



Materials and Technologies for Flexible and Printed Electronics

Edited by
Wang Weifang



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Wang Weitang



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Selected, peer reviewed papers from the
5th International Conference on Flexible
and Printed Electronics
(ICFPE 2014),
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Edited by

Liangliang Chen



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Preface

After one year intense and careful preparation, the 5th International Conference on Flexible and Printed Electronics (ICFPE) was successfully held in Beijing on 21-23 October 2014. The conference was organized by Beijing Institute of Graphic Communication and hosted by Beijing University of Technology. Co-organizers of the conference included the Suzhou Institute of Nanotech and Nanobionics, Changzhou Institute of Printed Electronics Industry, Institute of Chemistry, Organic Electronics Association in Germany and NanoGlobe of Singapore. CHINA CYTS M.I.C.E SERVICE CO.,LTD. took care of the conference logistics. The General chair of conference was Professor Zheng Cui who is the Director of Printable Electronics Research Center, Suzhou Institute of Nanotech and Nanobionics, Chinese Academy of Sciences.

Total 237 abstracts were received from 20 countries. 222 abstracts were selected. The conference had 19 oral sessions with 99 oral presentations and a poster session with 123 posters. 5 plenary speakers were invited, who are world renowned experts in flexible and printed electronics, including Professor John A. Rogers from University of Illinois at Urbana Champaign, USA, Dr. Kazumasa Nomoto who is the Senior General Manager of Device Development Division in Sony, Japan, Professor Andrea C. Ferrari of Cambridge University, UK, who also serves as the Chairman of Executive board for the European Graphene Flagship Project, Dr. Sang-Yoon Lee who is the Senior Vice President of Samsung Electronics, Korea, also serves as the Leader of Korea National Project 'the total solution for printed electronics'. Professor Cao Yong from South China University of Technology, an Academician of Chinese Academy of Sciences, was also one of the plenary speakers. In addition to plenary session, oral sessions and poster session, the conference organized 14 invited sessions with 28 invited speakers from China and overseas, who presented their latest progresses in their research fields. To help young researchers and people who are new to the fields, the conference organized a Master Class the day before the formal start of conference, with 4 lecturers talking about the basics in organic photovoltaic, printed electronic devices, printing machines and design for printed electronics. In the poster session, three posters were selected with the Best Poster Award. Apart from academic presentations, there was a trade show, with 11 companies and organizations setting up exhibition booths alongside the conference.

Although it was the first time the ICFPE was held in China and the organizers did not have experience relevant to running large international conference before, the conference has achieved a great success. The technical program was orderly executed and every detail of logistics was paid attention to. The structuring of technical program and the organization of conference were widely praised by the participants. Representatives from Korea and Japan who were organizers of past ICFPE conferences came to the conference chair to congratulate him on the success of this conference. Dr. Simon Ogier, who is the R&D manager of UK national printed electronics Center and an attendee of the conference, sent an e-mail to Professor Zheng Cui after going back to UK, saying "Dear Zheng – I would like to congratulate you on a very successful conference which I enjoyed very much – continuing the good tradition of ICFPE – well done to you and the other members of the organizing committee."

Flexible and printed electronics are rather new fields in China. In particular, the term of “printed electronics” was almost unheard of in China five years ago when Professor Cui setup the first research center dedicated to the R&D of this technology. He admitted that when he volunteered to organize the 5th ICFPE in China two years ago in Tokyo at the 3rd ICFPE, he was not quite confident that the conference would be as successful as previous ones because there were not many people actually working in this field in China. Two years on, the situation has changed greatly. Helped by the worldwide hypes of 3D printing and wearable electronics, more and more people in China start to pay attention to flexible and printed electronics. An increasing number of researchers start to get involved in the technology. The industry is also watching the development in the field. As the result, the 5th ICFPE has drawn wide participations from many sections of research community and industry in China. Among the 237 submitted abstracts, 138 abstracts were from mainland China. Among the 351 participants, 209 were from mainland China, which was truly beyond the organizers’ expectation.

The motive to have the 5th ICFPE held in China, as Professor Zheng Cui conceived, was to use it as a platform and an opportunity to let the Chinese researchers and industrialists see the worldwide development of flexible and printed electronics, and to let the world see what China has done and what are the opportunities of business and technology collaborations lying ahead. Now with the success of 5th ICFPE the goal has been achieved. We have every reason to believe that flexible and printed electronics will have rapid development in China in the coming years. With the sheer size of population, the potential market for flexible and printed electronics products in China will be huge. China as the world largest manufacturing base for nearly everything, particularly in sectors such as flat panel displays, solar cells, printed circuit boards, etc., will become one of the major driving forces to push the technology from research to commercialization. The Chinese researchers and industrialists will remember that the 5th ICFPE held in China in 2014 has played a part in the process.

Table of Contents

Preface

v

Flexible Pressure Sensor Based on Photo Paper-Molded Micro-Structural AgNWs/PDMS Electrode

L.X. Mo, Y.Q. Hou, Q.B. Zhai, W.G. Zhang and L.H. Li..... 1

Silver Nanowires Deposited on Grooved Surface as Bendable Resistance Sensor

X.M. Li, H.M. Tian, X.M. Li, X. Li and J.Y. Shao 5

Fabrication of Ultrathin Free-Standing Ceramic Chips Based on Printing Technology

W.W. Kong, B. Gao, C.P. Jiang and A.M. Chang..... 11

Modeling and Optimizing Industrial Inkjet Printhead for Printable Electronics Fabrication

L.B. Ma, M.W. He, K.Y. Hu and Y.L. Zhu 15

Synthesis of Nitro-Functionalized A₃B-Type Tetraphenylporphyrins Compounds and Potential Applications in Dye-Sensitized Solar Cells

H. Li, Y.B. She, H.Y. Fu and T.W. Jia 21

Conductive Improvement of Flexography Printed Silver Pattern by Water Washing

Y. Fang, W. Liu, Y.F. Xu and L.H. Li..... 25

Dip-Coating of Patterned Organic Semiconductor Films

M.Z. Qin, X.H. Wang, M. Yuan, S.C. Lv and X. Gu 29

Perovskite CH₃NH₃PbI₃ Heterojunction Solar Cells via Ultrasonic Spray Deposition

X. Du, Y. Wang, Z.G. Xia and H. Zhou 39

Influence of Annealing of PCDTBT:PC₇₀BM on the Performance of Polymer Solar Cells

S. Yan, L.F. Lv and Y.B. Hou 45

Electric-Field Assisted Hydrothermal Growth of ZnO Nanorods on Flexible Substrate and their Strain Sensing Applications

X.L. Zong, R. Zhu and C. Zhang 49

Preparation of Conductive Ink for Organic Solar Cell Electrode

W. Liu, Y. Fang, Y.F. Xu, L.X. Mo and L.H. Li..... 53

Novel Thieno[3,2-c]Pyridine Based Ir Complexes for Solution/Evaporation Hybrid OLED

T.C. Chao, H.C. Yeh, C.H. Chou, M.H. Chang and M.R. Tseng 57

Synthesis and Mesophase of a Triphenylene-Based Discotic Liquid Crystal with Plastic Columnar Phase

J.C. Wang, S.F. Zhang, C.X. Zhang, H. Wu, Y.F. Wang, X.T. Hao, F. Hong, A. Zhang and J.L. Pu..... 63

Controllable Synthesis of Silver Nanospheres with Uniform Size

Y.X. Zhao, C.M. Liu, L.N. Zhang, L.H. Li, Y. Wei and L. Han..... 67

Preparation of Au-Ag Nanoframe and its Application in SERS

S.L. Liu, Z.Q. Xin and L.H. Li 71

Graphene Oxide for Ink-Jet Printing Technology Y.L. Li, X. Guo, X.J. Feng and L.H. Li	77
Inductance Investigation of Screen-Printed Radio Frequency Identification Antennas Y.L. Li, F.Y. Zhao and L.H. Li	81
Magnetic Ink Based on Barium Ferrite and its Application in Magnetic Recording Paper Y.L. Li, F.Y. Zhao, J.X. Zhao and L.H. Li	85
Monolithic Integration of a Flexible Micro Thermal Flow Sensor S. Zhao and R. Zhu	89
Preparation and Characterization of Ultrafine Monodisperse Iron Oxide Nanoparticles by Solvothermal Method C.M. Liu, Y.X. Zhao, J. Dong, L.H. Li, Y. Wei and L. Han	93
Improved Synthesis of 5-(R-group)-10, 15, 20-tris(4-methylphenyl)porphyrins as Starting Compounds for the Preparation of Potential Sensitizer in Solar Cells T.W. Jia, Y.B. She, H.Y. Fu and H. Chang	97
One-Pot Synthesis of UV-Curable Au/PEDOT Conductive Ink by Using Amphiphilic Polymer PSMH as Templates Y.L. Zhang, Y.X. Zhai, X.Y. Liu, J. Luo and Y. Yuan	101
Synthesis and Mesophase of a Chiral Triphenylene-Based Discotic Liquid Crystal S.F. Zhang, J.C. Wang, C.X. Zhang, H. Wu, Y.F. Wang, F. Hong, X.T. Hao, A. Zhang and J.L. Pu	107
Preparation of Fe₃O₄ with Solvothermal Method and its Electrochemical Properties F.Y. Zhao, M.R. Ding, J. Chen, Y.L. Li and L.H. Li	111
Non-Invasive Wireless and Passive MEMS Intraocular Pressure Sensor Based on Flexible Substrate L.J. Liu, J.B. Wang, D.Y. Chen and J. Chen	115
Investigation on Electrical Stress over Metal-Insulator-Metal (MIM) Structures Based on Compound Dielectrics for the Inkjet-Printed OTFT Stability K.Y. Mitra, E. Sowade, C. Sternkiker, C. Martínez-Domingo, E. Ramon, J. Carrabina and R.R. Baumann	129
Electrohydrodynamic Direct-Write Micro/Nano Pattern with the Restriction of Inducing Tip Z.J. Yu, J.X. Jiang, L.L. Sun, G.F. Zheng and D.H. Sun	135
The Effect of Post-Annealing Temperature on the Performance of OTFT Memory L.J. Liang, Y. Tomoyashi and X.F. Wei	141
Electrohydrodynamic Direct-Write Multi-Layer Micro Circuit on Flexible Substrate L.L. Sun, J.X. Jiang, Z.J. Yu, G.F. Zheng and D.H. Sun	147
Preparation of Triangular Silver Nanoplates and its Application in Printed Electronics Z.Q. Xin, S.L. Liu, P.J. Deng, Y.L. Li and L.H. Li	153
A Flexible Ultrasensitive IgG-Modified rGO-Based FET Biosensor Fabricated by Aerosol Jet Printing W. Yu, P.J. Cai, R. Liu, F.P. Shen and T. Zhang	157

Preparation of BaTiO₃/PMMA Dielectric Films by Screen Printing X.Z. Wu, Z. Chen, T. Zhou, S.S. Shao, M.L. Xie and Z. Cui.....	163
Inkjet Printing Enabling Silicon Photonics X. Feng, B. Qian, Y. Zhou and Y.L. Xie	171
Controllable Fabrication of Flexible Multi-Walled Carbon Nanotubes/Reduced Graphene Oxide Hybrid Ultrathin Films W.X. Yu, S.J. Qin, Z.P. Xiong, Z.Q. Ren, X.W. Wang and T. Zhang	175
Effect of Additive on Surface Properties of Solution Coated PZT Ferroelectric Film S.Q. Wu, X.F. Zhang and Y.L. Xie.....	179
Synthesis and Characterization of Substituted μ-oxo-bis[tetra-phenylporphyrinatoiron] Compounds Z.C. Sun, S.Y. Chen, Z.P. Guo, M.J. Cao and L.H. Li	183
Intense Pulsed Light Sintering of Copper Nanoink for Conductive Copper Film W.B. Gu and Z. Cui	187
Enhancement Effect of UV Light Emission by ZnO/Au Film on Flexible Structures J. Yan, C.L. Xiong, C.J. Qin and X. Li.....	193
DFT Study on Geometric and Electronic Structures Properties of Dye Sensitizers M.J. Cao, Z.C. Sun, L.H. Li, Y.B. She, Z.L. Yang and T.Y. Wu.....	197
Keyword Index	201
Author Index	203

Flexible Pressure Sensor Based on Photo paper-molded Micro-structural AgNWs/PDMS Electrode

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Key words: electronic skin; stretchable electronics; silver nanowires; capacitive pressure sensor; electrode micro-structure

Abstract: The novel flexible pressure sensor with skin-like stretchability and sensibility has attracted tremendous attention in academic and industrial world in recent years. And it also has demonstrated great potential in the applications of electronic skin and wearable devices. It is significant and challenging to develop a highly sensitive flexible pressure sensor with a simple, low energy consuming and low cost method. In this paper, the silver nanowires (AgNWs) as electrode material were synthesized by polyol process. The polydimethylsiloxane (PDMS) was chosen as a flexible substrate and polyimide (PI) film as dielectric layer. The AgNWs based electrode was prepared in two methods. One is coating the AgNWs on photographic paper followed by in situ PDMS curing. Another one is suction filtration of the AgNWs suspension followed by glass slide transfer and PDMS curing. Then the capacitive pressure sensor was packaged in a sandwich structure with two face to face electrodes and a PI film in the middle. The sensitivity of the sensor as well as the micro-structure of the electrodes was compared and studied. The results indicate that the roughness of the electrode based on AgNWs/PDMS micro-structure plays an important role in the sensitivity of sensor. The as-prepared flexible pressure sensor demonstrates high sensitivity of 0.65kPa^{-1} . In addition, the fabrication method is simple, low energy consuming and low cost, which has great potential in the detection of pulse, heart rate, sound vibration and other tiny pressure.

Introduction

The electronic skin (e-skin) was characterized by its similarity to human skin, which has the ability to sense the spatiotemporal distribution of an external stimulus with a soft substrate [1]. The flexible e-skins for pressure sensing were first introduced for robotic about a decade ago [2]. Recently, e-skins have evolved to wearable or skin-attachable electronic devices for electrocardiograph signal measurement [3] [4], and muscle movement during speech [5]. To achieve high flexibility in sensing devices, various fabrication methods are available by structure design. Zhenan Bao et al. [6] demonstrated highly sensitive flexible pressure sensors with micro-structural rubber dielectric layers by copy inverted pyramid structure by electronic engraving. In addition, nano-interlocking structures of high-aspect-ratio Pt-coated polymeric nanofibres have been proposed by Kahp-Yang Suh et al. [3] as a high-sensitivity element to detect pressure, shear and torsion. Recently, another notable achievement for e-skin demonstrated by Ting Zhang et al. [5] is to copy the micro-structure of silk for electrode micro-structure. Despite the excellent pressure sensing performance have been demonstrated constantly, it is still a grant challenge to fabricate the sensor with good sensitivity in a simple, low energy consuming and cost-effective manner.

In this paper, an artful method was used to fabricate the electrode by duplicating the microstructure of photo paper. The sensitivity of the sensor as well as the micro-structure of the electrodes was compared and studied.

Experiment section

Synthesis of silver nanowires. AgNWs with a diameter of about 100 nm and a length of about 3~30 μ m were synthesized by polyol process [7]. 3g PVP (Mw =10000~70000, AR, Sinopharm Chemical Reagent Company) was dissolved in 240 ml EG (AR, Sinopharm Chemical Reagent Company) with moderate stirring and heated to 160 $^{\circ}$ C until the temperature was stable. Then 480 ml of 0.2 M NaCl (AR, Tianjing GuangFu Technology Company) was added into the flask. After one minute, 10ml EG solution containing 3.1g of AgNO₃ (AR, Beijing Chemical Works) was added to the flask by pipette. Once the reaction solution began to become hoar white with glittering, the reaction was stopped immediately. The obtained AgNWs were washed with acetone (AR, Beijing Chemical Works) and deionized water three times to remove the PVP residue. AgNWs were collected and dispersed into an ethyl alcohol (AR, Beijing Chemical Works). Silver nanowires were characterized by SEM (Hitachi New Generation Cold Field Emission SEM SU8020) and ultraviolet and visible spectrophotometer (UV-2501PC).

Pressure Sensors Fabrication and Measurements. Silver nanowire ink with 15 wt.% were coated by two methods as following: First method, AgNWs ink was coated on the photographic paper using automatic coating machine (ZAA 2300) with number 8 Mayer rod at 50mm/s (Fig. 1a). Second method, AgNWs were formed percolation network film by vacuum filtration, which was then transferred to the glass substrates by applying uniform suction pressure [Fig. 1b]. When the AgNWs films were dry at room temperature, the PDMS prepared using Sylgard184 (Dow coning) by mixing the “base” and the “curing agent” with a ratio of 10:1 were coated onto target substrate, afterwards, the AgNWs film with liquid PDMS were cured at 70 $^{\circ}$ C for 2 h. At last, the cured AgNWs/PDMS was peeled off substrate. The AgNWs/PDMS film was cut to 1 $\times$ 2cm² as electrodes of pressure sensor. The AgNWs/PDMS electrodes were superposed face to face and the PI with a thickness of 30 μ m was packaged between two electrodes as dielectric layer. The structural representation of pressure sensor was showed in Fig. 1c. Force gauge (Handpi Digital force gauge, HP-5) were used to apply the external pressure. The digital capacitance multimeter (VICTOR6013) was used to measure capacitance.

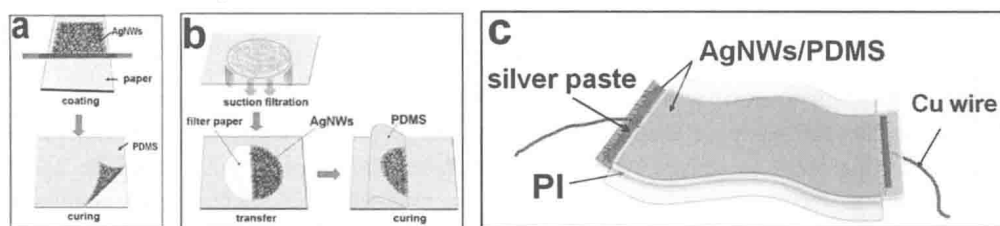


Fig.1 Fabrication process of electrode (a) coating the Ag NWs on photographic paper followed by in situ PDMS curing (b) suction filtration of the Ag NWs suspension followed by glass slide transfer and PDMS curing (c) structural representation of pressure sensor

Results and discussion

The pressure sensitivity can be defined as the slope of the traces in Fig.3, and the sensitivity

formula $S_p = \frac{\delta(\frac{C}{C_0})}{\delta p} = \frac{\delta(\frac{C-C_0}{C_0})}{\delta p}$; $C = \frac{\epsilon_0 \epsilon_r A}{d}$, where p denotes the applied pressure, and C and C_0

denote the capacitances with and without applied pressure, respectively. The pressure sensitivity of sensor made by the paper substrate electrode was substantially higher than that made by glass substrate. In the <400Pa pressure range, the sensitivity of sensor made by paper substrate was

0.65kPa^{-1} , it can detect an ultrasmall weight such as a water-drop (20 mg) onto sensor. $>400\text{Pa}$ showed a sensitivity of 0.33kPa^{-1} , while the sensitivity of sensor made by glass substrate showed a low sensitivity of 0.06kPa^{-1} in the $>50\text{Pa}$.

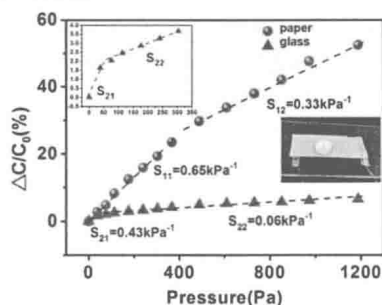


Fig. 3 Pressure-response curves for two types of micro-structured electrode films

The dramatic difference of the sensitivity with two different fabricate methods can be attributed to the micro-structure of AgNWs/PDMS electrodes. The micro-structures of electrode with two methods were showed in the SEM images (Fig. 4). In the process of coating, the overlap joint of AgNWs on photographic paper were fluffy showed in Fig. 4(a), and the AgNWs is tight relatively on glass substrate by suction filtration (Fig. 4d). After curing, the electrode surface peeled off photo paper is loosened, such as the SEM image Fig. 4b and Fig. 4c. But he AgNWs/PDMS surface is flat by the method of suction filtration, such as Fig. 4e and Fig. 4f.

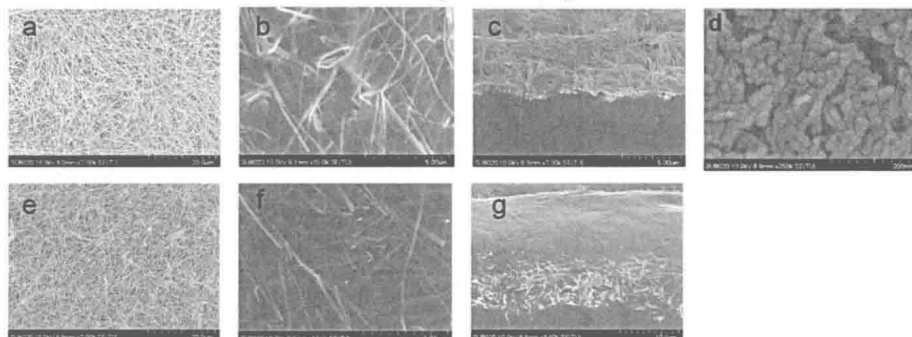


Fig. 4 SEM images (a) the fluffy AgNWs on photographic paper (b) loosened AgNWs/PDMS electrode surface (c) the profile image of electrode by photo paper in situ curing (d) the tight AgNWs on glass substrate by suction filtration (e) flat AgNWs/PDMS electrode surface (f) the profile image of electrode by suction filtration transfer curing (g) SEM image of micro-porous resin coated photo paper

The different micro-structure of electrode can be attributed to different curing substrate. The micro-porous resin coated photographic paper has micro-porous ink receiver layer, as illustrated in Fig. 4g. The AgNWs and PDMS can permeate through micro-porous, causing the uneven surface of electrode. While the glass substrate is even and the AgNWs also become tight by uniform suction pressure when suction filtration, which causing the even surface of electrode.

The loosened AgNWs/PDMS electrode surface can store a mass of air, when exert external pressure, the air was discharged, which has a lower dielectric constant ($\epsilon=1$) than PI ($\epsilon=3.0-3.5$). Therefore, the increase in capacitance of uneven electrode arises from the reduction in the distance between the two electrode plates, and is enhanced further by the increase in effective dielectric constant. Hence, the sensitivity of sensor with loosened electrode surface is higher than that with flat electrode.

Summary

We have developed a novel fabrication method of flexible sensor with micro-structured electrode molded by micro-porous photo paper. The roughness of the electrode based on AgNWs/PDMS micro-structure plays an important role in the sensitivity of sensor. In this paper, the fabricated pressure sensor demonstrates a high sensitivity of 0.65kPa^{-1} and can detect tiny pressure as low as 20 mg, which has great potential in the detection of pulse, heart rate, sound vibration and other tiny pressure.

Acknowledgements

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