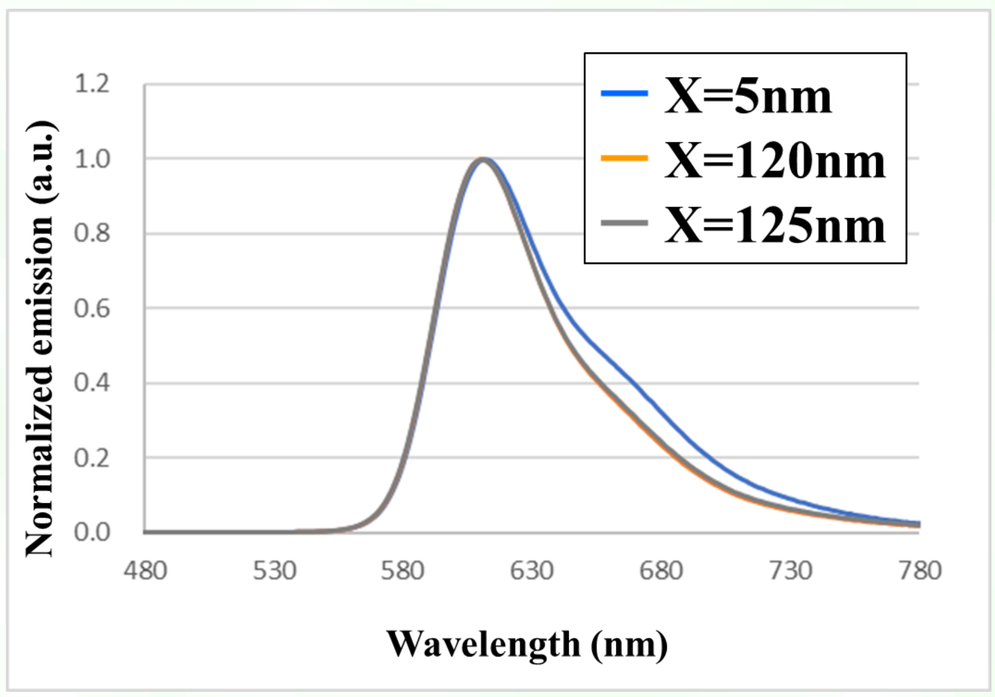
■ **Spectra simulation of OLED devices with different thickness of oeganic layers**

- **Simulation of OLED emission spectra dependence on thickness of hole injection layer (HIL) in OLED devices.**
- **Excellent consistency between simulations and experimental results.**





Device simulation



Experimental result

INOEL Yamagata University
Innovation Center for Organic Electronics
Research Group for Flexible Technologies (Nakada/Furukawa/Yuki/Koden)
山形大学 Yamagata University

Developed technology

Analysis of defects, failures, structures, etc.

We contribute to practical device technologies by using various analysis such as analysis of defects failures, structures, etc..

Technological features

- Optical microscope
- Digital microscope
- AFM (Atomic Force Microscope)
- Film thickness measurement apparatus
- Emission microscope
- Ionization potential measurement apparatus, etc.

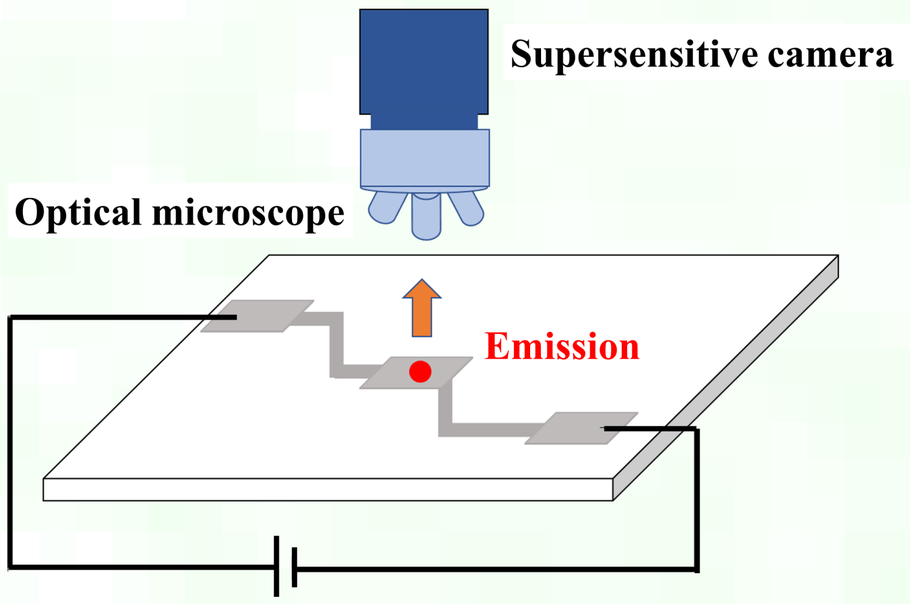
Analysis example 1

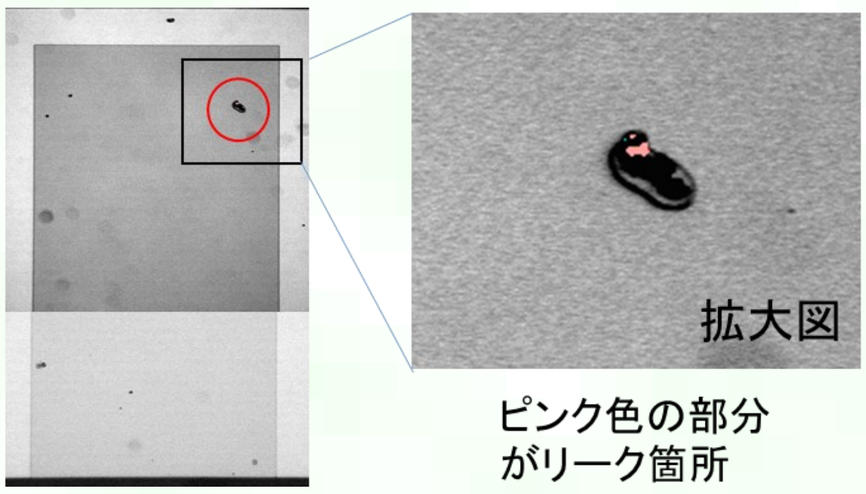
■ Assignment of defect point by emission microscope

- Assignment of defect point
- Investigation of cause of defects by combining with optical microscope, FE-SEM, etc.

【Measurement principle】

- System: optical microscope and high sensitive camera
- Supersensitive camera can detect emission induced by hot carrier generated by applying voltage.
- Emission point can be detected by combining emission image and reflective image.





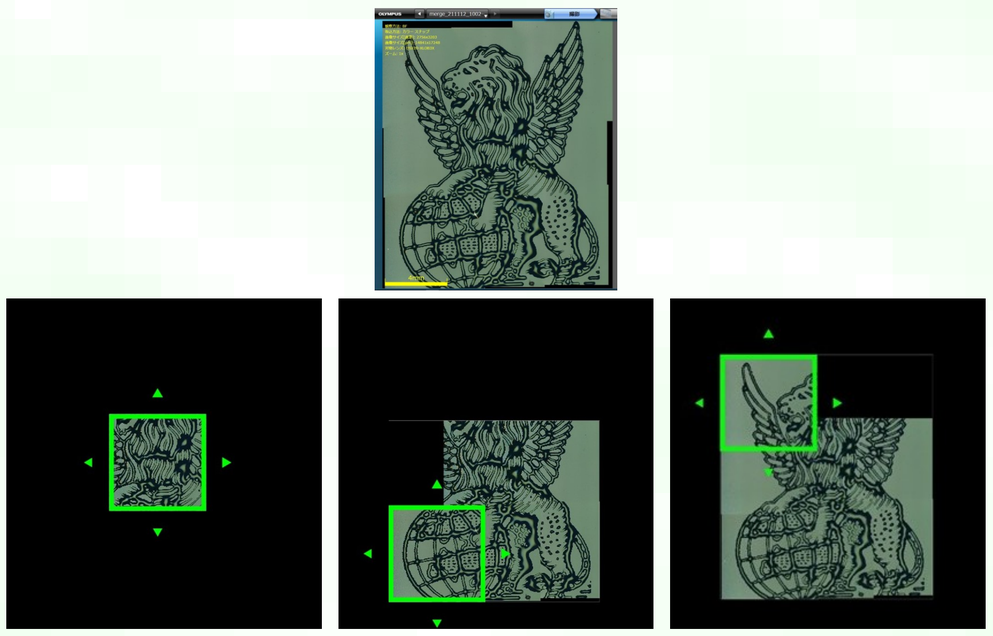
a) Detection of defects by emission microscope

b) Observation of leak point by confocal microscopy

Analysis example 2

■ Observation by digital microscope

- Tiling of plural images
- Observation with magnification of 42～5600
- Various types of observation (BF, focal illumination, DF, BF+DF、polarized illumination, differential interference)

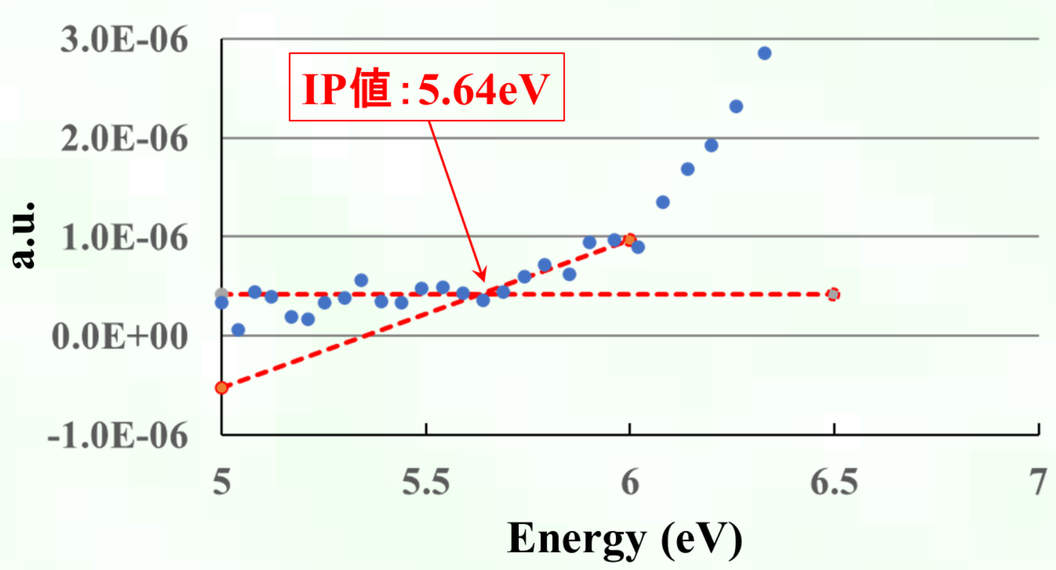


Observation of ink-jet printed pattern

Analysis example 3

■ Ionization potential (IP) measurement

- Measurement method: Photoelectron Yield Spectroscopy (PYS)

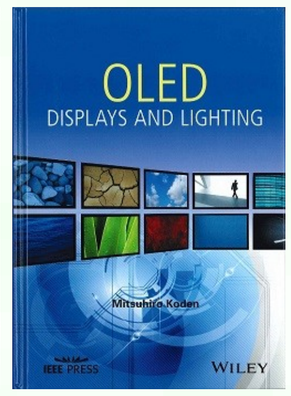


(Example)
Ionization potential measurement of a novel material.

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).
- M. Koden, T. Furukawa, T. Yuki, H. Nakada, Springer Link "Handbook of Organic Light-Emitting Diodes" (2020). "Transparent Electrodes"

Paper

- T. Yuki, T. Nishikawa, M. Sugimoto, H. Nakada, M. Koden, ITE Trans. on MTA Vol. 9, No. 4, pp. 216-221 (2021). "High Temperature Tolerant Barrier Films with Stacking Barrier Layers by Sputtering and ALD"
- 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

- T. Furukawa, J. Hauptmann, T. Nakagaki, R. Ikeuchi, M. Sagawa, D. Nagata, J. Nakatsuka, IDW'21,FLX5/FMC6-1 (2021). "Roll-to-Roll Fabrication for OLED Lighting Using Ultra-Thin Glass Substrate and Encapsulating Stainless Steel Foil"
- M. Natsuka, Y. Ono, H. Mataki, S. Usui, H. Suzuki, M. Abe, T. Furukawa, IDW'21, FLX5/FMC6-2 (2021). "Protection of OLED Lighting with Ultra-Thin Glass by Special Silicone Gel"
- Y. Kawamura, T. Takahashi, T. Furukawa, ICFPE 2Rm401-08-02 (2021). "Improvement of printed electrodes disconnection after 3D thermoforming by optimizing print process on PC film"
- M. Sugimoto, Y. Fukuchi, H. Tsuruta, M .Koden, H. Nakada, T. Yuki, A-COE 2021, PA-17 (2021). "OLEDs with on-demand patterns drown by ink-jet printing"
- M. Koden, M. Sugimoto, N. Kawamura, T. Yuki, H. Nakada, AM-FPD21, 3-1 (2021). [Invited] "Novel Flexible Films with High Gas Barrier Layers by Sputtering and ALD"
- T. Yuki, T. Nishikawa, M. Sugimoto, H. Nakada, M. Koden, IDW'20, FLX2-3 (2020). "High Temperature Tolerant Barrier Film with Stacking Barrier Layers by Sputtering and ALD"
- Y. Kawamura, T. Takahashi, K. Wakabayashi, H. Hirose, Y. Azakami, H. Itoh, T. Furukawa, IDW'20, FLX3-04L (2020). "Effect of Pressure Forming Conditions on PC Sheet integrating Electric Wiring for 3D Electronics Technology"
- T. Nakagaki, T. Kawabata, H. Takimoto, T. Furukawa, IDW'19, FLXp1-9L (2019). "Scribing Tool and Cutting Method for Ultra-thin Glass"
- K. Taira, T. 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. 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"

Exhibitions

- "CEATEC 2021" (Oct. 2021).
- "JFlex" (Jan. 2019, Jan. 2020, Dec. 2020).
- "Printable Electronics" (2014, 2015, 2015, 2016, 2017, 2018).
- "LOPEC" (2018, 2019 / Germany).
- "Flex Japan 2019" (May 2019).
- "LED & OLED EXPO 2017" (Jun. 2017 / Korea).
- "G7 Exhibition" (May 2016).
- "International Photonics Exhibition 2015" (Oct. 2015 / Korea).

Printable Electronics 2017 Award

JFlex Award (2019, 2020)

"International Photonics Exhibition 2015" (October 2015, Korea)

"JFlex 2020" (Jan. 2020, Tokyo)

"LOPEC" (Mar. 2019, Germany)

"Flex Japan 2019" (May 2019, Tokyo)

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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).

(Publication)
- M. Sugimoto, Y. Fukuchi, H. Tsuruta, M. Koden, H. Nakada, T. Yuki, A-COE 2021, PA-17 (2021).

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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 prototype fabricated by ink-jet (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).

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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)

(Papers)
- T. Furukawa et al, IEICE Trans. Electron, E100-C, 949-954 (2017).

(International conference)
- T. Furukawa et al., IDW'21, FLX5/FMC6-1 (2021).
- T. Furukawa, M. Koden, ICDT2019, 55.2 (2019). [China/Invited]
- 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, S. Tokito, SID 2015, 4.4 (2015).

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Polymer materials

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).

(Publication)
- T. Yuki, T. Nishikawa, M. Sugimoto, H. Nakada, M. Koden, ITE Trans. on MTA Vol. 9, No. 4, pp. 216-221 (2021).

Project Scientist
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1999 Graduated at Keio University (Master deg.)
1999～2004 Murata Manufacturing Co., Ltd.
2005～2019 Tohoku Pioneer Corporation
2019～ INOEL, Yamagata University (current position)
(Skills)
Film OLED, Encapsulation, Electrode, Equipment, etc.
(Publication)
- M. Sugimoto, Y. Fukuchi, H. Tsuruta, M. Koden, H. Nakada, T. Yuki, A-COE 2021, PA-17 (2021).

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2001～2007 IMES Co., LTD
2007～2013 ROHM Co., Ltd. / Lumiotec Inc.
2013～ INOEL, Yamagata University (current position)
(Skills)
OLEDs (Device, process, Evaluation)
(Publication)
- M. Koden, M. Sugimoto, N. Kawamura, T. Yuki, H. Nakada, AM-FPD21, 3-1 (2021).

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(Skills)
Printing (Screen printing, etc.), Roll-to-roll (R2R), OLEDs, Encapsulation, Equipment, etc.
(Publication)
- M. Natsuka, Y. Ono, H. Mataki, S. Usui, H. Suzuki, M. Abe, T. Furukawa, IDW'21, FLX5/FMC6-2 (2021).

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