

UL Standard-compliant Biomass Electrical Wire: IRRAX BM

Nayu YANAGAWA*, Shigeyuki TANAKA, Masaaki YAMAUCHI,
Jun ITABASHI, Hitoshi ENDO, and Jo YAGISAWA

To contribute to achieving carbon neutrality by 2050, we promoted the use of biomass-based insulating materials for UL-compliant electrical wires widely used in consumer applications, focusing on both 125°C and 80°C rated wires. For 125°C rated wires, we targeted the reinforcing filler and examined the application of biomass inorganic fillers. To suppress the decrease in tensile strength and elongation under high filler loading, we controlled the crystallinity of the base resin to enhance interactions with the filler, and used scallop shell fillers with controlled particle morphology, which enabled compliance with UL standards. For 80°C rated wires, we incorporated biomass content by utilizing plant-derived oils as plasticizers. As a result, we successfully commercialized UL-compliant biomass electrical wires rated for both 125°C and 80°C.

Keywords: carbon neutrality, biomass, scallop shell filler, plant oil, UL standard

1. Introduction

The global average temperature has risen by approximately 1.1°C in 2011–2020 compared with the pre-industrial era of 1850–1900.⁽¹⁾ Climate-change-induced extreme events such as heavy rainfall and drought have become increasingly severe worldwide, prompting the adoption of the Paris Agreement in 2015 as a global framework for environmental action. The Japanese government officially ratified the agreement in 2016 and declared in 2020 its goal of achieving carbon neutrality, i.e., net-zero greenhouse gas emissions including carbon dioxide.⁽²⁾

Electrical wires are essential components in consumer electronics, communication devices, industrial equipment, and power supply networks that support our society. Properly designed wires can contribute to the environmental efforts described above. Within our long-term vision (the 2030 Vision and Go for Green 2025), we have set a target of carbon neutrality by 2050 (Fig. 1)^{(3),(4)} and have established net-zero factories that promote energy-saving and energy-generating initiatives, which began operation in 2025. Furthermore, we actively engage in recycling used wires by separating recovered wires into

copper, covering materials, and metals; copper is melted in-house and reused for wires and various products, and other materials are effectively recycled as well.⁽⁵⁾

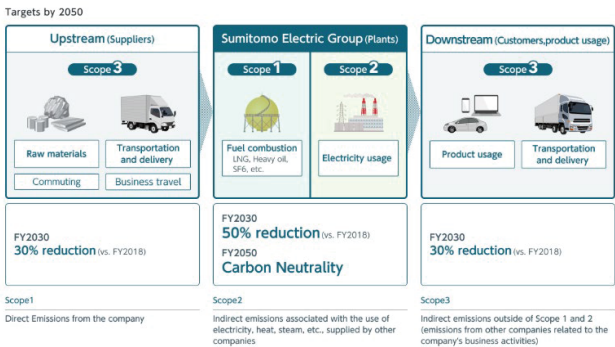
Biomass resources—plants that absorb CO₂ during growth—are attractive candidates for materials that can contribute to carbon-neutrality efforts. Accordingly, we focused on UL*1-rated 125°C and 80°C wires, which are employed in a broad range of products such as home appliances, medical devices, and tooling, and investigated the biomass utilization of their insulation.

2. Development Targets

The target specifications for UL-rated 125°C and 80°C wires are listed in Tables 1 and 2. This development

Table 1. Required characteristics for 125°C rated cables

Standard	Item	Condition	Unit	Target value
UL	Tensile properties	Tensile strength Elongation at break	MPa %	≥ 13.8 ≥ 300
	Heat resistance	After 168 hours at 158°C Tensile strength retention Elongation at break retention	% %	≥ 80 ≥ 80
	Heat deformation	121°C, 250 g Preheat 1 hour + compression 1 hour	%	≥ 50
	Flexibility test	Wound after 168 hours at 158°C		No cracks
	Thermal shock test	158°C for 1 hour after winding		No cracks
	Low-temperature winding test	Wound after 4 hour at -10°C		No cracks
	Voltage-withstand test method I	Post-winding withstand voltage test, initial and after 168-hour aging at 158°C, breakdown voltage test	%	No breakdown ≥ 50
	Voltage-withstand test method II	Post-winding withstand voltage test, initial, after 168-hour aging at 158°C, and 1-hour aging at 125°C		No breakdown
	Voltage-withstand test method III	Withstand voltage test after 24 hours of immersion		No breakdown
	Cable flame test	VW-1 flame test*4		≤ Afterglow 60 s ≤ Flag burn 25% No ignition of the cotton
Other	Biomass content	Biomass material usage ratio	wt%	≥ 10



Based on information from the Ministry of the Environment, Japan's "Green Value Chain Platform"

Fig. 1. Our carbon neutrality initiatives

Table 2. Required characteristics for 80°C rated cables

Standard	Item	Condition	Unit	Target value
UL	Tensile properties	Tensile strength Elongation at break	MPa %	≥ 20.7 ≥ 100
	Heat resistance	After 168 hours at 113°C Tensile strength retention Elongation at break retention	% %	≥ 70 ≥ 70
	Heat deformation	121°C, 250 g Preheat 1 hour + compression 1 hour	%	≥ 50
	Flexibility test	Wound after 168 hours at 113°C		No cracks
	Thermal shock test	113°C for 1 hour after winding		No cracks
	Low-temperature winding test	Wound after 4 hour at -10°C		No cracks
	Voltage-withstand test method I	Post-winding withstand voltage test, initial and after 168-hour aging at 113°C, breakdown voltage test	%	No breakdown ≥ 50
	Voltage-withstand test method II	Post-winding withstand voltage test, initial, after 168-hour aging at 113°C, and 1 hour aging at 80°C		No breakdown
	Voltage-withstand test method III	Withstand voltage test after 24 hours of immersion		No breakdown
	Cable flame test	VW-1 flame test*4		≤ Afterglow 60 s ≤ Flag burn 25% No ignition of the cotton
Other	Biomass content	Biomass material usage ratio	wt%	≥ 10

aimed to meet the required mechanical properties, long-term reliability, insulation performance, and flame-retardancy while simultaneously achieving biomass utilization of the insulation. The biomass content*2 target was set to ≥ 10 wt% of biomass-derived raw material, which qualifies for the Biomass Mark*3 certified by the Japan Organics Recycling Association.

3. Policy for Biomass Insulation

Different base resins are employed according to the rated temperature: poly(ethylen) (PE) for the 125°C wire and poly(vinyl chloride) (PVC) for the 80°C wire. To satisfy the UL requirements, additives such as flame retardants and plasticizers are compounded with the base resin (Fig. 2). For the 125°C insulation, high-temperature resistance is further imparted by electron beam*5 irradiation to cross-link the PE matrix (Fig. 3).

Increasing the biomass content of the 125°C insulation is most effective by biomaterializing the resin that constitutes the largest weight fraction. Commercial

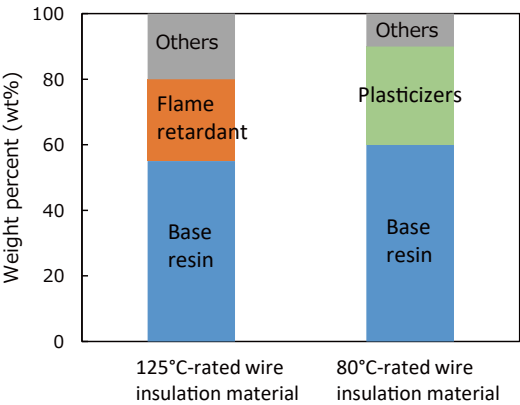


Fig. 2. Insulation material formulation

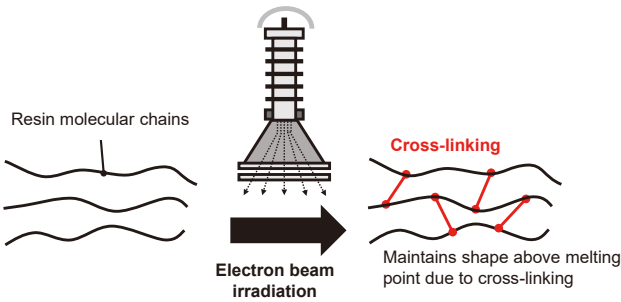


Fig. 3. Cross-linking of resin by electron beam irradiation

biomass-derived PE is produced either by a segregated method (physical separation with dedicated production lines) or by a mass balance method (mixing biomass and petroleum feedstocks in common equipment with biomass content assigned accordingly).⁽⁶⁾ Both have the same chemical structure and material properties as petroleum-derived PE, but are currently more expensive. Considering the importance of price for widespread biomass use, both methods were excluded for now; future demand growth may warrant reconsideration.

The flame retardants, which constitute another major component with large weight ratio, are essential for flame resistance and difficult to change. Consequently, we sought to reduce petroleum-derived content by introducing additional biomass-derived components. Inorganic fillers, which are chemically stable and commonly used as reinforcement agents in insulation, were examined for biomass origin. Three candidates—shell filler, eggshell filler, and rice husk filler—were selected (Table 3).

Table 3. Biomass fillers

	Shell filler	Eggshell filler	Rice husk filler
Main component	CaCO ₃	CaCO ₃	SiO ₂
Manufacturing method	Washing grinding	Washing grinding	Calcination, purification
Average particle size	≤ 10 μm	≤ 30 μm	≤ 10 μm
Cost	Good	Good	Expensive

Shell and eggshell fillers are produced by cleaning and grinding shells and eggshells that are discarded annually in quantities of several hundred thousand tons. These fillers are utilized in soil conditioners, animal feed, building materials, and other applications.^{(7),(8)} Rice husk fillers are obtained by refining calcined rice husk ash and are also used in soil conditioners and feed. Shell and eggshell fillers mainly consist of calcium carbonate (CaCO₃), while rice husk fillers mainly contain silicon dioxide (SiO₂); all are chemically stable and potentially applicable as wire insulation fillers. To avoid adverse effects on mechanical properties such as impact resistance, filler particles larger than 30 μm were excluded.⁽⁹⁾ Rice husk filler was omitted due to its high cost.

For the 80°C wire, the base resin is PVC. Pure PVC is rigid and brittle; therefore, plasticizers are added to impart

the flexibility required for wiring. PVC has many advantages as an insulating material, such as being able to be made flexible by the addition of plasticizers, having strong chemical resistance, and being inexpensive. Since approximately 60 wt % of PVC's raw material is chlorine derived from seawater, the dependence on petroleum-based feedstock is relatively low.⁽¹⁰⁾ Consequently, we focused on biomaterializing the plasticizer, which has a higher petroleum-based content.

4. 125°C-Rated Wire Insulation

4-1 Base resin selection

Wires are often bent in limited spaces within home appliances and devices; therefore, flexibility of insulation materials is important for handling. Excessive filler loading deteriorates tensile and flexibility properties. To add 10 wt% or more biomass fillers while maintaining these properties, a base resin with high filler acceptance was needed.

PE resin is a semi-crystalline polymer composed of regularly arranged crystalline regions and randomly arranged amorphous regions (Fig. 4).

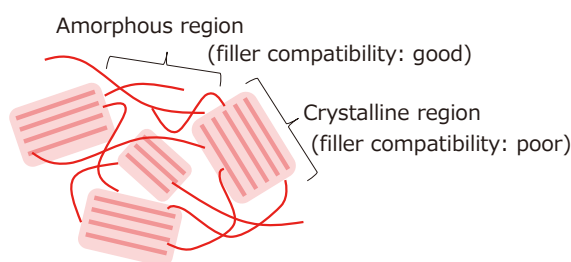


Fig. 4. Schematic diagram of crystalline and amorphous regions in PE

Fillers cannot enter densely packed crystalline regions and are contained in the amorphous regions. Highly crystalline PE offers limited free volume for filler, leading to filler agglomeration and weak polymer-filler interfacial interactions, which diminish mechanical performance. To increase filler loading, the ratio of crystalline to amorphous regions needs to be controlled to increase the amorphous regions (Fig. 5). One way to reduce the crystalline regions and increase the amorphous regions is to use copolymers^{*6} containing comonomers

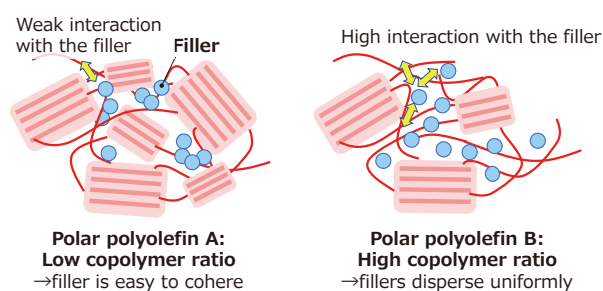


Fig. 5. Schematic diagram of filler acceptance in crystalline resin

mers^{*7} that inhibit crystallization in the polymer chains. Moreover, since the biomass fillers used here mainly consist of calcium carbonate or silicon dioxide and are hydrophilic, selecting polar polyolefins with a high content of polar comonomers was considered effective to enhance interaction with fillers and increase filler acceptance.

We prepared two polar polyolefins, A and B, differing in the incorporation level of the polar comonomer. Both resins were compounded with 10 wt% biomass filler, flame retardants, and other additives, and the resulting compounds were compression-molded into sheets for tensile testing. The sheet based on the higher-comonomer-content, more flexible polar polyolefin B exhibited superior tensile strength and elongation, with a particularly marked improvement in elongation at break (Fig. 6).

Based on these results, polar polyolefin B was selected as the base resin. Subsequent work focused on optimizing the biomass filler to further enhance tensile performance.

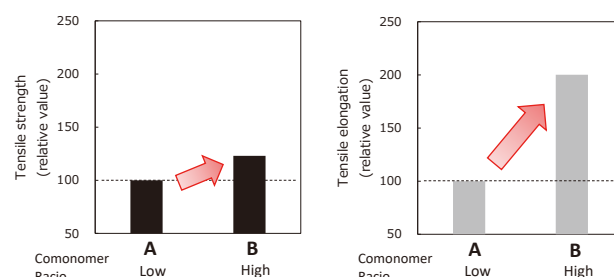


Fig. 6. Tensile test results for base resin selection

4-2 Utilization of biomass fillers

Shell and eggshell fillers were added at 10 wt% to the polar polyolefin with the higher comonomer ratio studied in Section 4-1. Compounds were prepared with flame retardants and formed into pressed sheets, which were then subjected to tensile testing. As a reference, heavy calcium carbonate (HCC)—produced from ground limestone and possessing a particle size comparable to that of the shell filler—was also evaluated. Compared with HCC, the shell-filled sheet showed comparable elongation but higher tensile strength, whereas the eggshell filled sheet displayed reductions in both strength and elongation (Fig. 7).

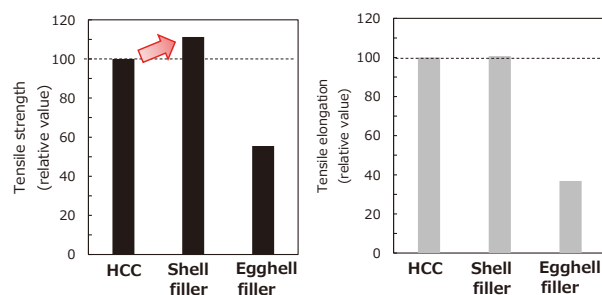


Fig. 7. Tensile test results for filler selection

Scanning electron microscopy (SEM) observation revealed that the shell filler contained rod-shaped particles with aspect ratios*8 of 2–12, the eggshell filler had porous irregular particles, and the HCC showed non-porous cubic particles (Fig. 8). Generally, rod-shaped particles improve tensile strength more effectively than cubic particles.⁽⁹⁾ Shell filler’s calcium carbonate, the main component, has an aragonite crystal structure and forms rod-shaped particles upon grinding,⁽⁹⁾ which explains the improved strength. In contrast, HCC has a calcite structure and forms cubic-shaped particles upon grinding. Synthesizing aragonite CaCO₃ requires precise control of processing conditions and is cost-intensive⁽¹¹⁾ by utilizing shell-derived CaCO₃ we obtained aragonite-like performance at low cost. Eggshell filler, also calcite CaCO₃, possessed larger particle size and internal porosity, leading to brittleness and the observed decline in mechanical properties.

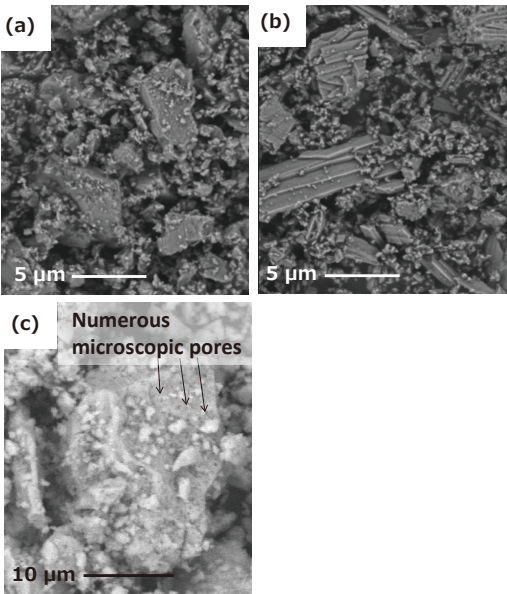
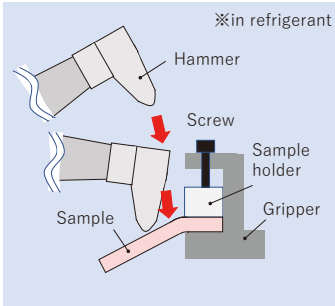


Fig. 8. Particle observation results using a scanning electron microscope
(a) HCC, (b) Shell filler, (c) Eggshell filler

Higher aspect ratio particles improve tensile strength but may reduce impact resistance.⁽⁹⁾ To assess low-temperature impact performance, we conducted the JIS K7216 low-temperature impact embrittlement test, which fixes specimens in a cryogenic medium, subjects them to hammer impact, and calculates the embrittlement temperature from the number of fractures at each temperature (Fig. 9). Samples with 10 wt% each of shell filler and HCC having comparable particle sizes were tested for low-temperature impact embrittlement. These results showed that the embrittlement temperature with HCC was −32.5°C, while shell filler showed slightly higher at −31.5°C, but both met UL requirements, demonstrating sufficient low-temperature impact resistance at −10°C low-temperature winding (Table 4).



$$T_b = T_h + \Delta T \left(\frac{S}{100} - \frac{1}{2} \right) \dots\dots\dots (1)$$

T_b : Embrittlement temperature (°C)
T_h : Highest temperature at which all specimens fracture (°C)
ΔT : Test temperature interval (°C)
S : The sum of the failure percentages at each test temperature from the lowest temperature with no failures up to T_h

Fig. 9. Schematic diagram of low-temperature impact embrittlement test

Table 4. Embrittlement test results

	HCC	Shell filler
Embrittlement temperature (°C)	−32.5	−31.5

Based on these results, representative values evaluated in-house for AWG22 wire (insulation thickness of 0.30 mm) are shown in Table 5. The developed insulation materials satisfy all UL 125°C requirements with ≥ 10 wt% biomass content.

Table 5. Cable evaluation results (UL 125°C)

Standard	Item	Condition	Unit	Target value	Result
UL	Tensile properties	Tensile strength	MPa	≥ 13.8	19.9
		Elongation at break	%	≥ 300	481
	Heat resistance	After 168 hours at 158°C	%	≥ 80	101
		Tensile strength retention	%	≥ 80	86
		Elongation at break retention	%	≥ 80	86
	Heat deformation	121°C, 250 g Preheat 1 hour + compression 1 hour	%	≥ 50	87
	Flexibility test	Wound after 168 hours at 158°C		No cracks	No cracks
	Thermal shock test	158°C for 1 hour after winding		No cracks	No cracks
	Low-temperature winding test	Wound after 4 hour at -10°C		No cracks	No cracks
	Voltage-withstand test method I	Post-winding withstand voltage test, initial and after 168-hour aging at 158°C, breakdown voltage test	%	No breakdown ≥ 50	No breakdown ≥ 137
Other	Voltage-withstand test method II	Post-winding withstand voltage test, initial, after 168-hour aging at 158°C, and 1 hour aging at 125°C		No breakdown	No breakdown
	Voltage-withstand test method III	Withstand voltage test after 24 hours of immersion		No breakdown	No breakdown
	Cable flame test	VW-1 flame test**		≤ Afterglow 60 s ≤ Flag burn 25% No ignition of the cotton	pass
	Biomass content	Biomass material usage ratio	wt%	≥ 10	10

5. 80°C-Rated Wire Insulation

PVC is utilized not only for wire insulation and sheathing but also extensively in building materials, packaging, medical devices, and various consumer goods. A wide variety of petroleum-based plasticizers are available, each offering distinct properties such as low volatility or

high transparency in addition to flexibility. Although a few bio-based plasticizers have recently entered the market, concerns about supply continuity and stability led us to explore the repurposing of existing plant-oil-derived compounds that have historically been used as stabilizers.

The substitution of plasticizers often affects mechanical properties and flame retardancy. When the plant-oil-derived plasticizer was added at a level that restored the flexibility of the reference product, the flame-retardancy decreased, causing the UL vertical flame test (VW-1) to fail. This behavior can be explained by the chemical structures: petroleum-based plasticizers typically contain aromatic rings, which confer thermal stability and low oxygen content, making them less prone to combustion. In contrast, plant-oil-derived plasticizers are derived from fatty acids, which decompose more readily under heat and promote burning. To recover flame retardancy, a new flame retardant system was introduced, and the resulting insulation met all UL specifications.

Representative in-house evaluation results for AWG26 wire (insulation thickness of 0.25 mm) are shown in Table 6. In addition to the combustion test, all requirements related to 80°C were also met.

Table 6. Cable evaluation results (UL 80°C)

Standard	Item	Condition	Unit	Target value	Result
UL	Tensile properties	Tensile strength Elongation at break	MPa %	≥ 20.7 ≥ 100	27.0 204
	Heat resistance	After 168 hours at 113°C Tensile strength retention Elongation at break retention	% %	≥ 70 ≥ 70	107 104
	Heat deformation	121°C, 250 g Preheat 1 hour + compression 1 hour	%	≥ 50	79
	Flexibility test	Wound after 168 hours at 113°C		No cracks	No cracks
	Thermal shock test	113°C for 1 hour after winding		No cracks	No cracks
	Low-temperature winding test	Wound after 4 hour at -10°C		No cracks	No cracks
	Voltage-withstand test method I	Post-winding withstand voltage test, initial and after 168-hour aging at 113°C, breakdown voltage test	%	No breakdown ≥ 50	No breakdown ≥ 120
	Voltage-withstand test method II	Post-winding withstand voltage test, initial, after 168-hour aging at 113°C, and 1 hour aging at 80°C		No breakdown	No breakdown
Other	Voltage-withstand test method III	Withstand voltage test after 24 hours of immersion		No breakdown	No breakdown
	Cable flame test	VW-1 flame test		≤ Afterglow 60 s ≤ Flag burn 25% No ignition of the cotton	Pass
Other	Biomass content	Biomass material usage ratio	wt%	≥ 10	20

6. Conclusion

In this study, we have developed UL-compliant 125°C and 80°C-rated wires, which are widely utilized in consumer applications, by incorporating shell fillers and plant-oil-derived plasticizers. This achievement realizes both UL standard conformity and biomass content of 10 wt% or more. The 125°C-rated wire product named IRRAX BM has acquired the Biomass Mark certification from the Japan Organics Recycling Association. To further reduce environmental impact, we are now considering products compliant with standards other than UL, as well as wires rated at temperatures other than 80°C and 125°C.

• IRRAX and Go for Green are trademarks or registered trademarks of Sumitomo Electric Industries, Ltd.

Technical Terms

- *1 UL standard: A standard established by the U.S. certification organization Underwriters Laboratories Inc. It is one of the most influential safety standards worldwide.
- *2 Biomass content: The percentage by weight of biomass used relative to the product's dry weight.
- *3 Biomass Mark: A trademark or registered trademark of the Japan Organics Recycling Association. It can be displayed on products that contain 10 wt% or more of renewable biomass (biologically derived resources) by weight relative to the product's dry weight. Biomass includes not only organic materials but also inorganic substances formed by living organisms, such as shells.
- *4 VW-1 Combustion Test: A UL standard vertical burning test used to evaluate the flame retardancy of wires and similar products.
- *5 Electron beam: A type of ionizing radiation that can be generated and controlled by electron beam irradiation equipment and is used in industrial applications.
- *6 Copolymer: A polymer compound made by chemically bonding two or more different types of monomers.
- *7 Comonomer: A monomer that copolymerizes with a base monomer (such as ethylene in the case of PE) to become part of the polymer's molecular structure.
- *8 Aspect ratio: The ratio of particle length to width.

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Contributors The lead author is indicated by an asterisk (*).

N. YANAGAWA*

• Energy and Electronics Materials Laboratory



S. TANAKA

• Assistant Department Manager, Energy and Electronics Materials Laboratory



M. YAMAUCHI

• Department Manager, Energy and Electronics Materials Laboratory



J. ITABASHI

• Assistant Manager, Sumitomo (SEI) Electronic Wire, Inc.



H. ENDO

• Group Manager, Sumitomo (SEI) Electronic Wire, Inc.



J. YAGISAWA

• Department Manager, Sumitomo (SEI) Electronic Wire, Inc.

