様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費
KAKENHI

科学研究費助成事業　　研究成果報告書

令和　元 年　６ 月 ２４ 日現在

機関番号：８２１０８
研究種目：研究活動スタート支援
研究期間：2017～2018
課題番号：１７Ｈ０７３５０

研究課題名（和文）Microstructural control of supramolecular hydrogel by teslaphoresis

研究課題名（英文）Microstructural control of supramolecular hydrogel by teslaphoresis

研究代表者
ＮＧＯ　ＨｕｙｎｈＴｈｉｅｎ（NGO, Huynh Thien）

国立研究開発法人物質・材料研究機構・機能性材料研究拠点・NIMSポスドク研究員

研究者番号：６０７２３４８４

交付決定額（研究期間全体）：（直接経費）　　2,100,000円

研究成果の概要（和文）：本研究では、新たな技術「テスラフォレシス」を用いた超分子相互作用の制御を進めている。このテスラフォレシスを用いてヒドロゲル中のカーボンナノチューブ（CNT）を整列させることで、ヒドロゲルの超分子相互作用を変化させ、ヒドロゲルの機械的強度およびその安定性を向上させた。またゲル中のCNTの配向を制御することで、ゲルの電気伝導性の異方性制御を達成した。
さらに、テスラフォレシスによりCNTを配向させたヒドロゲルの嗅覚センサへの応用可能性も示した。CNTを配向させたヒドロゲルを膜型表面応力センサの感応膜として用いることで、通常のゲルと比べて感度を1000倍以上も向上させることを見出した。

研究成果の学術的意義や社会的意義
The result of this investigation extends the academia and has many applications in real world.
We can now make stronger hydrogels using aligned carbon nanotubes for stronger water-like materials.
We could detect small concentration of gases using this hydrogel, useful for agricultural applications.

研究成果の概要（英文）：Using the new technique Teslaphoresis, I could align the carbon nanotubes in synthetic hydrogel using supramolecular interactions. The hydrogel showed enhanced mechanical strength and stability. Furthermore, we investigated the anisotropic properties, such as conductivity of the hydrogel-carbon nanotube hybrids. depending on the direction of the alignment, we could enhance the conductivity of the gel in certain directions. In another related topic, we used the pluronic hydrogels as receptor materials for the membrane-type surface stress sensor MSS to detect various gasses. We observe that the direction of the alignment of carbon nanotubes strongly affects the sensitivity. In some cases we could enhance over 1000 times the sensitivity of the sensor materials. This remarkable finding is now under further investigation.

研究分野：materials science

キーワード：Teslaphoresis　hydrogel　supramolecular chemistry

１．研究開始当初の背景

Despite their potential, synthetic hydrogels are typically mechanically weak which limits their applications. Comparison between synthetic hydrogel from biopolymers and natural hydrogels shows: i) SYNTHETIC HYDOGEL has NO ORDER in microstructure, is mechanically WEAK and possesses self-healing properties while ii) NATURAL HYDROGEL has anisotropic ORDER in microstructure, is mechanically STRONG and show NO or slow self-healing. The structural order in natural hydrogels gives the natural gels its mechanical strength.

２．研究の目的

We want to mimic this ordered alignment in synthetic hydrogels using Teslaphoresis. I want to combine supramolecular chemistry with teslaphoresis (TEP) to engineer sustainable hydrogel-CNT composites with above-mentioned improved properties by aligning the CNTs in an ordered fashion in synthetic hydrogels.

３．研究の方法

To produce strong self-healing smart materials by TEP and supramolecular chemistry I:

- Constructed the Teslaphoresis apparatus.
- Studied and characterised the properties of hydrogels with supramolecular CNT cross-links.
- Study and optimise supramolecular-CNT hybrid hydrogels formed under TEP field

４．研究成果

During the first 6 months of the project, the Teslacoil was constructed. Using synthetic gelators we could to align the carbon nanotubes (CNTs) inside of the gels.

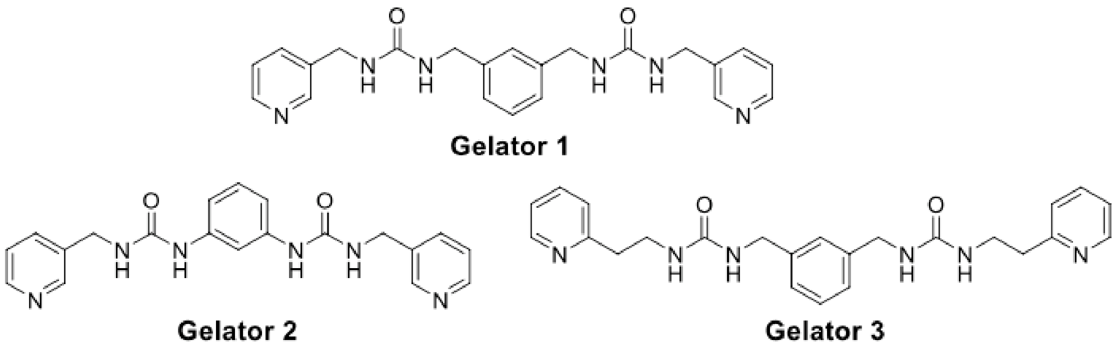
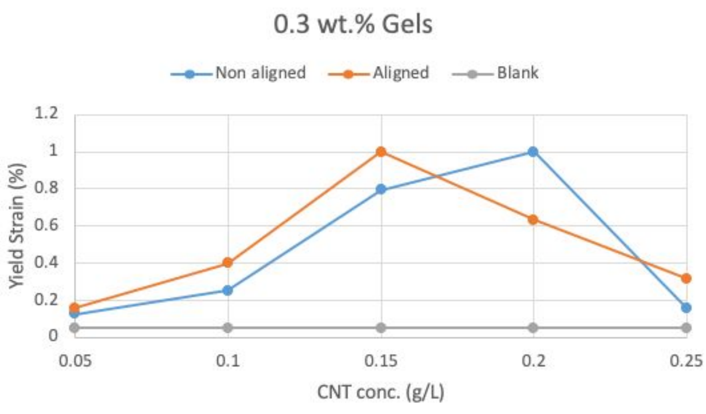


Figure 1: Structures of gelators tested for the stabilization of the aligned CNTs.

Next, the aligned CNTs were successfully stabilized by forming hydrogels around them. Different types of gelators were tested, but only one seemed to work for our intended application. This had to do with gelation time and gel strength, which were optimal for 0.3 wt.% gels from gelator 1 (see figure 1). Next,



the retention of alignment was followed using optical microscopy, and it was found that the alignment was retained for at least 2 weeks. Furthermore, the alignment was retained when the hydrogels were placed in a Tesla field with a different orientation.

Figure 2: Graph presenting the difference in yield strain for hydrogels containing CNTs at different concentrations (and a blank, without CNTs), and between aligned and non-aligned CNTs. The yield strain is here defined as the percentage of strain, at which the value of the storage modulus is 5% lower than value of the storage modulus of the previous data point.

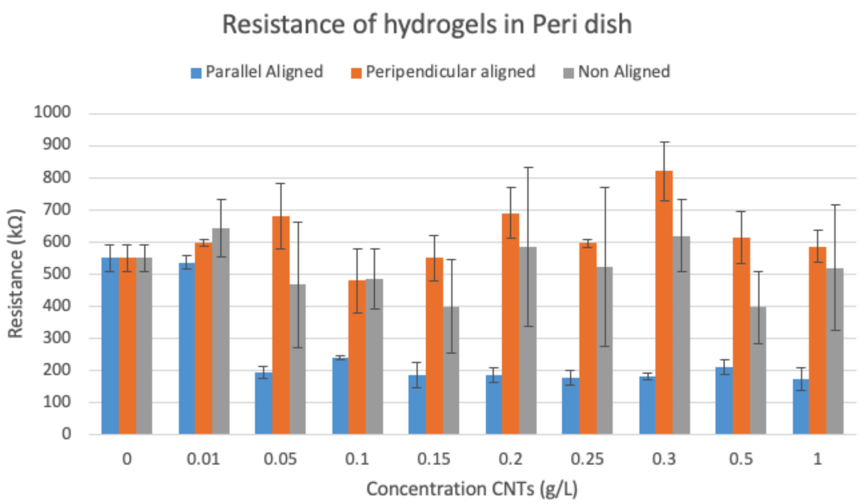


Figure 3: Resistivity measurements for CNT containing hydrogels prepared in a Petri dish.

From months three to five, the material properties were studied of the CNT-containing hydrogels. The mechanical properties of the materials (CNT-containing gels, both aligned and non-aligned, and blanks) were studied using oscillatory rheology. An effect of the addition of CNTs was observed, as well as an effect of their alignment. It seemed that the CTNs increased the yield strain of the gels, this difference was even more profound when they were aligned in a direction parallel to the direction of the oscillation (see figure 2). Finally, the conductivity of the gels was tested. A sample preparation method was developed, in which the resistivity meter could be attached to wired which were embedded in to the gels. This sample preparation showed only significantly different results at higher CNT concentrations. Therefore, larger gels were prepared in a Petri dish. The resistance was measured along, and perpendicular to, the direction of the self-assembled CNTs wires (see figure 3). These were compared to blanks without CNTs and with randomly oriented CNTs. The results of these experiments show that the direction of the alignment of the CNTs affects the conductivity.

In summary: the use of Teslaphoresis, to make aligned CNT hydrogels, allowed us to study the effect of this alignment on the mechanical and conducting properties of the materials.

５．主な発表論文等

〔雑誌論文〕（6 件）

1) Taizo Mori, Hokyun Chin, Kazuhiro Kawashima, Huynh Thien Ngo, Nam-Joon Cho, Waka Nakanishi, Jonathan P. Hill, and Katsuhiko Ariga
Dynamic Control of Intramolecular Rotation by Tuning the Surrounding Two-Dimensional Matrix Field
Peer reviewed
ACS Nano, *13* (2), 2019, pp 2410–2419
2) Kosuke Minami, Kota Shiba, Gaku Imamura, Huynh Thien Ngo, Genki Yoshikawa
Highly Sensitive and Selective Receptor Materials for Membrane-type Surface Stress Sensor (MSS) and their Applications as an Artificial Olfaction
Peer reviewed
Journal of Japanese Association on Odor Environment,, 49, 2018, 297–304.
3) Kota Shiba, Ryo Tamura, Takako Sugiyama, Yuko Kameyama, Keiko Koda, Eri Sakon, Kosuke Minami, Huynh Thien Ngo, Gaku Imamura, Koji Tsuda, and Genki Yoshikawa
Functional Nanoparticles-Coated Nanomechanical Sensor Arrays for Machine Learning-Based Quantitative Odor Analysis
Peer reviewed
ACS Sensors, 3 (8), 2018, 1592-1600
4) D. Stefani, M. Perrin, C. Gutiérrez-Cerón, A. C. Aragonès, J. Labra-Muñoz, R. D. C. Carrasco, Y. Matsushita, Z. Futera, J. Labuta, T. H. Ngo, K. Ariga, I. Díez-Pérez, H. S. J. van der Zant, D. Dulić, J. P. Hill
Peer reviewed
ChemistrySelect, *3*, 2018, 6473–6478
5) Ngo, H.T., Minami, K. Imamura, G. Shiba, K. Yoshikawa, G.
Effects of Center Metals in Porphines on Nanomechanical Gas Sensing.
Peer reviewed
Sensors, *18*, **2018**, 1640
6) Kosuke Minami, Kota Shiba, Thien Huynh Ngo, Gaku Imamura, and Genki Yoshikawa
Nanomechanical Sensors(MSS/AMA)for Odor/Mass Analyses
Peer reviewed
J. Mass Spectrom. Soc. Jpn., *66*(1), **2018,** 25–29

〔**学会発表**〕（2 **件**）

1) Ngo, H.T., Minami, K. Imamura, G. Shiba, K. Yoshikawa, G.
Nanomechanical Sensors with AI towards IoT Olfactory Sensor System and Supramolecular Manipulation to control Photo physics/chemistry
Invited talk at Oxford university
2018
2) Ngo, H.T., Minami, K. Imamura, G. Shiba, K. Yoshikawa, G.
Nanomechanical sensors (MSS) with AI toward Olfactory IoT Sensing System
IWMS2018, 2018

〔**図書**〕（2 **件**）

1) **南 皓輔，**Thien Huynh Ngo**，今村 岳，柴 弘太，吉川 元起**, "MSS**（膜型表面応力センサ）を用いた嗅覚センサと応用展開**"**口・鼻・耳の感覚メカニズムと応用技術**,**第**4**章 第**2**節**, S&T**出版**, p224-233, 308 pages, 2018

2) Thien Huynh Ngo, Kosuke Minami, Gaku Imamura, Kota Shiba, Genki Yoshikawa, Membrane-type surface stress sensor for artificial olfactory system, Chemical, Gas, and Biosensors for Internet of Things and Related Applications, Elsevier, p27-38, 386 pages, 2019