# Low Temperature Bonding by using Nanoporous Gold

Dr. Wei-Shan Wang
Department System Packaging
Fraunhofer Institute for Electronic Nano Systems ENAS

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ENAS

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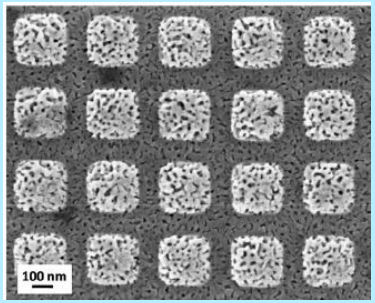
# Outline

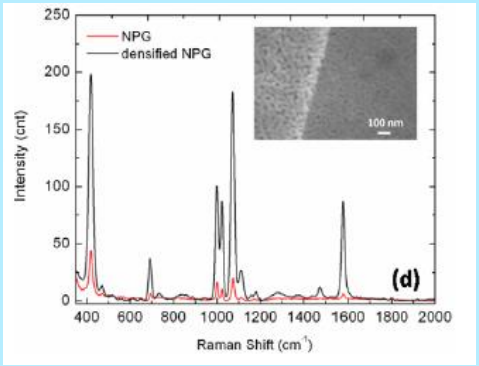
- Introduction of nanoporous metals
- Low temperature bonding by using nanoporous gold
  - Substrate bonding at low temperature
  - Substrate bonding by using plasma-activated porous gold
  - heterogeneous bonding
- Summary and outlook

# Nanostructured Metals

highly active surface area ⇨ sensors, actuators, catalysis, packaging…

## As SERS Template



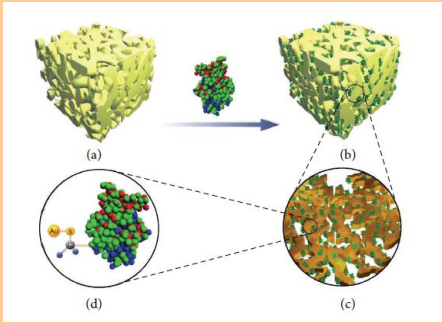




SERS spectra of benzenethiol molecules

*Nanotechnology* **22**, 295302, 2011

SERS: surface-enhancement Raman scattering

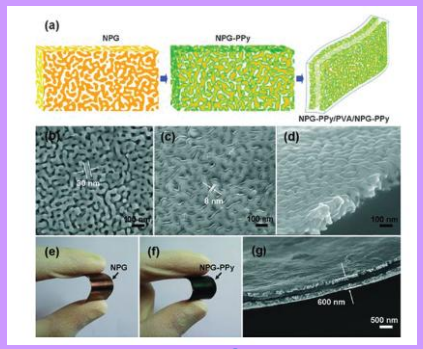
## Enzyme-Based Biosensors




Adsorption of lacease on nanoporous Au

*J. Phys. Chem. C* **112**, 14781, 2008

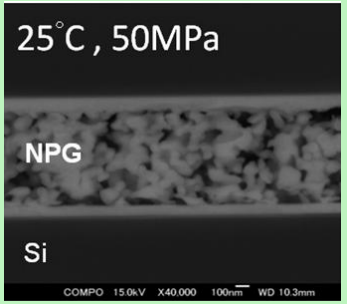
## Energy systems




Nanoporous Au for supercapacitors

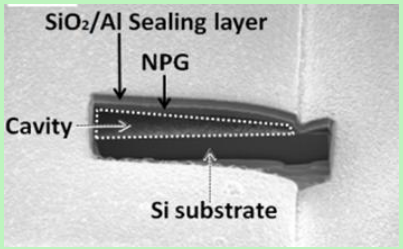
*Adv. Mater.* ***23***, 4098, 2011

## Packaging Applications




Low temperature bonding

*2012 IEEE Sensors*, 355, 2012




Thin film encapsulation

*J. Microelec Sys.* **12**, 998, 2013



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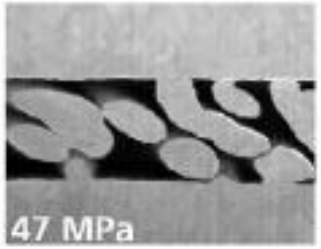
# Bonding by using Nanostructured Metals

## Nano-lawn Au

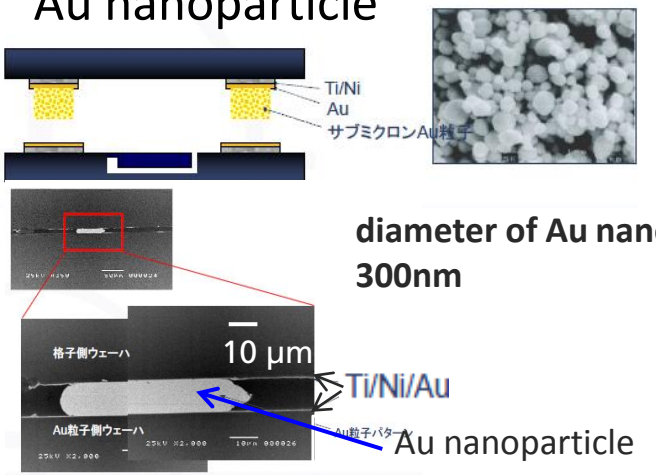



**wire diameter 600nm,**

**length 1-5 microns**

S. Fiedler et al., *IEEE Electron Systeminte.Tech. conference, 886, 2006.*

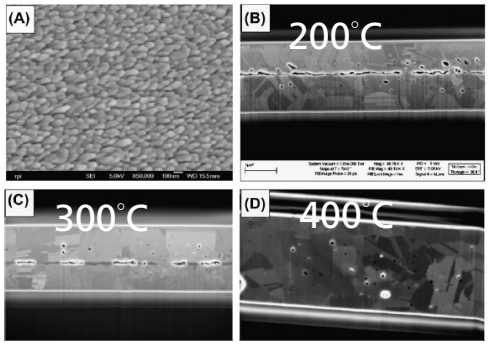
## Au nanoparticle




**diameter of Au nanoparticle: 300nm**

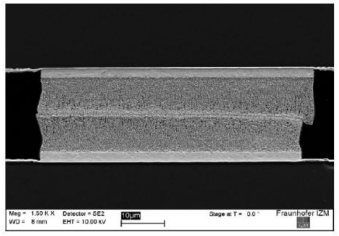
Tanakakikinzoku Kogyo K.K. www.tanaka.co.jp

## Copper nanorod array




P.I. Wang et.al., Electrochemical and Solid-State Letters, 12 4 H138-H141 2009 . (Rensselaer Polytechnic Institute, USA)

## Nanoporous Au bump



H. Oppermann and L. Dietrich, *Microelectronics Reliability* 52, 356, 2012



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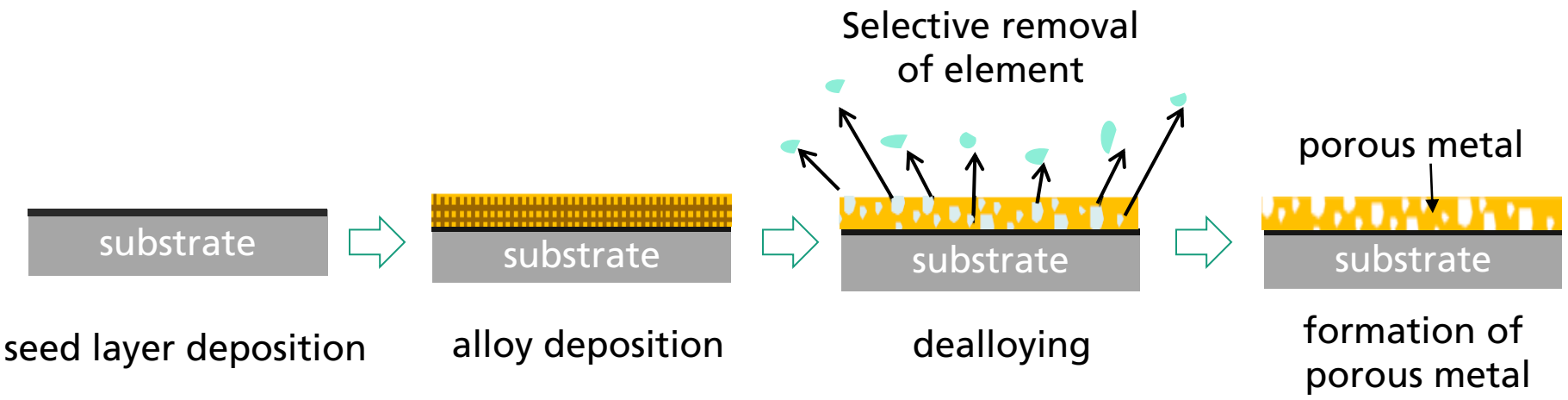
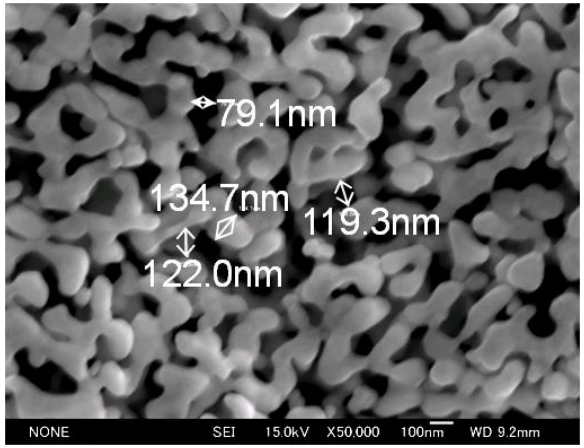
# Our Approach-- Fabrication of NPG by Dealloying

- Easy fabrication
- MEMS compatible process
- Non-cyanide single bath

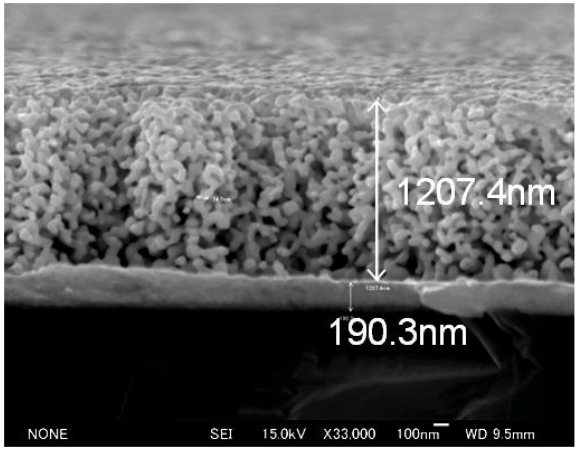


# Structure of Nanoporous Gold

Top view

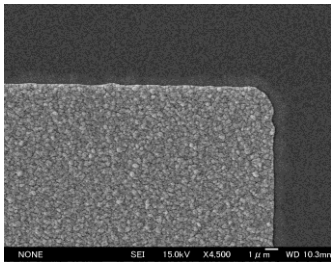


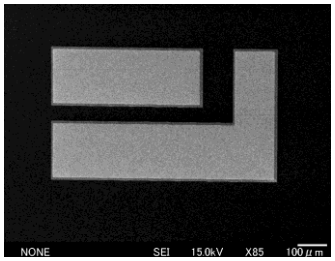

Cross section

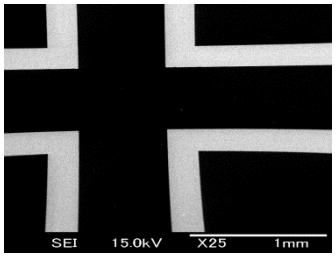



- **thickness:**
  from hundreds of nm up to several µm
- **porous size:**
  around 100nm
- **ligament size:**
  up to 100nm

Patterned porous Au








- **pad width:**
  40~700µm
- **frame width:**
  100~500µm



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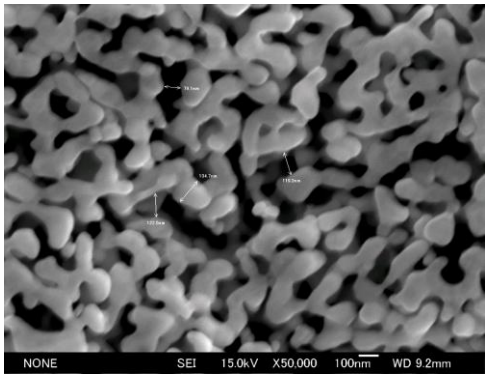
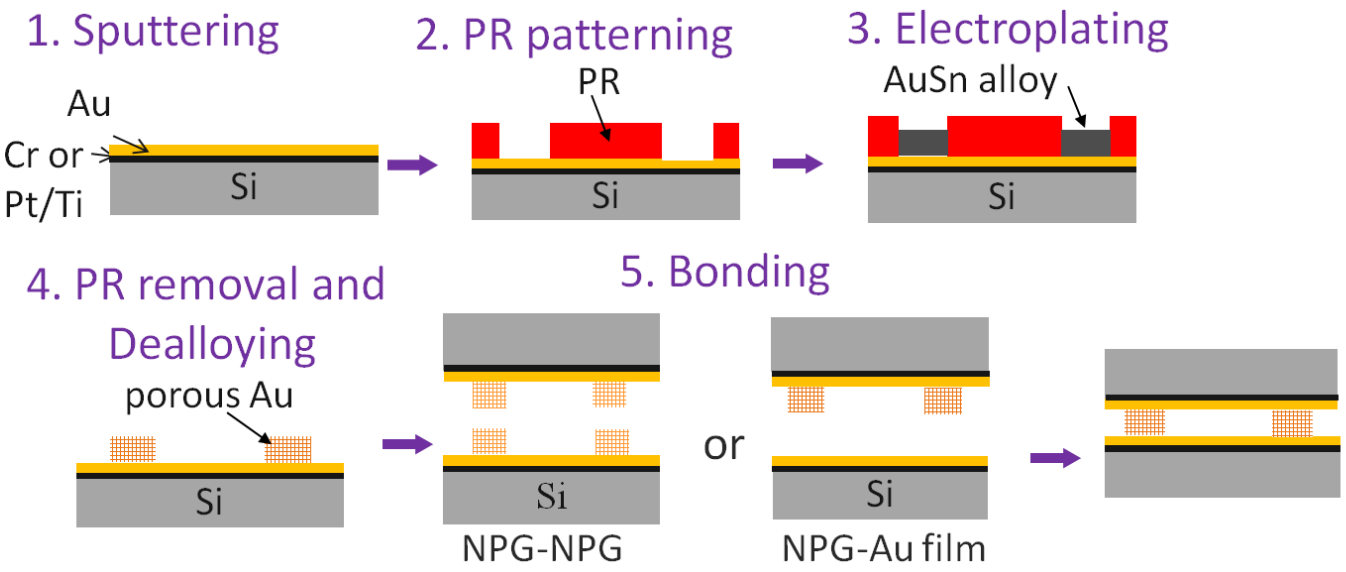
# Concept of using Porous Au for Bonding

- High surface to volume ratio
- Low temperature bonding (thermalcompression)
- Electrical inter-connection achieved during bonding
- Sponge-like compressibility, tolerate implanarities



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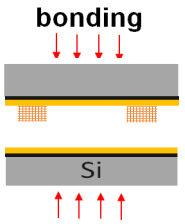
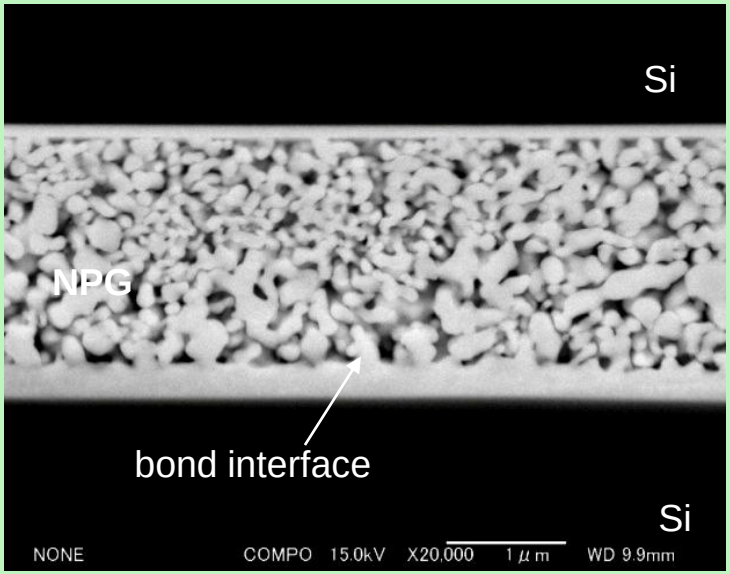
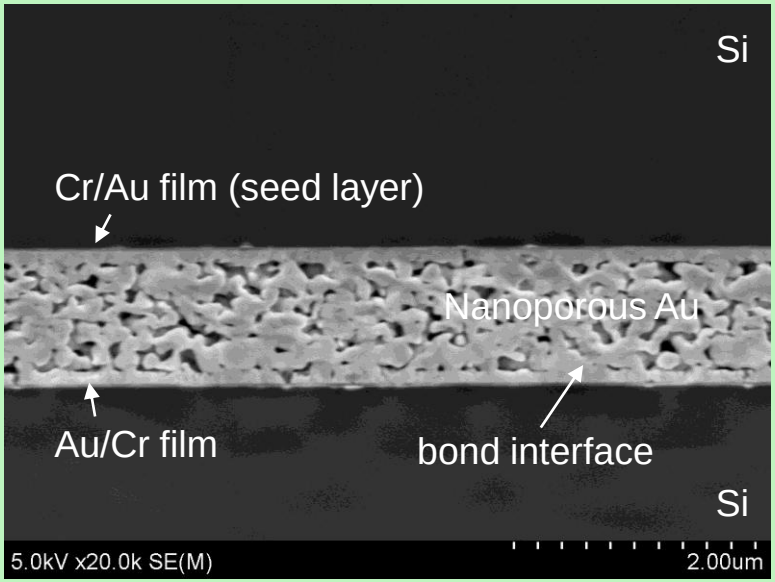
# Substrate bonding by using NPG




- bonding temperature below 250°C achieved

| 200°C, 50MPa | 250°C, 50MPa |
|---|---|
|  |  |
| ▪~1.5µm-thick nanoporous gold<br>▪200 nm-thick Au film<br>▪Bonding in vacuum | ▪~1µm-thick nanoporous gold<br>▪200 nm-thick Au film<br>▪Bonding in vacuum |





W.-S. Wang et. al., Substrate Bonding at Low Temperature by using Plasma Activated Porous Gold, 335, IEEE Sensors 2012



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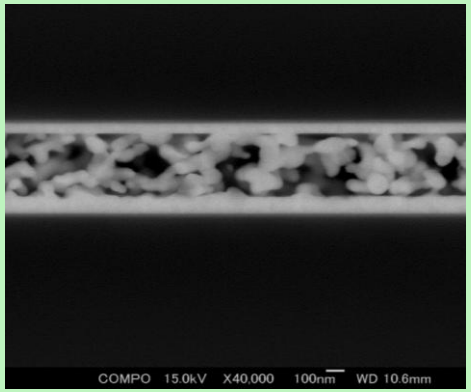
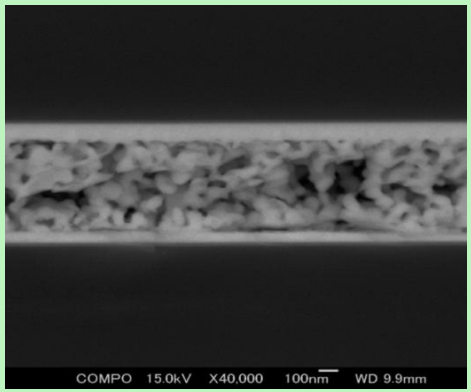
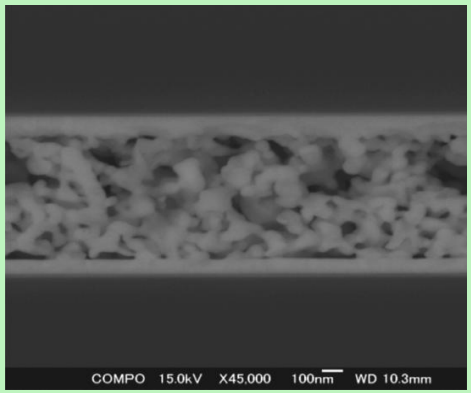
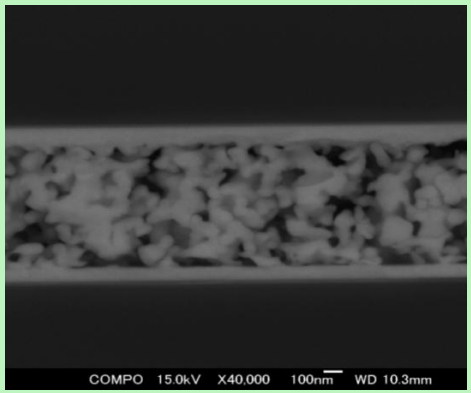
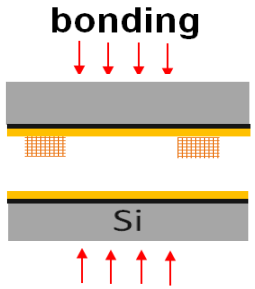
# Substrate bonding by using plasma-activated NPG

- bonded at room temperature with plasma-activated NPG

| 150°C, 50MPa | 100°C, 50MPa |
|---|---|
|  |  |
| 50°C, 50MPa | 25°C, 50MPa |
|  |  |






- **NPG thickness:**

  400-800nm, flexible thickness control for bonding

- **Au thin film:**

  200nm

- **Bonding condition:**

  in ambient air



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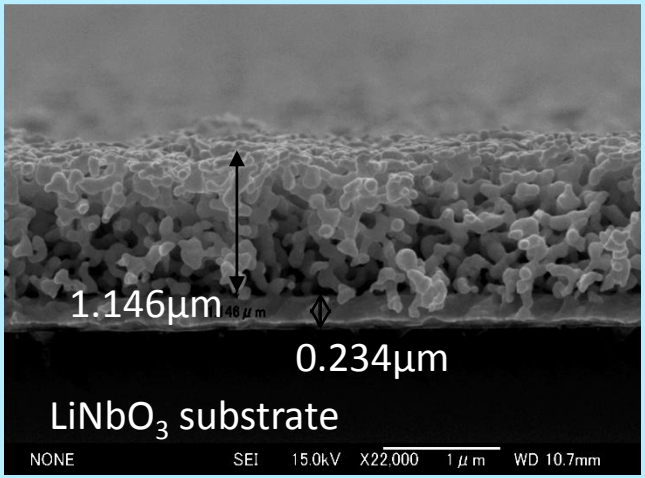
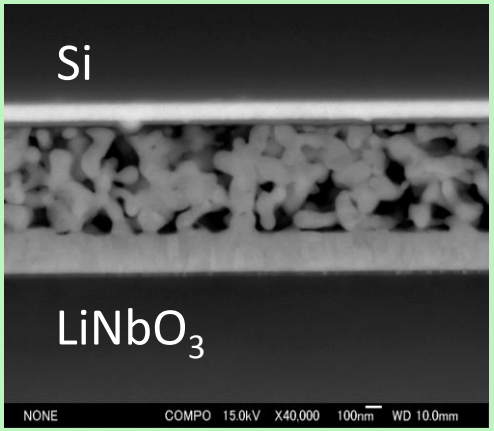
# Heterogeneous bonding by using NPG



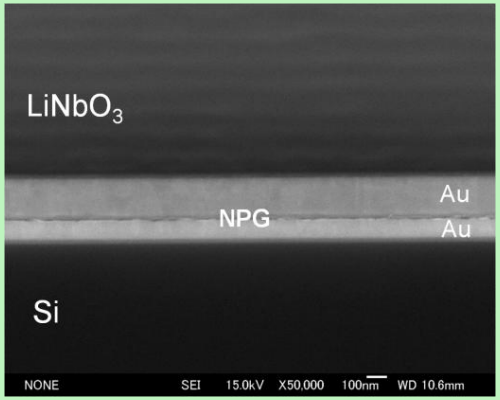

- NPG fabrication on various substrates possible ($Si$, $LiNbO_3$, glass,..)
- Various pad sizes ( width 40µm-700µm)
- Various NPG thickness

## Si-$LiNbO_3$ bonding with NPG layer




- 700 nm-thick NPG
- 100nm-thick Au film
- bonding temperature: 200° C
- bonding pressure: 50 MPa
- without plasma treatment

## Si-$LiNbO_3$ bonding with ultra-thin NPG layer




- several tens of nanometer-NPG
- 100nm-thick Au film
- bonding temperature: 190° C
- bonding pressure: 50 MPa
- without plasma treatment

# Cooperation - special strengths

## JAPAN (Sendai)

### Prototype

- Provide key components to systems
- Pioneer leading-edge research
- Open research environment with plenty of home made equipments
- Process by researchers: flexible & novel

## GERMANY (Chemnitz)

### Wafer level

- Smart system integration and reliability
- In preparation for industrially mass production and back end of line
- Latest commercialized equipments including class 10 cleanroom
- Process by technician: professional & stable

Innovation

Application

# Summary and Outlook

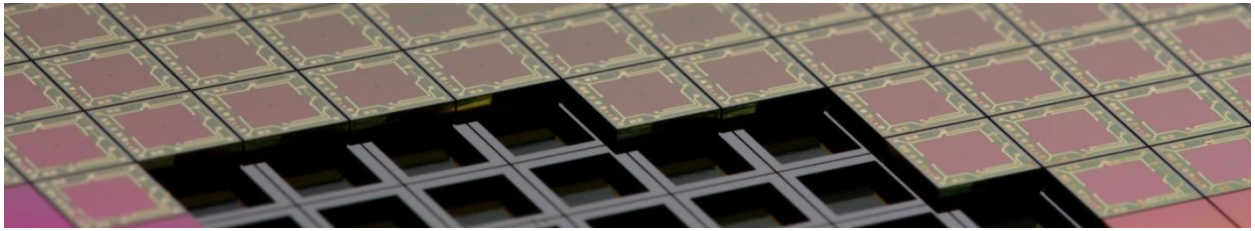
## Characteristics of Nanoporous Gold

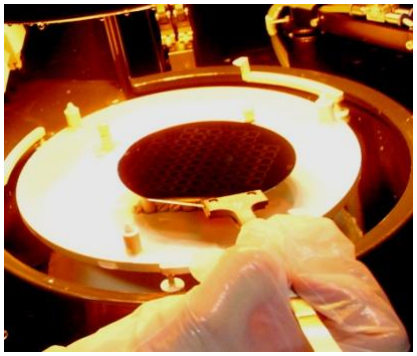
- **MEMS-compatible** fabrication process
- **High surface area**:
  - decrease bonding temperature - down to 200°C or even at room temperature
  - potential candidate for heterogeneous bonding
- **Sponge-like compressibility**:
  - bonding without critical requirements of surface cleanliness and roughness
- **Flexible control of thickness**:
  - bonding achieved regardless of thickness of NPG

## More Possibilities of Nanoporous Metals

- Advanced materials for packaging
- As catalysts for electrochemical applications
- Biosensors, chemical and physical sensors
- Energy storage/conversion systems

# Thank you for your attention





## Contact

Dr. Wei-Shan Wang

Fraunhofer ENAS
Department System Packaging

Mail: wei-shan.wang@enas.fraunhofer.de

Phone: 0371-45001-495

Technologie-Campus-3
09126 Chemnitz
Germany

Fraunhofer ENAS