Applications of PTFE nanofibers for flexible devices

1. Introduction

Valqua has considered various application utilizing PTFE nanofibers.

In this project, we worked with CONNECTEC JAPAN and started from the stage of brainstorming for ideas on utilizing PTFE nanofibers. CONNECTEC JAPAN has their proprietary low-temperature application technology and is experienced in producing flexible devices.

Among several of the candidates, we focused on the air permeability and flexibility of PTFE nanofibers and also the insulating and water-repellent properties of PTFE material to consider the possibilities of PTFE as a flexible device.

As flexible devices, we assumed uses in healthcare and wearables. Here we introduce a concept model for flexible devices that was produced by conducting technological development that included direct wiring formation on PTFE nanofibers.

2. Characteristics of PTFE nanofibers

First, we will have a general overview of PTFE nanofibers[1]. As a material, PTFE nanofibers have a nonwoven fabric structure and are an aggregate of PTFE fibers with a diameter of approximately 600 to 700 nanometers (Figure1). The fibers consist of 100% PTFE and are produced from PTFE dispersion using a special electrospinning method.

PTFE nanofibers have the following features through its characteristics as PTFE material and having nanofiber structure.

- Chemical -resistant, climate-resistant, heat-resistant (260℃), fire-resistant
- Safe for humans (non-invasive, clean)
- Water-repellent
- High electric resistance, low dielectric constant
- Flexible material
- Good air permeability
- Resistant to thermal deformation

Table1 shows the general properties of PTFE nanofiber nonwoven fabric. It is a material with porosity of 80 to 90 % and repels water but has permeability. Expanded PTFE is a material with similar structure and characteristics, but it shrinks significantly when exposed

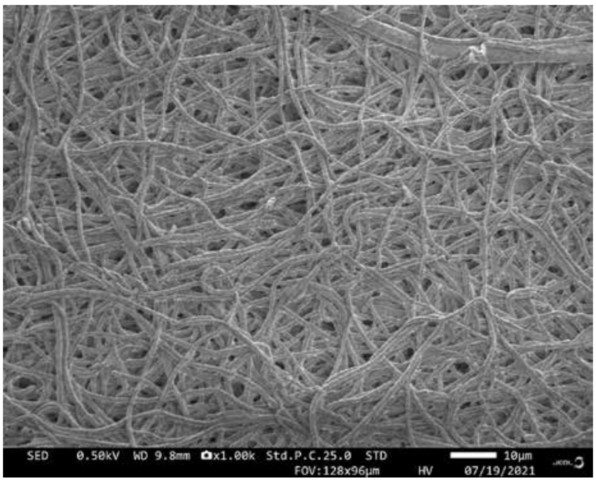

Figure1 Structure of PTFE nanofibers

Table1 PTFE nanofiber properties (representative values)

Properties	Value
Basis weight [g/cm^2]	16.7
Thickness [um]	56
Volume resistance [Ω・cm]	10^{13}
Dielectric constant (@6 GHz)	1.14
Water contact angle [°]	140
Air permeability [L/min/cm^2/psi]	4.3

to 260℃, whereas PTFE nanofiber nonwoven fabric barely shows any thermal shrinking (Figure2).

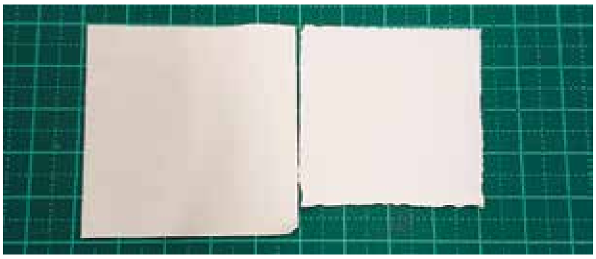

Figure2 Difference in thermal shrinking of PTFE nanofiber nonwoven fabric (left) and ePTFE (Right)

3. Formation of wiring on PTFE nanofibers

3-1) Wiring formation

To use as a flexible device, we considered using PTFE nanofibers itself as a circuit board.

Wiring formation on PTFE nanofiber was conducted by the printing method. In general, as wiring formation methods for electric circuits, there are several methods: photolithography method, inkjet printing method, screen printing method and gravure offset printing method. This project used the screen-printing method and jet dispenser method.

Control parameters include conductive ink type (conductive particle type and diameter, solvent, viscosity), printing speed, and discharge pressure in the case of jet dispenser. Optimization of these parameters made it possible to conduct wiring formation on PTFE nanofibers.

Figure3 and 4 show examples of printing of circuits using screen printing and jet dispenser. Both methods were able to form wiring without any bleeding of conductive ink when printed under optimal conditions.

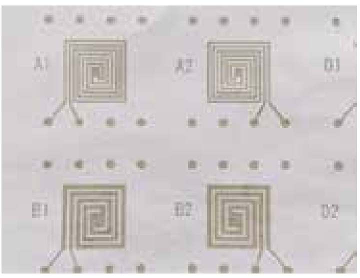

Figure3 Example of wiring by screen printing

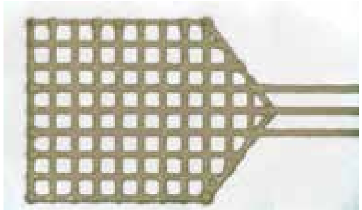

Figure4 Example of wiring by jet dispenser

3-2) Microstructure

Figure5 and 6 show a cross-section photograph of circuit boards formed by the jet dispenser method. Generally, the PTFE surface is water-repellent and oil-repellent, and it is a material that is difficult to be printed on as designed by conductive ink. However, as the figure shows, wiring material is formed and attached at the designated line widths on the PTFE nanofibers. Additionally, it can be seen in the enlarged figure, that a portion of the conductive ink component has entered the micropores of PTFE nanofibers, thus maintaining adhesion with PTFE nanofibers, and no bleeding of conductive ink is confirmed.

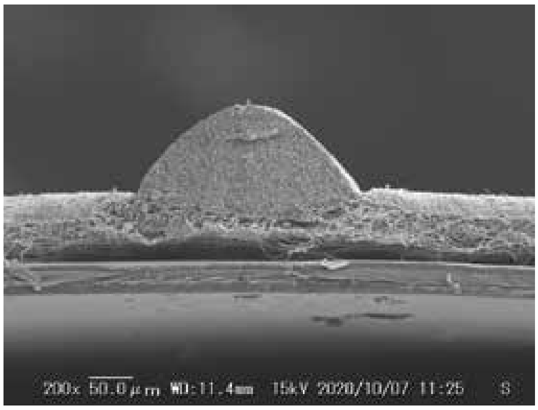

Figure5 Surface of PTFE nanofibers and wiring

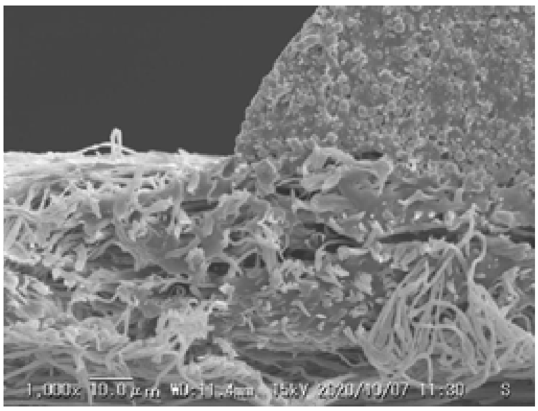

Figure6 Enlarged view

3-3) Durability tests

In this project, we confirmed the adhesion of conductive ink with PTFE nanofibers and the change in electric resistance value using MIT tests.

The sample used this time was an electromyography sensor that will be mentioned later, and it was used after circuit formation with line width of 0.5mm, followed by covering the circuit with insulation material.

The MIT test was conducted using a tester as shown in Figure7. Table2 shows the test conditions (refer to JIS P8115. However, considering the strength of PTFE nanofibers, no load as designated). Circuit properties were measured as electric resistance between the two edges of the electric circuit before and after the test.

Table2 MIT testing conditions

Parameter	Testing conditions
Test rate	90 cpm
Bending angle	135°
Radius of curvature	0.38 mm
Test repeats	3,000 repeats
Load	—

Figure7 MIT tester

As a result of the test, Figure8 shows no sign of disconnection at the bending section (red dotted line). In addition, Figure9 shows no significant change in electric resistance value, and this means good electric conductivity was maintained even after the test.

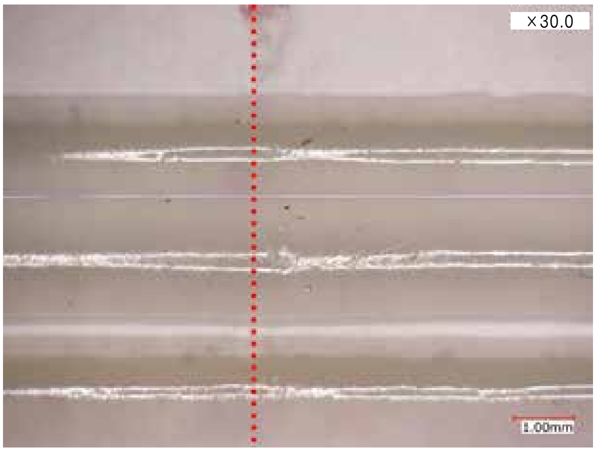

Figure8 Photograph of the bending section (After 3,000 repeats)

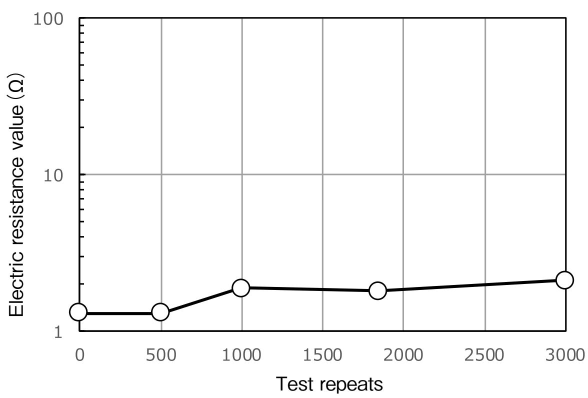

Figure9 Relationship of conductivity change due to MIT test

4. Application to flexible devices

Figure10 shows a photograph of PTFE nanofibers with various wiring patterns. By using printing methods, it is possible to form various wiring patterns.

Figure10 PTFE nanofibers forming various wiring patterns

As an example of a flexible device using PTFE nanofibers with wiring patterns, we tried electromyography sensors and touch sensors.

Generally, electromyography sensors are made of patch-type electrodes and assumed to be unsuited for continuous use because they do not have air permeability. In contrast, sensors that use PTFE nanofibers would have the characteristics of PTFE itself and be safe for medical use, non-invasive, and water-repellent, as well as air permeability that nanofiber structures have. Therefore, it would be unlikely that they have an adverse effect on the body even if continuously used, and they would be appropriate for wearable devices. In addition, it is difficult to convey over words, but the material has a gentle texture when next to the skin, and this is another point that makes it ideal for continuous use.

Figure11 shows a trial electromyography sensor. In this figure, the 3 electrodes are made to be worn separately, but it is also possible to combine them as shown in Figure12, and it could be considered to be used as a wristband type device.

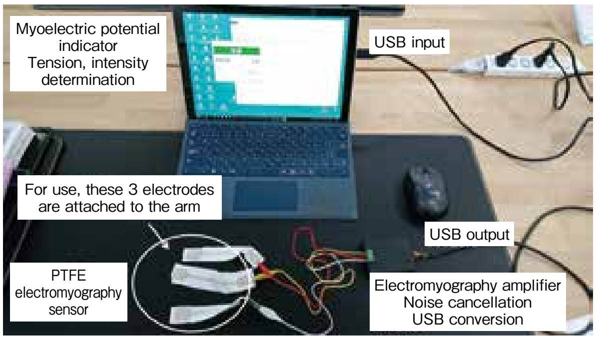

Figure11　Trial electromyography sensors
(Electromyography amplifier and display software are products from Tokyo Devices Inc.)

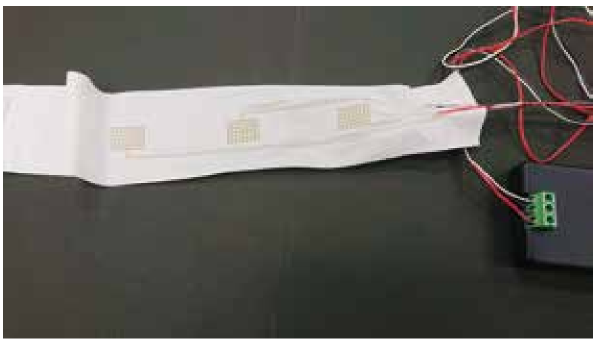

Figure12　Electromyography sensor, integrated type

Figure13 shows a trial touch sensor. A capacitance change type touch sensor was manufactured as a trial. The sample shown in the figure had variability in the detection sensitivity per matrix, but was confirmed to have the basic functionality of a capacitance change type touch sensor.

PTFE nanofibers themselves do not have stretchability, but they have the ability to follow free-form surfaces of a certain degree of size, and applications to various input user interfaces including wearables can be considered.

Figure13　Trial touch sensor
(Microcomputer board and display software from Renesas Electronics Corp.)

5. Future developments

This time, we investigated the utilization of PTFE nanofibers in flexible devices. By forming wiring on PTFE nanofibers, we think that we have shown possibilities as to their application that go beyond their utilization as only a material. In the future, with the progressively ageing society in Japan, we think that the use of wearable devices in the healthcare field will increase. In addition, there are types of devices such as foldable smartphones that have not been seen before, and it is predicted that various user interfaces will be further required in the future.

To be able to follow this drastic changing society in a flexible way like nanofibers, we will continue our efforts on further expanding the examples we have shown here and also produce products that benefit society.

6. Conclusions

Through a collaborative effort with CONNECTEC JAPAN, we were able to show new possibilities for utilizing PTFE nanofibers. We think that the utilization cases that we introduced in this report are only a portion. We consider that the development of novel devices could be possible using Valqua's unique material, PTFE nanofiber, and CONNECTEC JAPAN's proprietary low temperature technology. With this, we hope that we can help realize our readers' ideas.

7. References

1) Tsuji, Setoguchi, Valqua Technology News, No. 23, pp.13-15.

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