Graduate School of Creative Science and Engineering
Waseda University

# 博　士　論　文　概　要
# Doctoral Dissertation Synopsis

## 論　文　題　目
Dissertation Title

## Development of Polymer-based Additive Manufacturing for Smart Devices

## スマートデバイスのためのポリマーベース積層造形の開発

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Additive manufacturing (AM), also known as 3D printing, is an emerging manufacturing technique that uses a digital model as a basis to create physical objects by building up material layer by layer. With the development of relevant materials, processes and equipment technologies over the years, additive manufacturing has been widely used in construction, medical care, aerospace, automobiles, Electronics, food. With the development of cutting-edge technologies such as green technology, life sciences, functional devices, and 3D smart devices, additive manufacturing technology is forced to undergo continuous technological innovation. At present, additive manufacturing technology is changing from "shape-oriented control" manufacturing mode to "performance-oriented control" manufacturing mode, from the connotation of "additive manufacturing" to the manufacturing connotation of "additive creation", from "single technology" to "multiple Process integration" innovative model. This research is based on a new generation of advanced polymer-based additive manufacturing technology, focusing on the manufacturing model innovation of "performance-oriented control", the manufacturing connotation innovation of "additive creation", and the process innovation of "multi-process integration". For the construction of green self-cleaning functional devices, the preparation of medical testing functional devices and the manufacturing of cutting-edge 3D intelligent electronic devices, research on material preparation, manufacturing system development, process construction and application exploration, were carried. The research aims to promote the development of polymer-based additive manufacturing technology through the following three specific sub-topics, and provide new material preparation technology, experimental platform foundation, innovative process strategy and cutting-edge application guidance for the manufacture and construction of polymer-based additive manufacturing functionality devices.

This dissertation focuses on polymer-based additive manufacturing technology, and conduct research on material preparation, experimental platform construction and manufacturing process improvement and innovation for its application in green technology, medical diagnosis and 3D smart electronics.

**Chapter 1**, introduction: This chapter systematically introduces the process types, technology status and application status of additive manufacturing technology. Through analysis, this chapter shows the development trend and direction of additive manufacturing technology, expounds the technical upgrading and research direction for environmental protection, medical detection and 3D intelligent period manufacturing, and thus leads to the three aspects of this paper. sub-topics. Finally, this chapter expounds the technical problems and research purposes of the three sub-topics that need to be solved from the perspective of mechanical engineering.

**In chapter 2**, a $TiO_2$-based self-cleaning membrane with a double-layer structure and a multi-spinner multi-material segmental blending process were proposed, and an environmentally friendly recyclable nano-$TiO_2$ photocatalytic SCF with a double-layer structure was successfully prepared. This chapter elaborates the method of preparing novel spinning solution (ABS spinning solution) with high mechanical properties and upgrading the electrospinning process and equipment (stepwise multi-jet multi-material blending), and constructs a multifunctional self-clean film with tunable microstructure and contact angle. Different functional layers (substrate layer for adhesion and high mechanical properties, and self-cleaning layer for photocatalysis) perform their duties and cooperate with each other, so that the proposed self-cleaning film has good mechanical properties, self-cleaning effect and Water wets the corners. Microscopic characterization and a series of performance testing experiments verified the effectiveness of the proposed film in terms of enhanced lifetime, self-cleaning efficiency, recyclability, and mechanical strength. Due to the good adhesion of PVA fibers, SCF has the property of being recyclable, making it a promising application. The mechanical strength of the proposed self-cleaning membrane can be further enhanced by controlling the moving speed of the receiver and the process steps. In particular, existing studies have shown that $TiO_2$ has photocatalytic properties and showed a greater potential to inactivate the COVID-19 virus. The double-layer structure of this film allows the recycling of medical products and also allows the medical products to be used in daily life after being used in the medical environment, thereby significantly saving resources and reducing the generation of single-use waste. This study was carried out to inspire and facilitate functional polymer-based additive manufacturing technologies, especially the electrospinning process for constructing functionalized high-performance thin-film devices. Studies have shown that the construction strategy of multifunctional materials with enhanced processes has a good contribution to the enhanced functionality and performance of functional thin films.

**Chapter 3** studies the high-precision DLP 3D printing technology based on functional polymers, and its applications in medicine and the response to Covid-19. This section proposes a new 3D printed throat swab design with higher detection accuracy and comfort. The 3D printed throat swab is mainly composed of two parts, namely the throat swab body and the cover used to protect it from contamination during the detection process. Among them, the head of the 3D printed throat swab has a specially designed microstructure, to collect mucus samples for SARS-CoV-2 testing. In this chapter, on the basis of realizing the high-precision batch manufacturing of the designed 3D printed throat swab based on biocompatible photosensitive resin, relevant material characterization, mechanical performance testing, finite element analysis and actual collection process simulation experiments were carried out to confirm Its improved mechanical properties and processing effectiveness for RT-PCT analysis. Our findings build on recent research in the US, where 3D printed swabs are being tested. The results of the study showed that capping had the benefit of maintaining the safety of PCR testing and accurate virus extraction from the nasopharynx. The tip design used in this study requires more volumetric space than other hollow structural designs, limiting the number of swabs that can be batch-printed using SLA. Due to the widespread use of 3D printing technology, most developed and developing countries can ensure a sufficient local supply of cotton swabs. Depending on the situation and needs, swabs can be easily designed and produced in a short time. Due to the scalability of this new manufacturing method, thousands of engineered swabs can be produced and shipped every day. The ability to manufacture swabs on demand significantly reduces waste and inventory. The high false negative rate of current testing methods demonstrates how 3D printing can lead to a healthier, greener future.

**In chapter 4**, this research demonstrated a means of fabricating high-precision 3D metal-plastic structures having arbitrarily complex internal and external metal pattern with a resolution of 40 μm, utilizing a combination of improved stereolithography for multi-materials and plating. Creating defined metal patterns on the surface of a complex 3D functional device is key to advanced electronic devices, but it is highly challenging or expensive limited by traditional MEMS or PCB processes. We developed a new multi-material digital light processing 3D printing (DLP) apparatus to fabricate microstructures comprising combinations of standard resin and resin containing metal ions (referred to as the active precursor). These arbitrarily complex devices have specific 3D spatial distributions that allow 3D selective electroless plating (ELP). To the best of our knowledge, this is the first time that DLP and ELP have been used to create such precise metal patterns on the surface or even the interior of 3D plastic functional parts. We have made multiple 3D electronic structures with defined metal patterns inside, which would be highly challenging using traditional semiconductor technology. The unique through-hole structure (A small hole with a diameter of 250 μm and the inner wall is covered with metal) were used to connect the inner and outer layers of the circuit (The wire width in this device was 200 μm) to achieve the reduction of the electronic size and the improvement of the function. Some highly integrated and customizable 3D sensors were manufactured by constructing electrode patterns on the surface or inside of functional materials. Strip electrodes with a width of 500 μm are constructed inside the rectangular tube to achieve a high degree of integration between the strain sensor and the measured object. The comb-shaped electrode is constructed on the surface of the flexible piezoelectric part to realize the piezoelectric effect on the force change. The metal electrodes on the surface of the flexible watchband parts can directly monitor human ECG signals. This technology will open up new pathways in the development of functional devices based on metal-plastic composite structures and novel advanced 3D electronics in fields of robot, microsensor field, and health monitor. The above three sub-topics are all based on polymer-based additive manufacturing technology, and carry out innovative research on materials, processes, equipment, etc., aiming to explore technology improvement methods and advanced application strategies in the fields of environmental protection, medical testing, and 3D smart equipment. Construction. The above research shows that polymer-based additive manufacturing technology has good development prospects. Based on the multi-process fusion and multi-material coupling enhancement process, this technology has shown great potential in the manufacture of more complex, functional, and intelligent pen-related equipment. potential. From the perspective of mechanical engineering, the above three sub-topics belong to the research field of micro-nano manufacturing technology. This research provides innovative theory and technology examples for the manufacture of specific functional devices and structural parts. The strategies and technical routes involved have promoted the development of micro-nano manufacturing technology, enriched its theory and applications.

# List of research achievements for application of Doctor of Engineering, Waseda University

Full Name： 宋　珂炜 seal or signature

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| 種類別 (By Type) | 題名、 発表・発行掲載誌名、 発表・発行年月、 連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself) |
|---|---|
| 投稿論文 | |
| 1 | 〇Kewei Song, Yue Cui, Liang Liu, Boyang Chen, Kayo Hirose, Md. Shahiduzzaman, and Shinjiro Umezu."Electro-spray deposited TiO2 bilayer films and their recyclable photocatalytic self-cleaning strategy." Scientific reports 12.1 (2022): 1582. |
| 2 | 〇Kewei Song, Yue Cui, Tiannan Tao, Xiangyi Meng, Michinari Sone, Masahiro Yoshino, Shinjiro Umezu, and Hirotaka Sato."New metal–plastic hybrid additive manufacturing for precise fabrication of arbitrary metal patterns on external and even internal surfaces of 3D plastic structures." ACS Applied Materials & Interfaces 14.41 (2022): 46896-46911. |
| 3 | Fan Huang, Kewei Song, Yue Jiang, Kayo Hirose, and Shinjiro Umezu."3D-printed swab with cover for precision diagnosis." Journal of Materials Science: Materials in Medicine 33.1 (2022): 8. |
| 4 | A.T.K. Perera, Kunlin Wu, Wei Yang Wan, Kewei Song, Xiangyi Meng, Shinjiro Umezu , Yifan Wang , and Hirotaka Sato. "Modified polymer 3D printing enables the formation of functionalized metallic micro-architectures." Additive Manufacturing 61 (2023): 103317. |
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| 4 | Kewei Song, Meng Xiangyi , Shinjiro Umezu, and Hirotaka Sato. "Constructing 3D electronics through mult-material 3D printing for hybrid systems", IEEE International Conference on Robotics and Automation 2022.May 23-27, 2022, Philadelphia (PA), USA. |

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