Micro/nano and precision manufacturing technologies and applications

Dazhi Wang

School of Mechanical Engineering
Dalian University of Technology

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Outline

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  - Cross-scale manufacturing technology
  - E-Jet micro/nano print-patterning
  - Ultra precision grinding and chemical mechanical polishing technologies
Research background

Made in China 2025

Premier Li Keqiang advanced the "Made in China 2025" concept in his Government Work Report.

The major areas include:

- Biomedicine and high-performance medical apparatus
- Information technology
- Aerospace and aviation equipment
- Advanced rail equipment
- ..................

Manufacturing of high-performance parts and devices play an important role.
Research challenges of high-performance parts and devices

- The size has been decreased to micro- and nano-scale.
- The shape and structure become more complex and precise.
- The machining accuracy has been improved continuously.
- The material scope has been increased continuously.

It is difficult to satisfy the requirements of these parts and devices using conventional manufacturing technologies.
Research progress

- Cross-scale manufacturing technology
- E-Jet micro/nano print-patterning
- Ultra precision grinding and chemical mechanical polishing technologies
Microfluidic chips have broad application prospects in rapid diagnosis of major diseases and personalized medicine.

Micro-nano cross-scale structure and nano-structure are needed for special function such as filtering, block flowing.

Key difficulties

Controllable manufacturing of micro-nano cross-scale structure and special area nano-structure.

Genome mapping on nanofluidic chips (Nature Biotechnology, 2012)
Cross-scale manufacturing technology

- A composited fabrication method based on plasma etching and nanoparticle assembly was proposed.
- Microchannel, nanochannel and modified biological sample were integrated fabricated.
- A high quality nanofluidic sensing of biotin was achieved, the concentration of 1 aM can be detected.

Fabrication of nanochannels and Ag microelectrodes

Layout of the NPC-based nanofluidic biosensor

Micro- and nano-channel and test result

Biosensors and Bioelectronic, 2015
Cross-scale manufacturing technology

- An integration of hot embossing and inverse UV photolithography is developed to fabricate micro and nanochannels.
- A complete SU-8 nanofluidic chip was fabricated with a replication precision of 99.5%.

Process flow of the 2D nano-mold fabrication

SU-8 micro and nanochannels fabrication

130 nm wide, 150 nm high, 4 mm long
Cross-scale manufacturing technology

- A controllable fabrication of nanopores based on photopolymerization was proposed.
- Microfluidic chips with high density nanopore array at specific area was realized.

Glass micro-nanofluidic chips integrated with nano gel structure

Photosensitive polymerization based on an inverted fluorescent microscope

AC Impedance of different nanopores

Enrichment ratio of fluorescence ions is 600

*Applied Physics Letters, 2014*
Cross-scale manufacturing technology

Disease diagnosis microfluidic chips

- Cooperated with CapitalBio Corporation, detection of respiratory tract bacteria.
- Simultaneously detect 13 kinds of bacteria, detecting time reduced from 2 days to 3 hours, it is in clinical test now.

![24-channel radial microchip](image1)
![Isothermal amplification & real-time fluorescent detector](image2)
E-Jet micro/nano print-patterning

- Multi-layer composite element commonly exists in MEMS devices, which are widely used in energy, information, medical treatment, etc.
- The performance of multi-layer composite MEMS devices was determined by their material composition and microstructure.

Key difficulties
- Controllable fabrication of material and structural composited fabrication.
E-Jet micro/nano print-patterning

- Print-patterning is an effective way to obtain the material and structural composited fabrication.
- Print-patterning is an additive manufacturing method and has the advantages of no mask, non-contact, no pressure and low cost.
E-Jet micro/nano print-patterning

- Electrohydrodynamic effect was used to develop a new print-patterning technology.
- Electrohydrodynamic jet (E-Jet) print-patterning makes use of electrical and mechanical forces to form a fine liquid jet and droplets.
### Advantages of E-Jet print-patterning

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<th>Description</th>
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<tr>
<td><strong>High resolution</strong></td>
<td>Droplet diameter can be at nano-scale</td>
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<tr>
<td><strong>Low requirement of needle and ink</strong></td>
<td>Droplet size is much smaller than needle size: less than 1/100</td>
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<td><strong>Strong controllability</strong></td>
<td>Droplets are charged</td>
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<td><strong>Suitable for different substrates</strong></td>
<td>Non-contact patterning</td>
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![Diagram of E-Jet print-patterning process](image)
A layer-by-layer nano structure deposition method based on E-Jet was proposed.

Material and structural composited fabrication with nano-scale layers were achieved.

E-Jet deposition process

Modeling of E-Jet deposition

Porosity prediction equation

Deposition of catalyst layers with different porosity
E-Jet micro/nano print-patterning

- Template-assisted E-Jet deposition method combined with embossing sacrificial layer technology was developed.
- Complex microstructures with high side wall angle and high aspect ratio were achieved.

Template-assisted E-Jet deposition process

Patterned PZT thick film structures

Patterned graphene structures

A point focus electrode was used in E-Jet printing, which enabled the printing of structure in micro-scale resolution.
E-Jet micro/nano print-patterning

Micro fuel cell: integrated MEA

- An integrated MEA was developed, the common delamination problem was solved, and the reliability of the device was improved.
- The catalyst layer with material and structure gradient variation was developed, the catalyst utilization was improved.

Gas-liquid two-phase model

Mass transferring process

Modeling of cell performance

Integrated MEA after life test

Structure of integrated MEA

Cell performance test

J. Power Sources, 2013, Fuel cells, 2014
Annular array high frequency piezoelectric ultrasonic transducer was designed and developed, which achieved a working frequency of 70 MHz.
Ultra precision grinding and chemical mechanical polishing technologies are widely used for obtaining ultra flat and ultra smooth surface, such as blank wafer flattening, wafer back thinning.

Key difficulties
- large size, nano-scale flatness, sub-nm roughness, low residual stresses and damage-free.
A new ultra precision and low damage grinding technology with soft abrasive grinding wheel was developed.

Ultra smooth and low damage ground surface wafer was produced.

- Damage depth: 170nm, Ra = 3.8nm
- Damage depth: 10nm, Ra = 0.7nm

Developed SAGW

Grinding mechanism of SAGW
Ultra precision grinding and chemical mechanical polishing technologies

- A full-automatic grinder was developed for 300 mm wafer.
- A ultra precision wafer grinding-polishing machine was developed.

The first automatic ultra precision grinding machine for 300 mm wafer grinding in China

Silicon wafer  Sapphire wafer  SiC window  Optical window

Principle and process of back thinning integrated grinding and polishing for wafer with outer rim

Thinned wafer thickness < 50μm, Ra < 5nm
Ultra precision grinding and chemical mechanical polishing technologies

- KDP is soft-brittle, temperature sensitive, dissolved in water, which is a difficult-to-machine material.
- Abrasive-free polishing slurry with water molecular cluster was developed.
- Ultra smooth and damage-free surface was obtained using micro water-dissolution and mechanical action of polishing pad.

Developed polishing slurry

Water-dissolution polishing surface

Natural dissolution
Summary

- Micro-nano cross-scale manufacturing technologies were introduced, microfluidic chips for disease diagnosis and biosensing were produced.

- E-Jet micro/nano print-patterning technique and equipment were developed, which enables the material and structural composited manufacturing at micro/nano scale.

- Ultra precision grinding and chemical mechanical polishing technologies were introduced, ultra smooth and low damage surface wafer was produced.
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