

# 高真空ウェハレベルパッケージングを 適用したMEMSセンサーの研究開発

事業者 東北大学 マイクロシステム融合研究開発センター  
ソニーセミコンダクタマニュファクチャリング株式会社

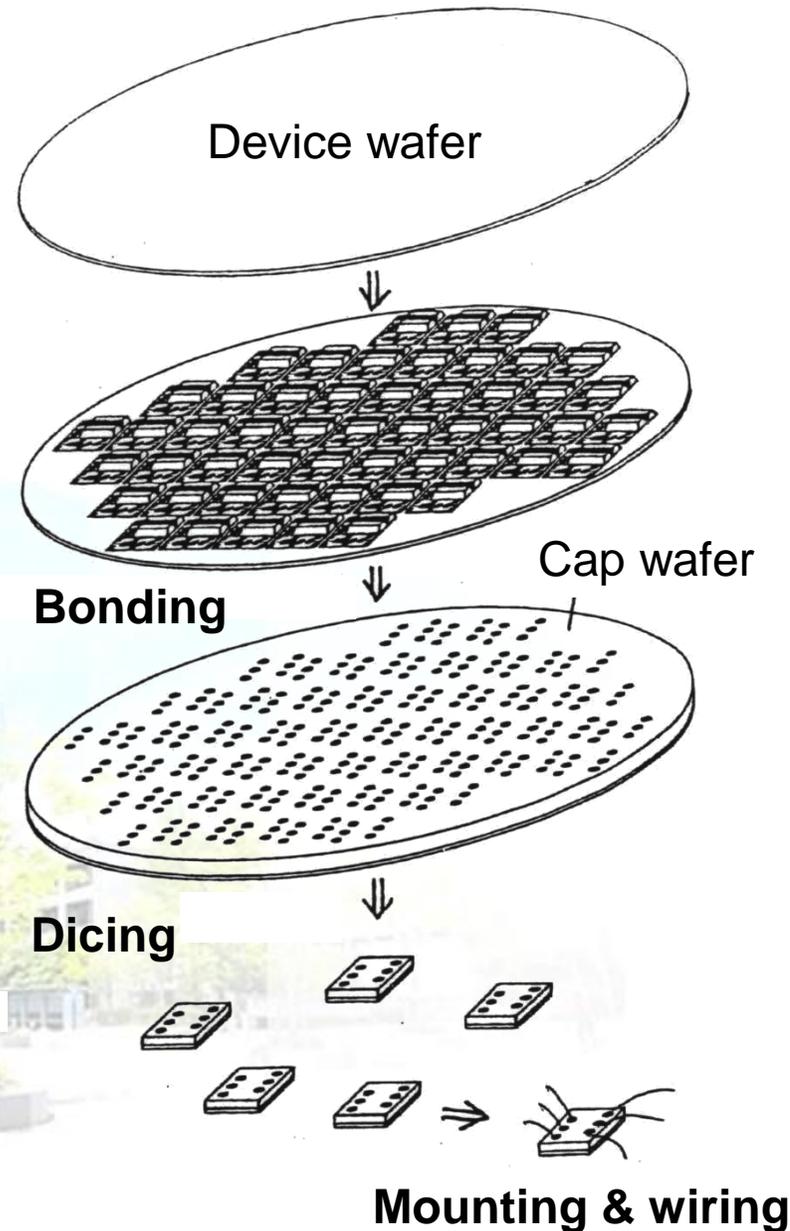
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IEEE Fellow

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# MEMSのウェハ レベルパッケージ ング



MEMS with moving or suspended structures

→ Direct molding with plastics is impossible.

## Wafer-level packaging

→ Small size (Chip-size encapsulation suitable for surface mounting)

→ High yield (Protection of MEMS structures during dicing)

→ High reliability (Hermetic sealing)

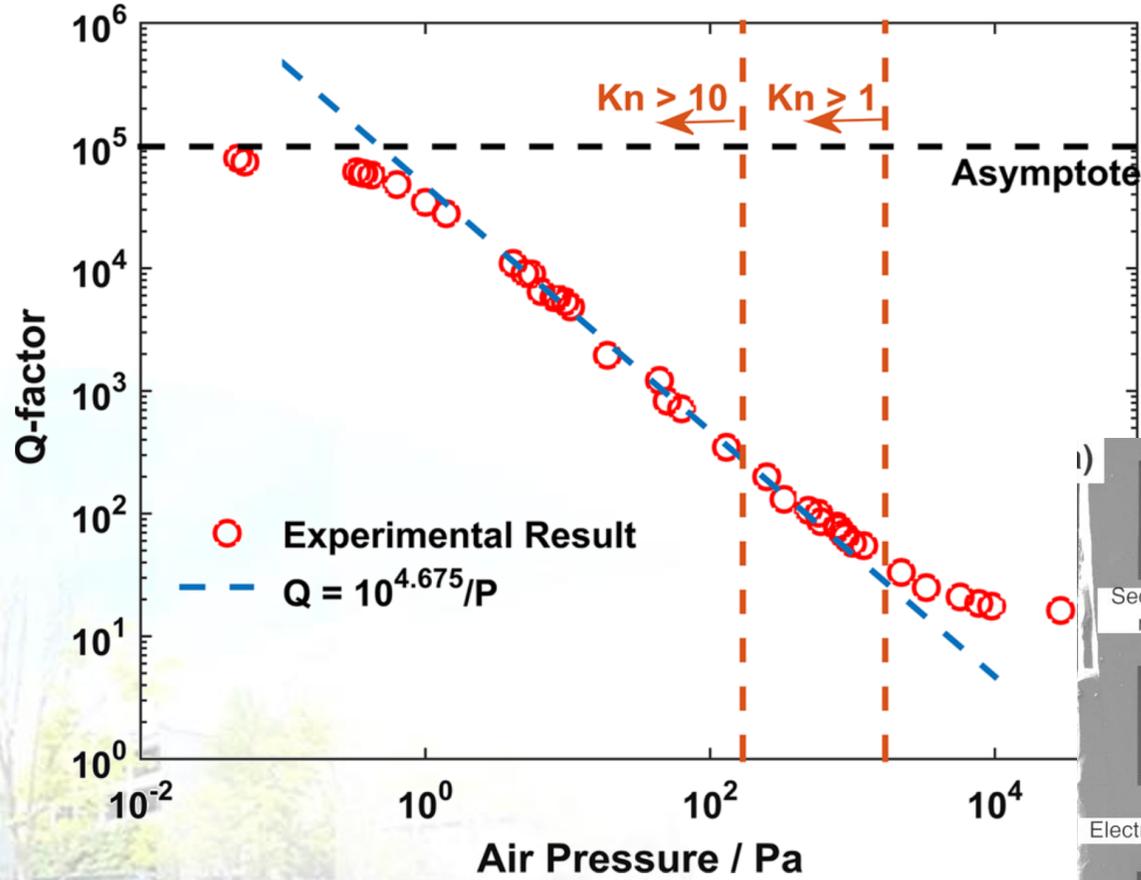
→ Low cost (Minimal investment for assembly, No expensive ceramic packages etc.)

- Hermetic sealing
- Electrical feedthrough
- Vacuum level
- Long term reliability

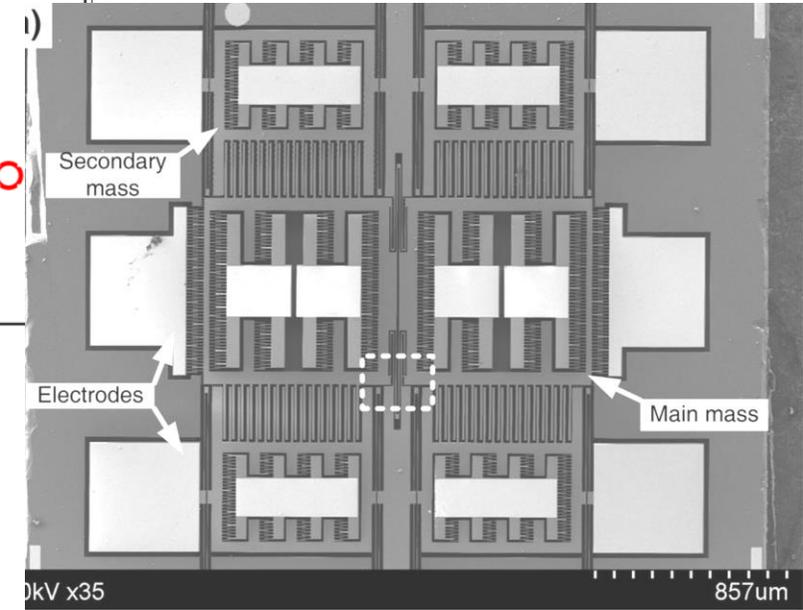


# 封止圧とQ値

Cong Liu *et al.* (Tohoku University), *Microsystem Technologies*, 25, pp. 487-497 (2019)



$$\frac{1}{Q} = \frac{1}{Q_{\text{gas}}} + \frac{1}{Q_{\text{support}}} + \frac{1}{Q_{\text{TED}}} + \dots$$

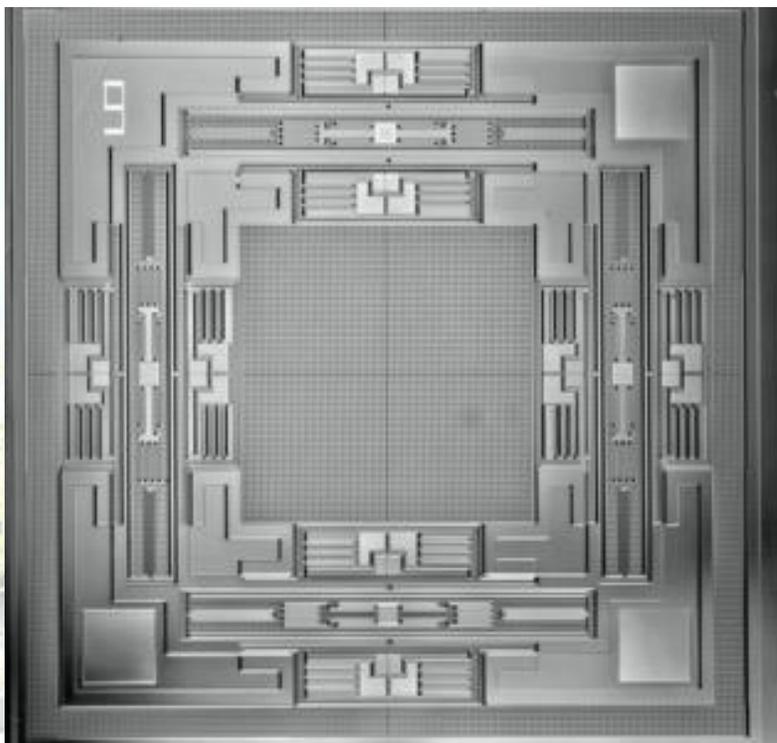
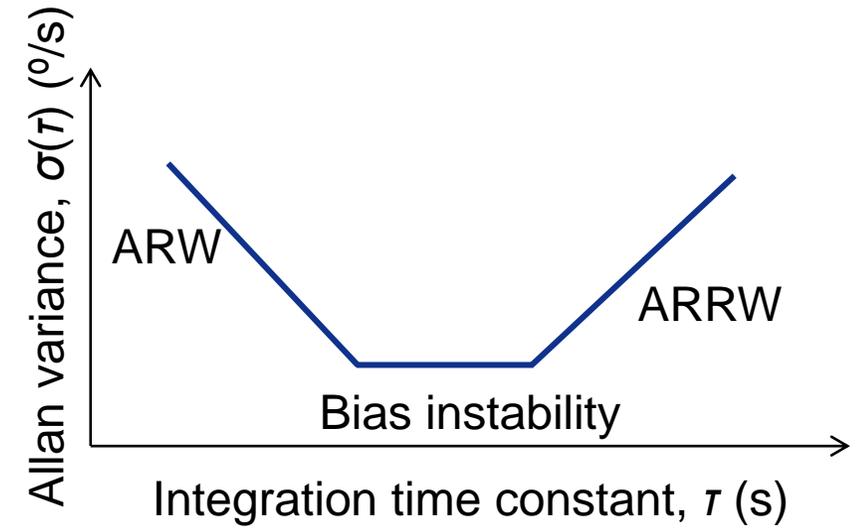


Tuning fork resonator on cavity SOI

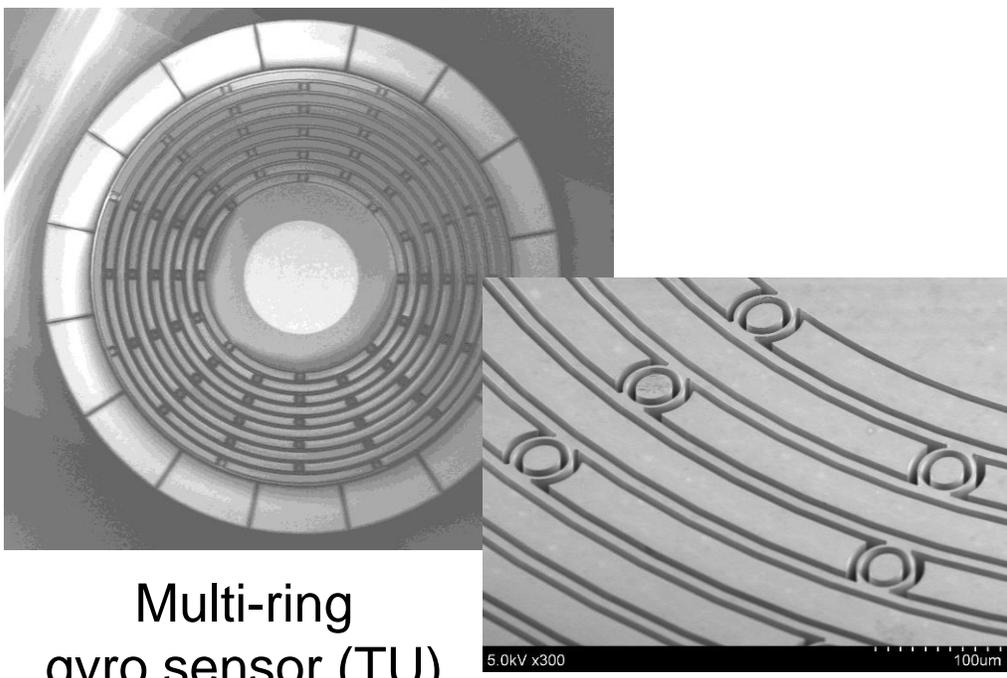
# MEMSジャイロ センサーでのQ値 の重要性

Noise equivalent angular rate

$$\Omega_{\text{noise}} = \frac{1}{k} \sqrt{\frac{k_B T}{m Q_y X_0^2 \omega_x}}$$



Triple-mass gyro sensor (TU)



Multi-ring gyro sensor (TU)

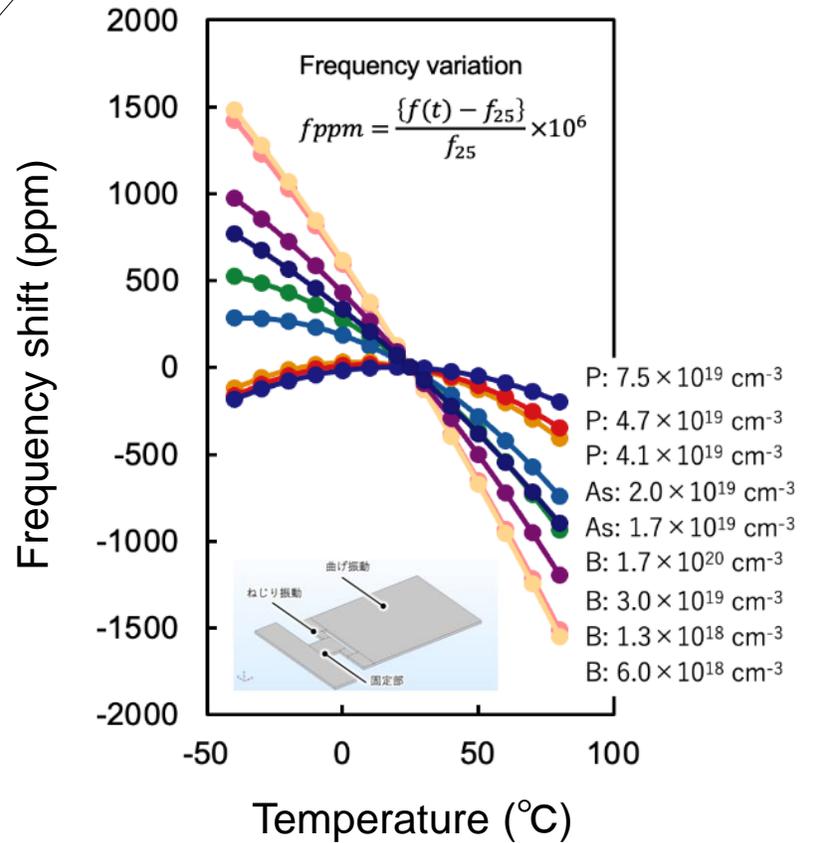
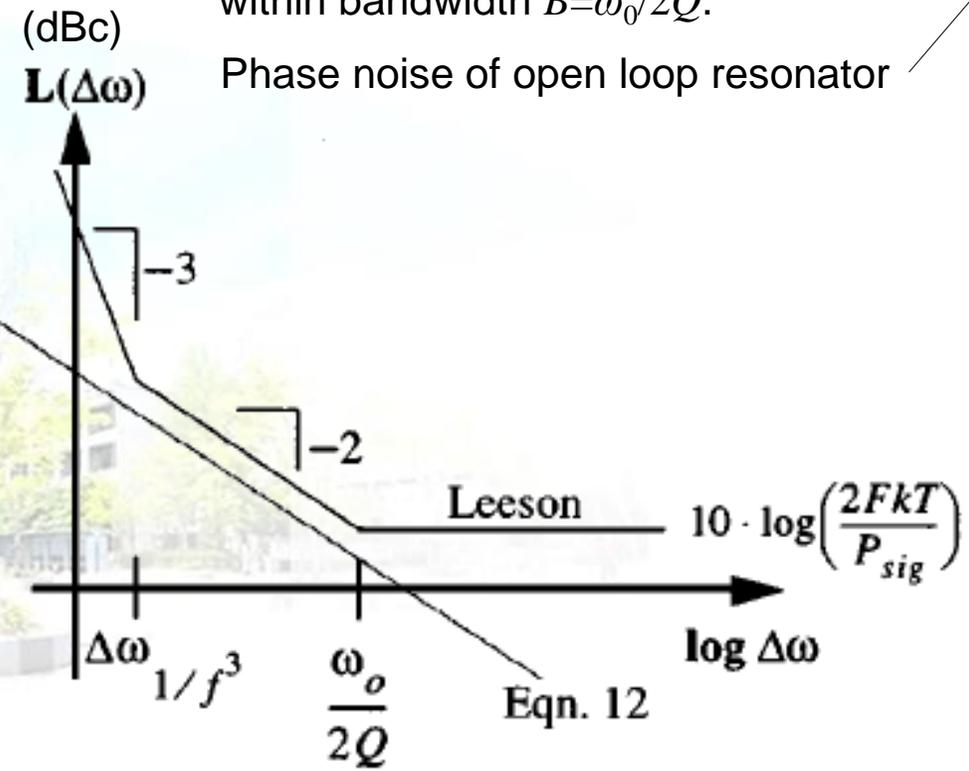
# タイミング共振子でのQ値の重要性

Leeson's equation D. B. Leeson, Proc. IEEE (1966) 329

$$L\{\Delta\omega\} = 10 \log \left[ \frac{2FkT}{P_{sig}} \left\{ 1 + \left( \frac{\omega_0}{2Q\Delta\omega} \right)^2 \right\} \left( 1 + \frac{\Delta\omega_1/f^3}{|\Delta\omega|} \right) \right]$$

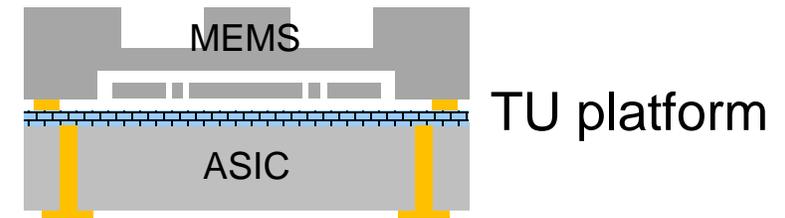
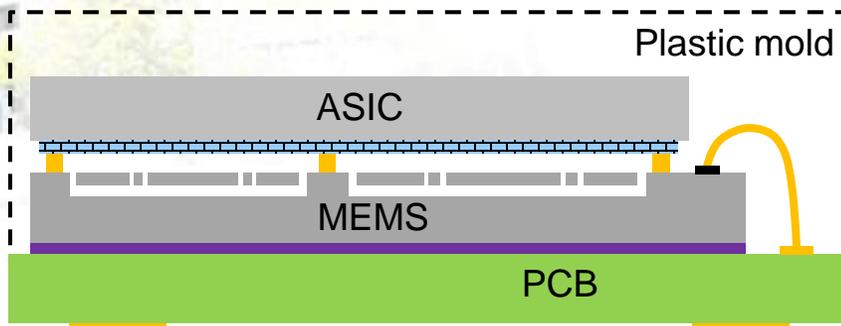
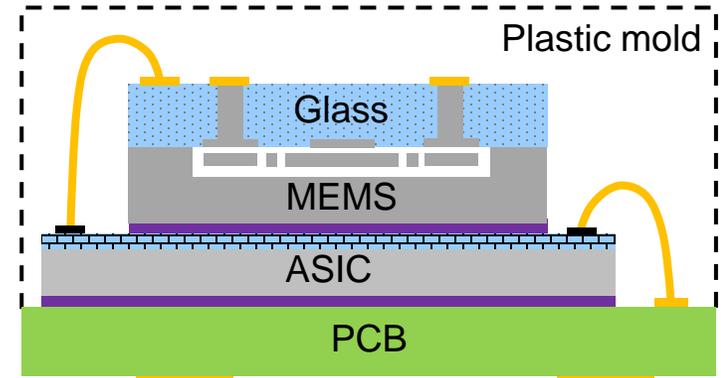
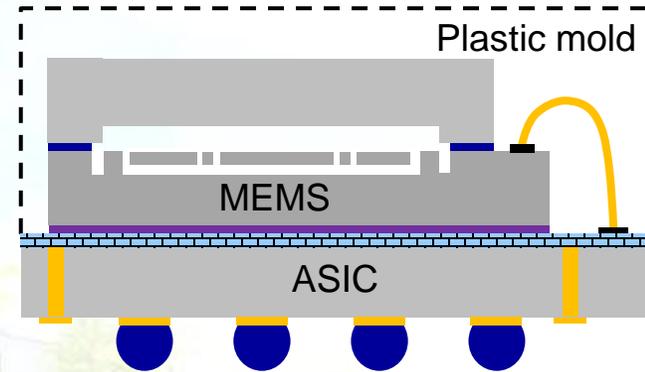
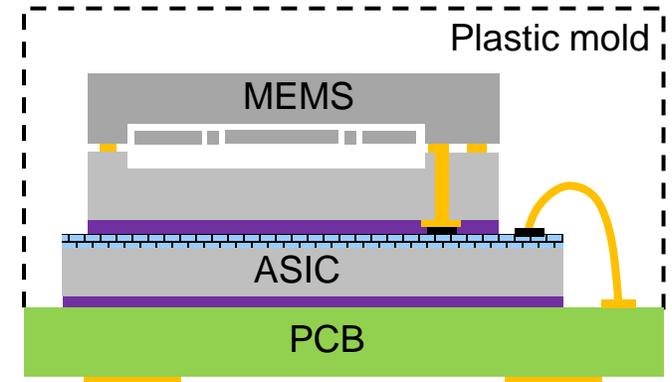
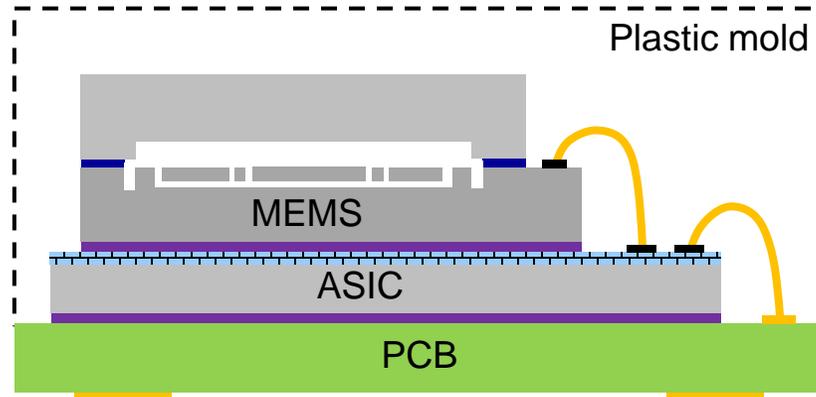
- $\omega_0$  Carrier frequency
- $\Delta\omega$  Offset frequency
- $F$  Noise factor  $\times$  Gain
- $P_{sig}$  Power of amplifier

Closed loop term  
Phase is kept constant by PLL within bandwidth  $B = \omega_0/2Q$ .  
Phase noise of open loop resonator



# 様々なMEMS パッケージング形態

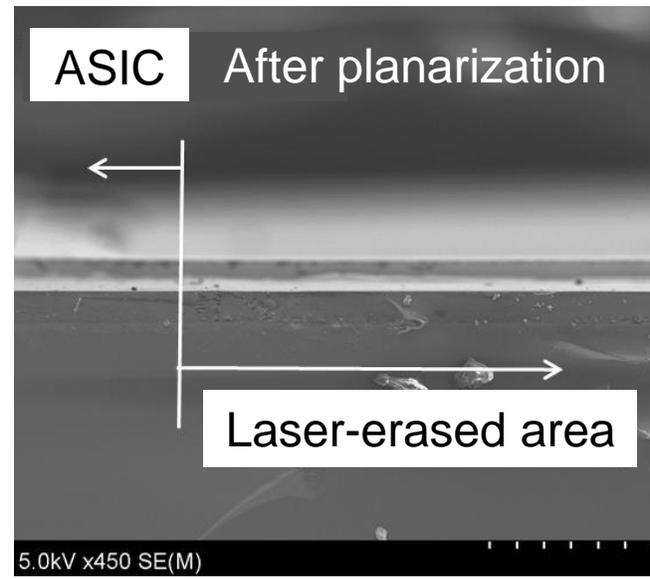
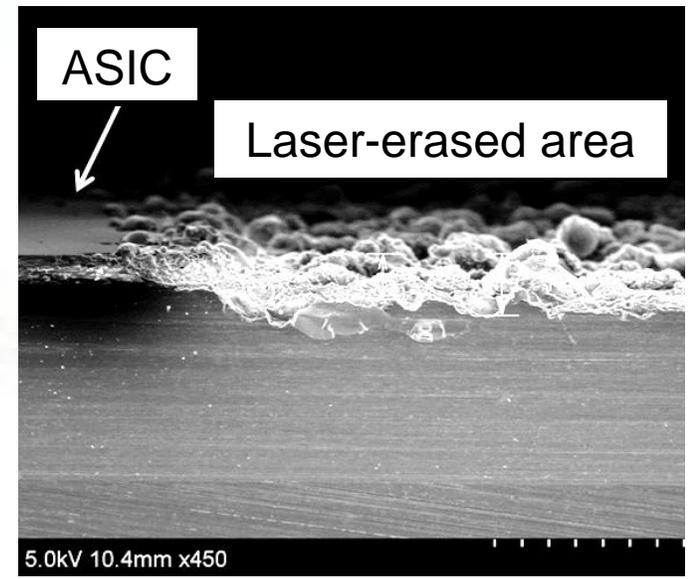
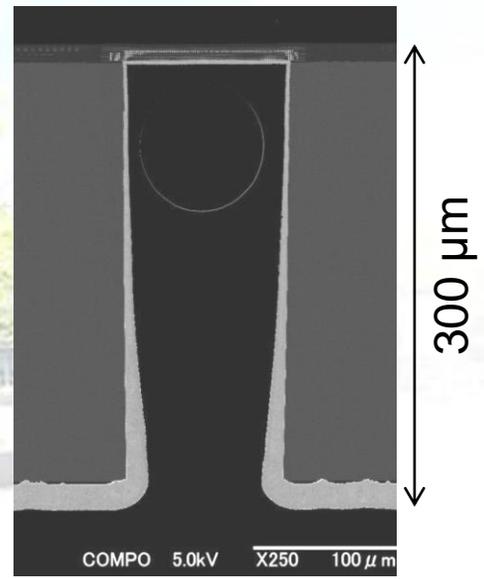
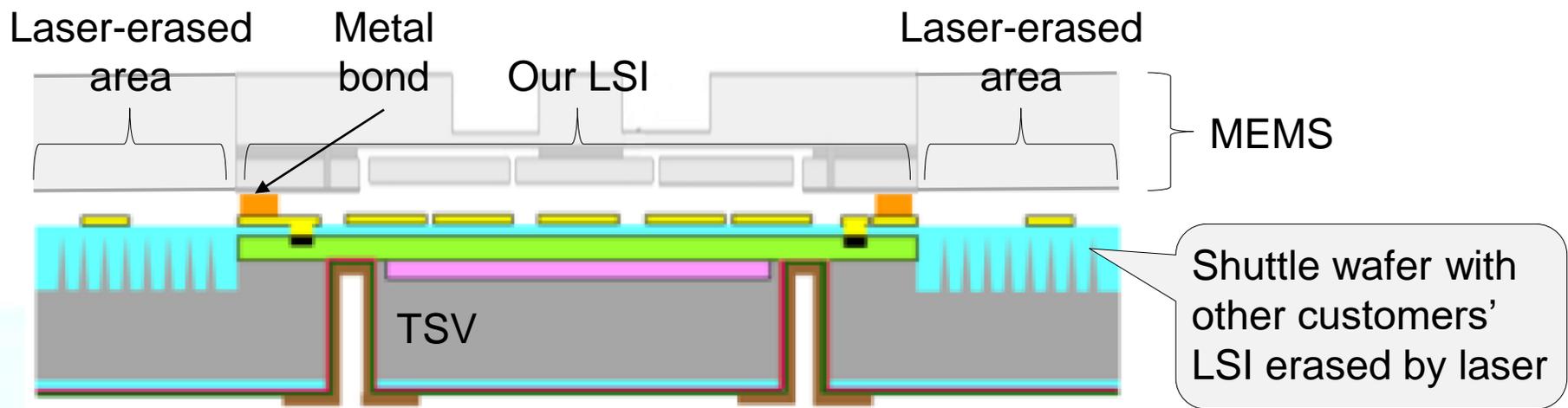
田中, MEMSのウエハーレベルパッケージングの基礎, 日経 xTECH 2020/8/20, 21, 24



# MEMSパッケージ

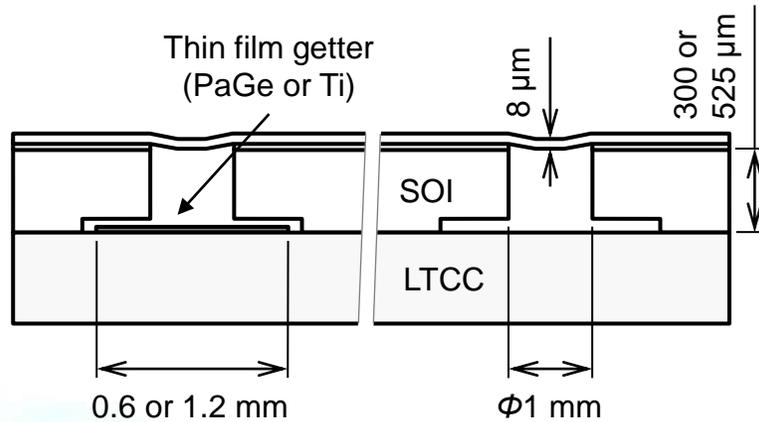
## ジングの一例: 集積化センサー

Yukio Suzuki *et al.*, IEEE MEMS 2017, pp. 744-747  
 日経xTECH, トヨタと東北大が新技術, ロボットセンサーとICを安く積層, 2016/11/2



# ウェハレベル パッケージの内 圧

S. Tanaka, H. Fukushi (Tohoku University), Transducers 2015

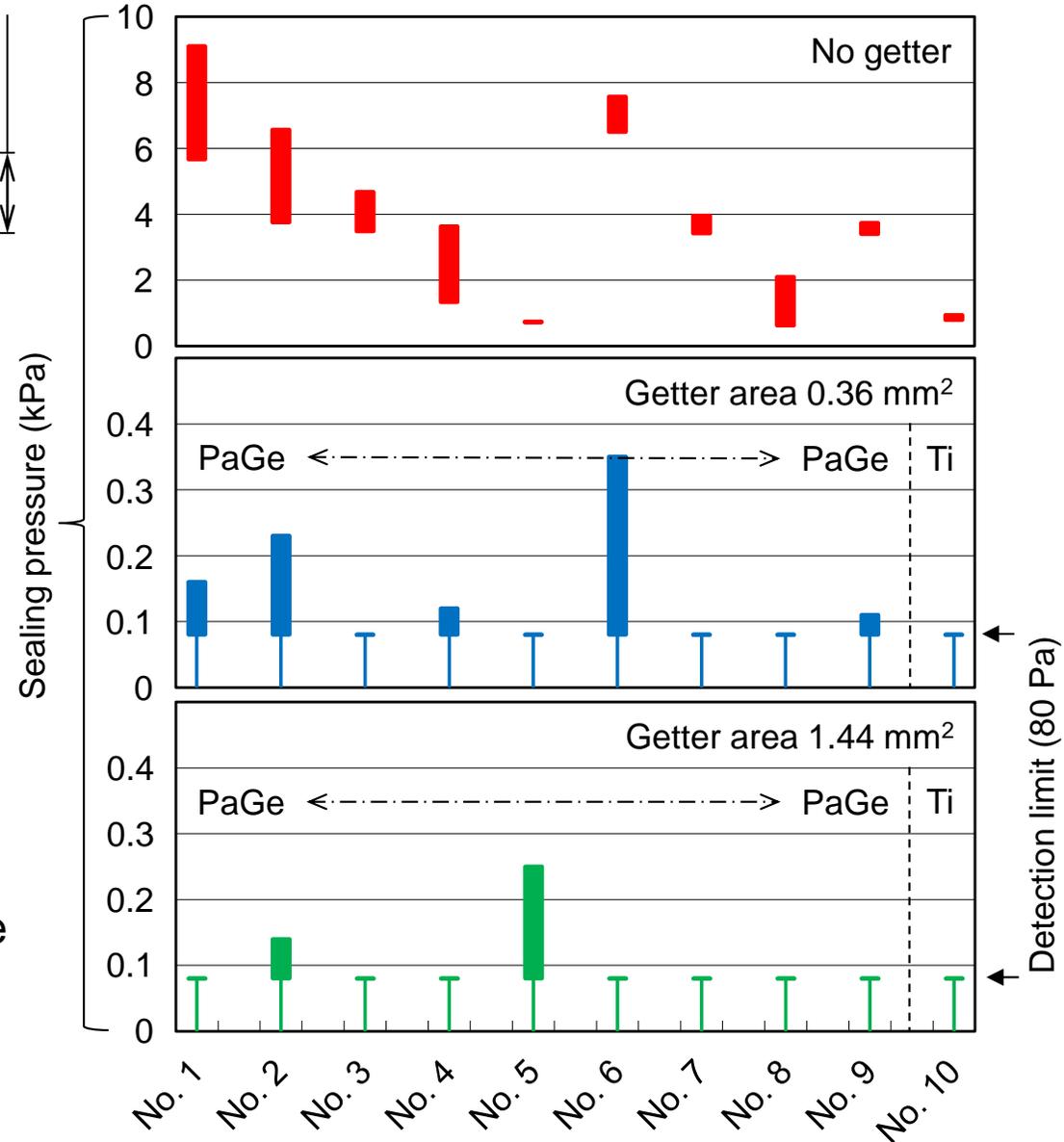


Anodic bonding on different conditions (e.g. 400°C, 600 V)

- No. 1-5 EVG
- No. 6-10 SussMicrotec
- No. 6 N<sub>2</sub> purge × 1
- No. 7-10 N<sub>2</sub> purge × 3

Cavity volume 0.26 or 0.43 mm<sup>3</sup>  
→ Larger volume, lower pressure

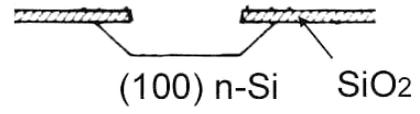
Both PaGe (Saes Getters) and sputtered Ti film are effective.



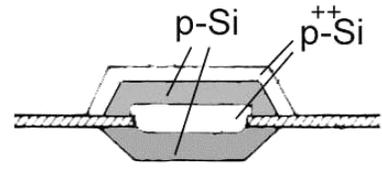
# 高真空・高信頼性封止の例: 横河電機・圧力センサー

K. Ikeda *et al.* (Yokogawa Electric), 7th Sensors Symposium (1988) 55

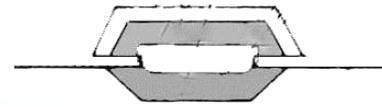
1) Si etching



2) p-Si, p<sup>++</sup>-Si, p-Si, p<sup>++</sup>-Si epitaxial growth



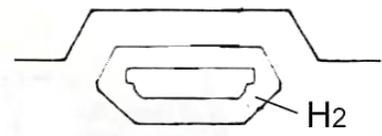
3) SiO<sub>2</sub> etching



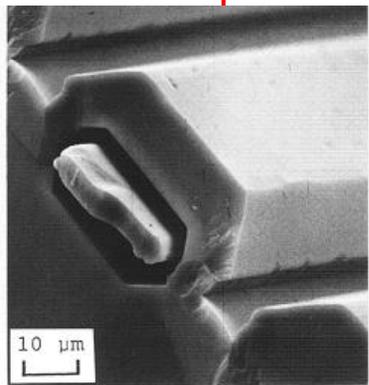
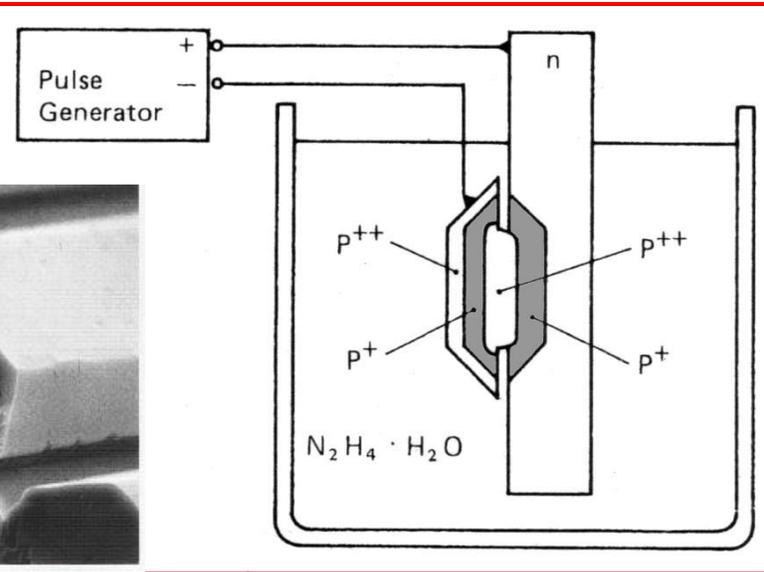
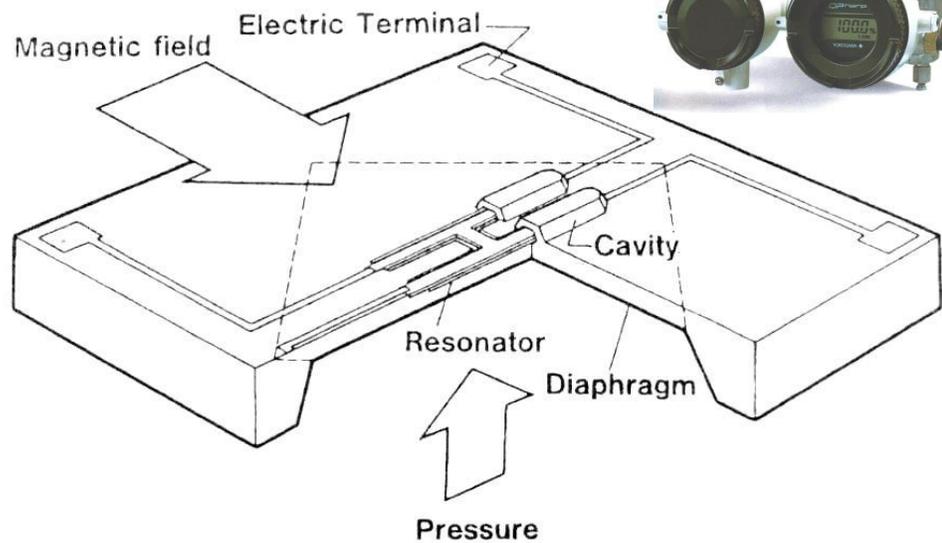
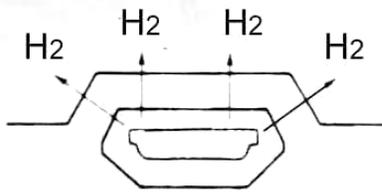
4) p-Si selective etching



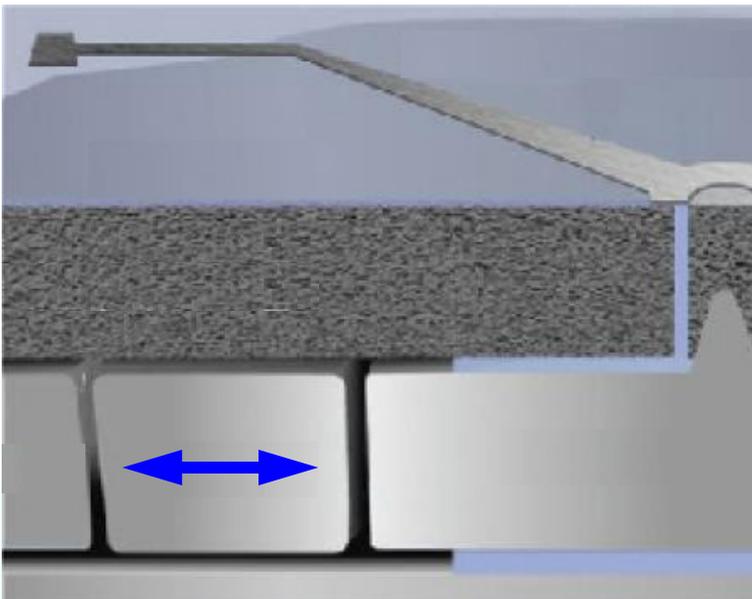
5) n-Si epitaxial growth (Sealing)



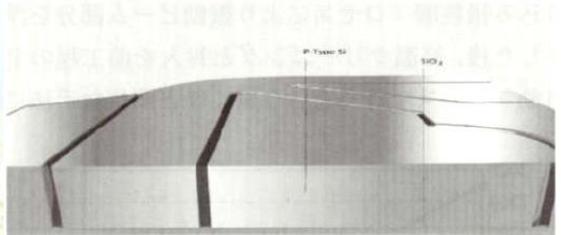
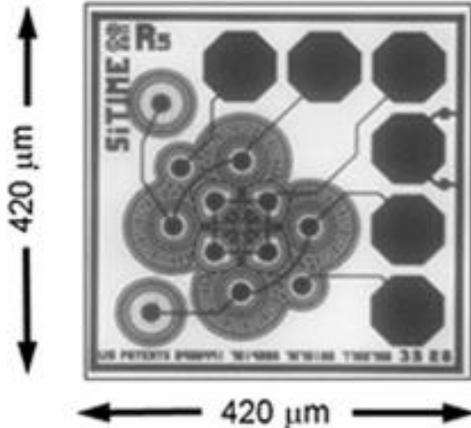
6) Annealing in N<sub>2</sub> (Vacuum cavity)



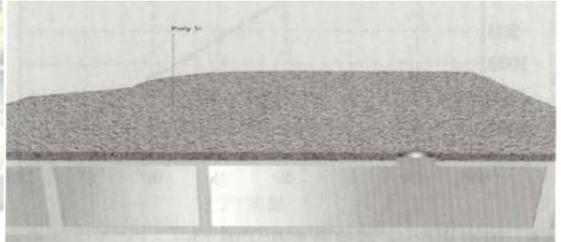
# 高真空・高信頼性封止の例：SiTime・クロック共振子



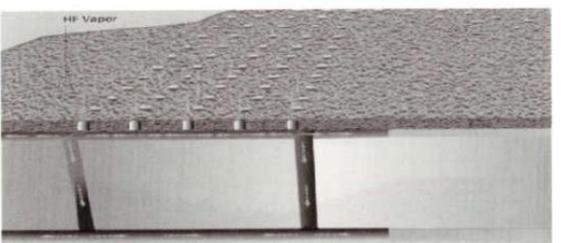
SiTime



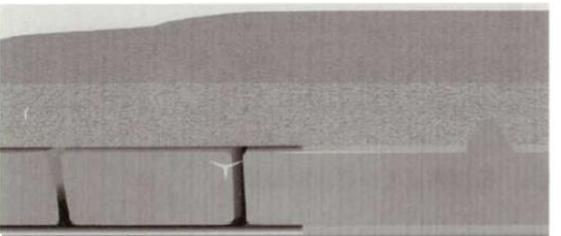
1) Si RIE (0.18 μm rule)



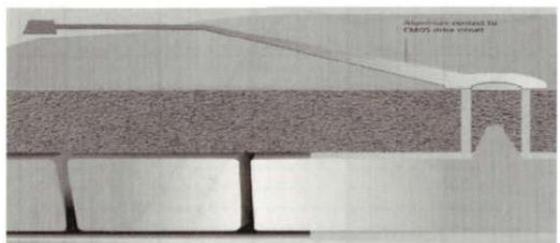
2) Deposition of Sacrificial SiO<sub>2</sub> and Si



3) HF vapor etching from release holes



5) Sealing by Epi-poly Si



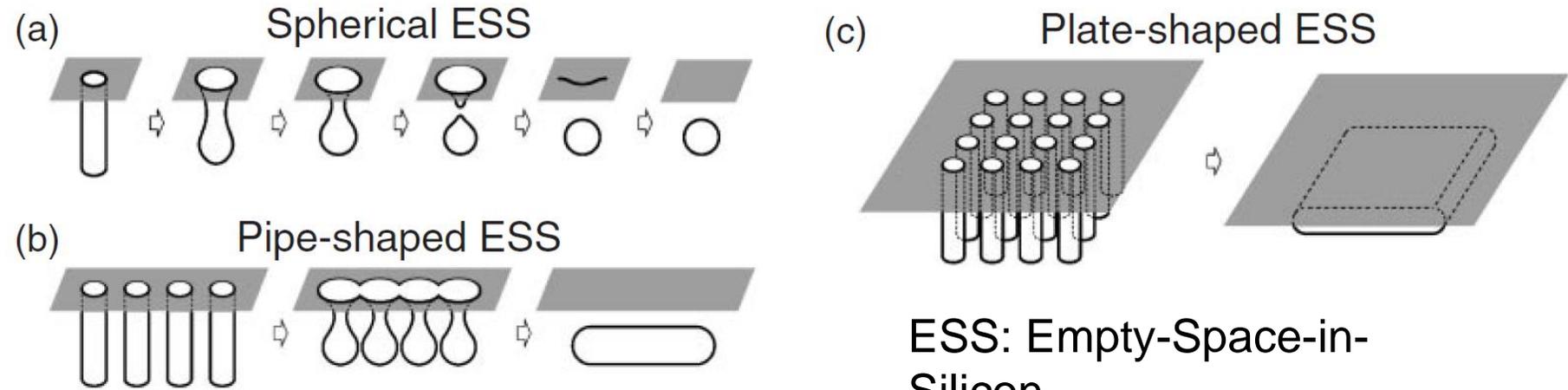
5) Metalization

Sealing in an epitaxial reactor (clean and high temperature)

櫻井, 金属, 77 (2007) 37

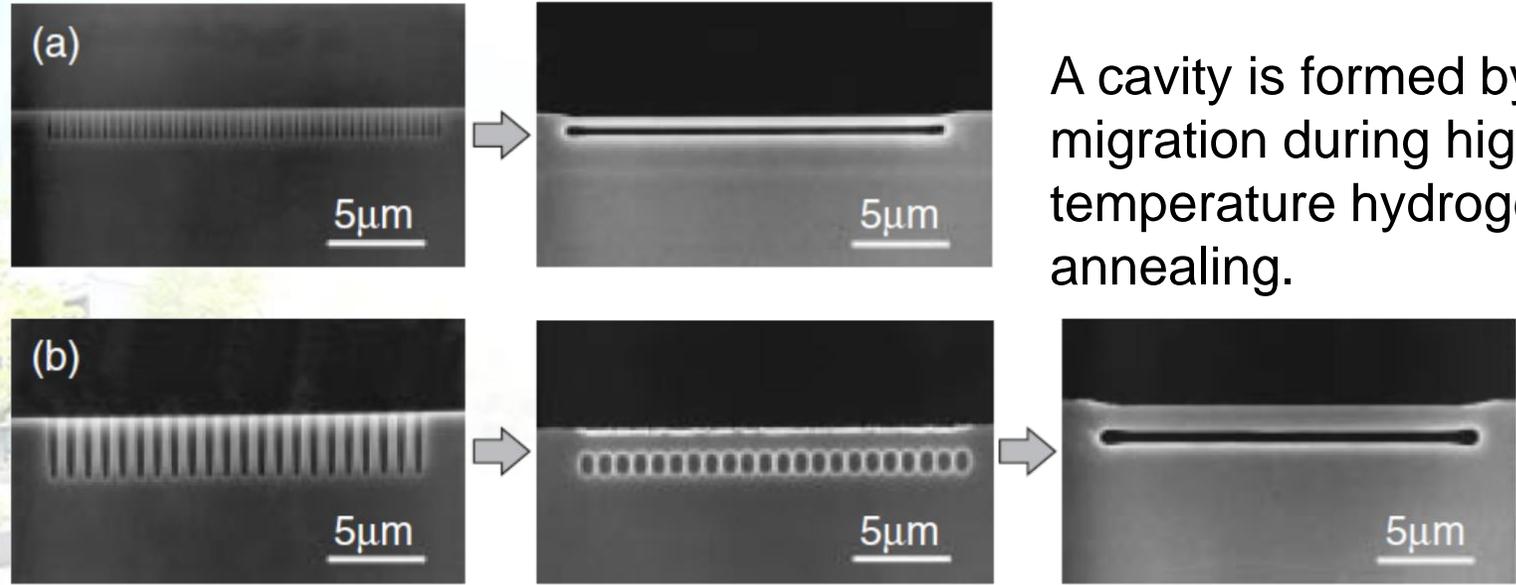
# Silicon-on-Nothing 技術

Tsutomu Sato *et al.* (Toshiba), Jpn. J. Appl. Phys., 43, 1 (2004) pp. 12-18



ESS: Empty-Space-in-Silicon

A cavity is formed by silicon migration during high-temperature hydrogen annealing.

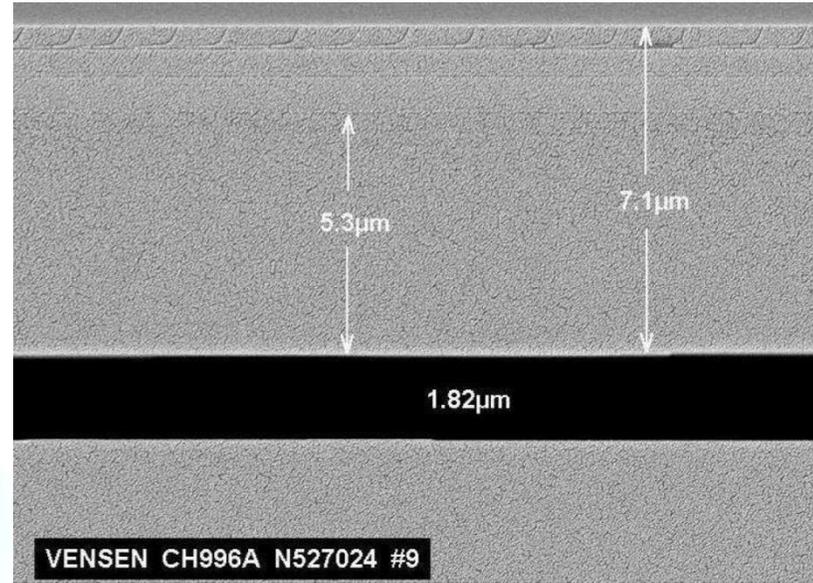


1100°C, 10Torr, 10min

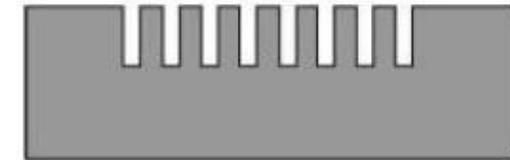
1150°C, 10Torr, 10min



# SONの応用例: STMicroelectronics・圧力セン サー



Si substrate

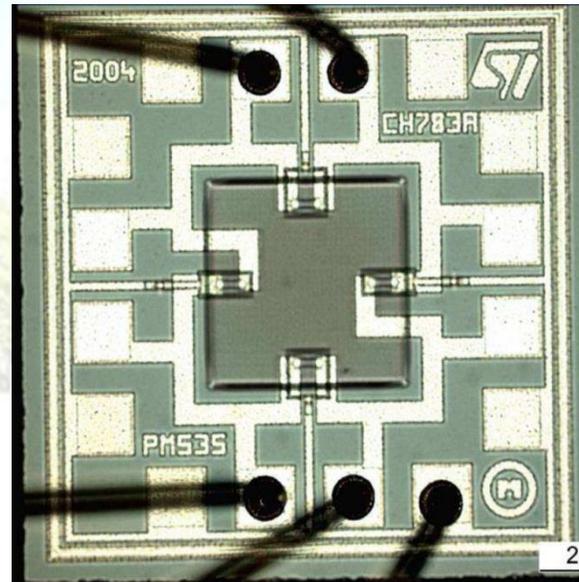


DRIE making hole array



Si deposition and Si reflow  
by vacuum annealing

VENSENS (VENice SENSor) process



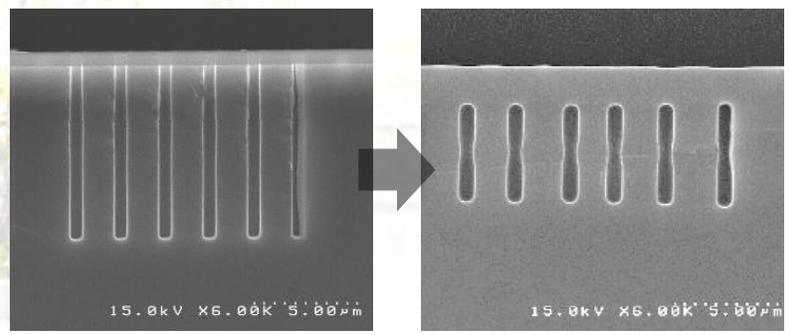
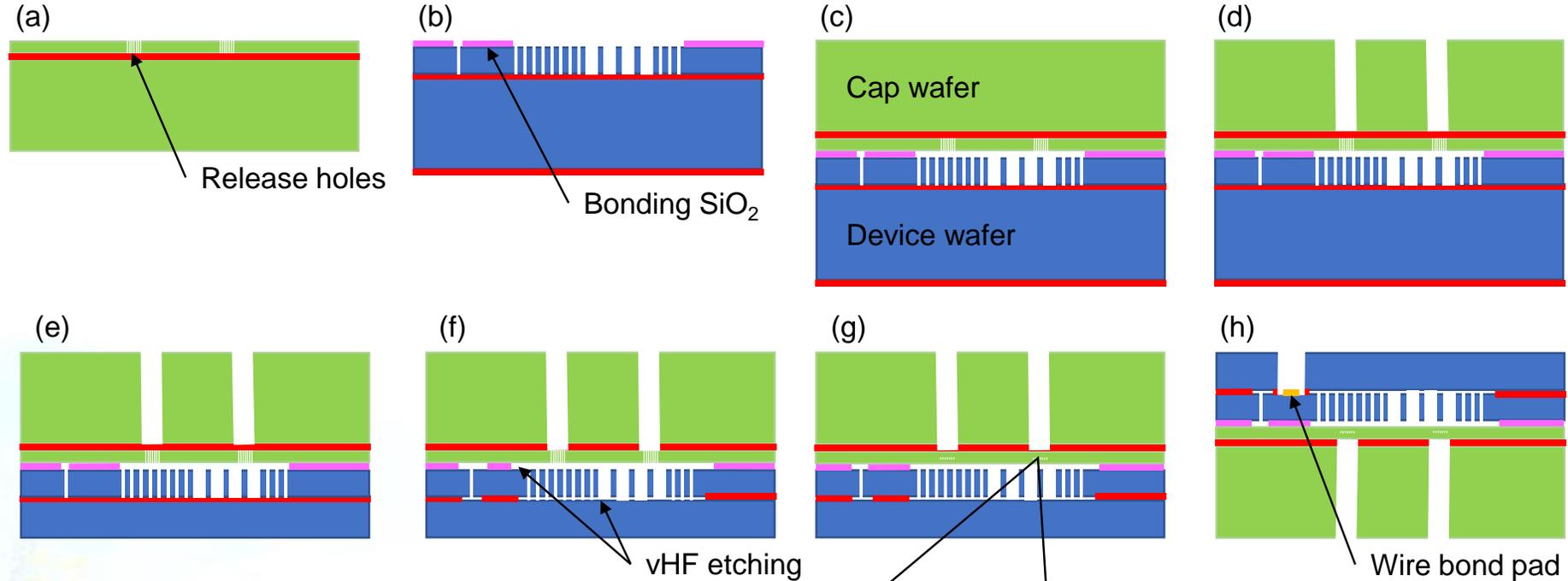
STMicroelectronics



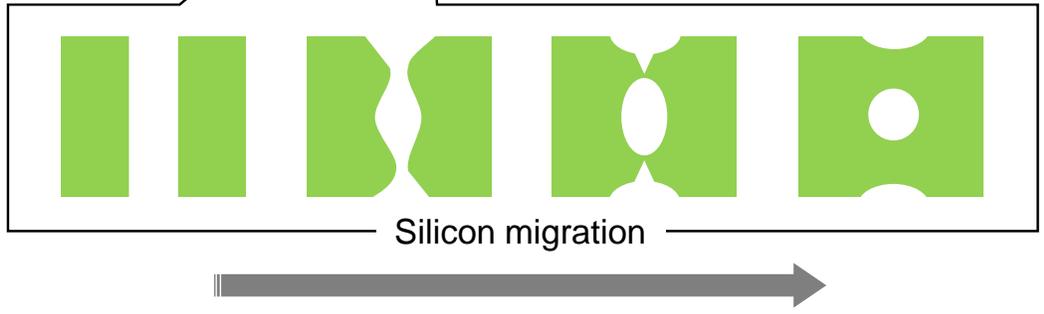
Micro Electro Mechanical Systems Lab  
Tanaka Shuji Laboratory

# Silicon Migration Sealing (SMS) WLPプロセス

Y. Suzuki *et al.* (Tohoku University), IEEE MEMS 2020, pp. 994-997

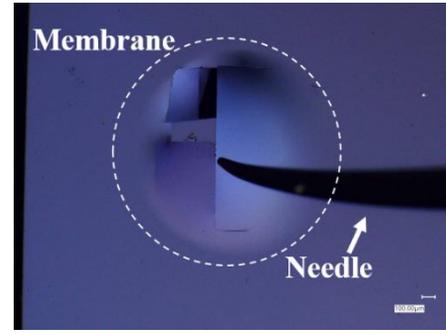
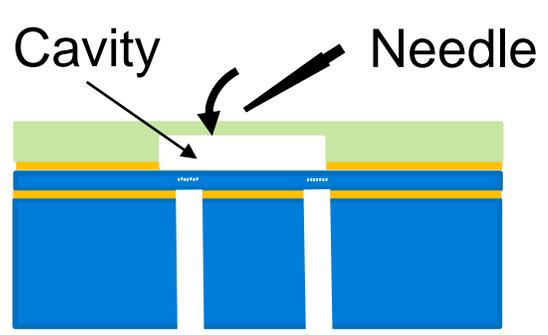


H<sub>2</sub> annealing at 1100°C for 20 min

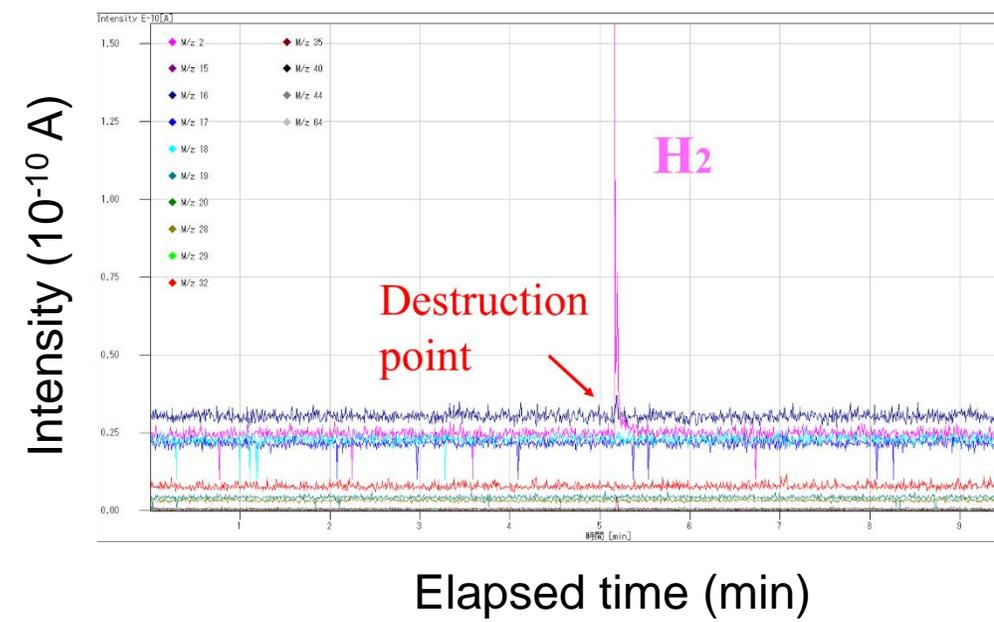
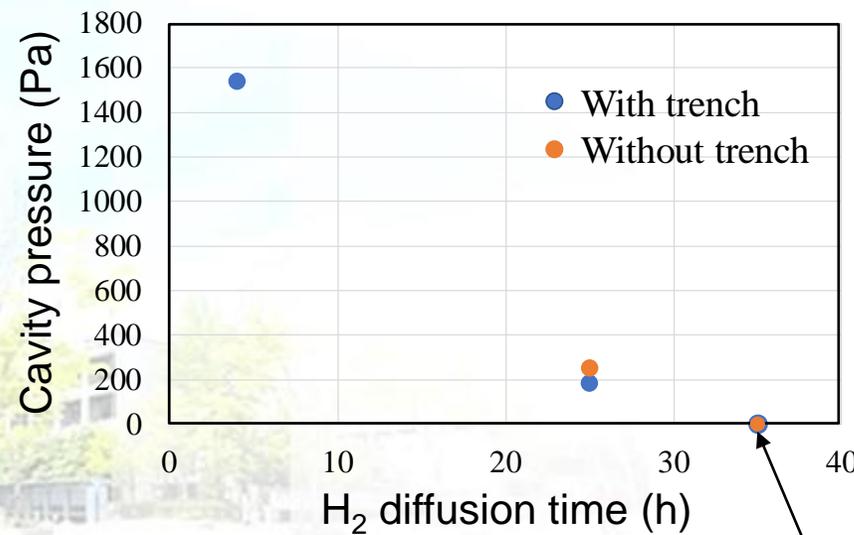


# SMS-WLPプロセスの原理検証

H. Suzuki *et al.* (Tohoku University), IEEE MEMS 2022, pp. 565-568

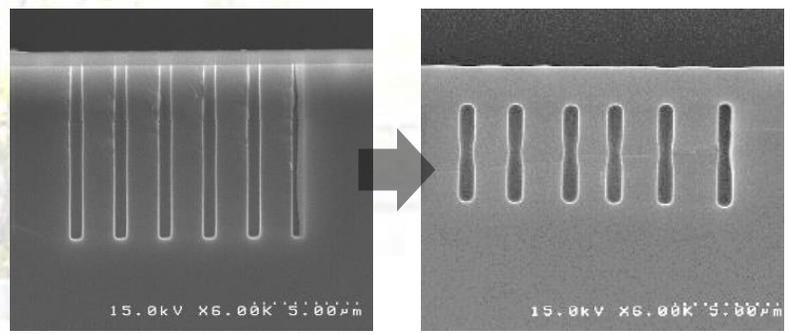
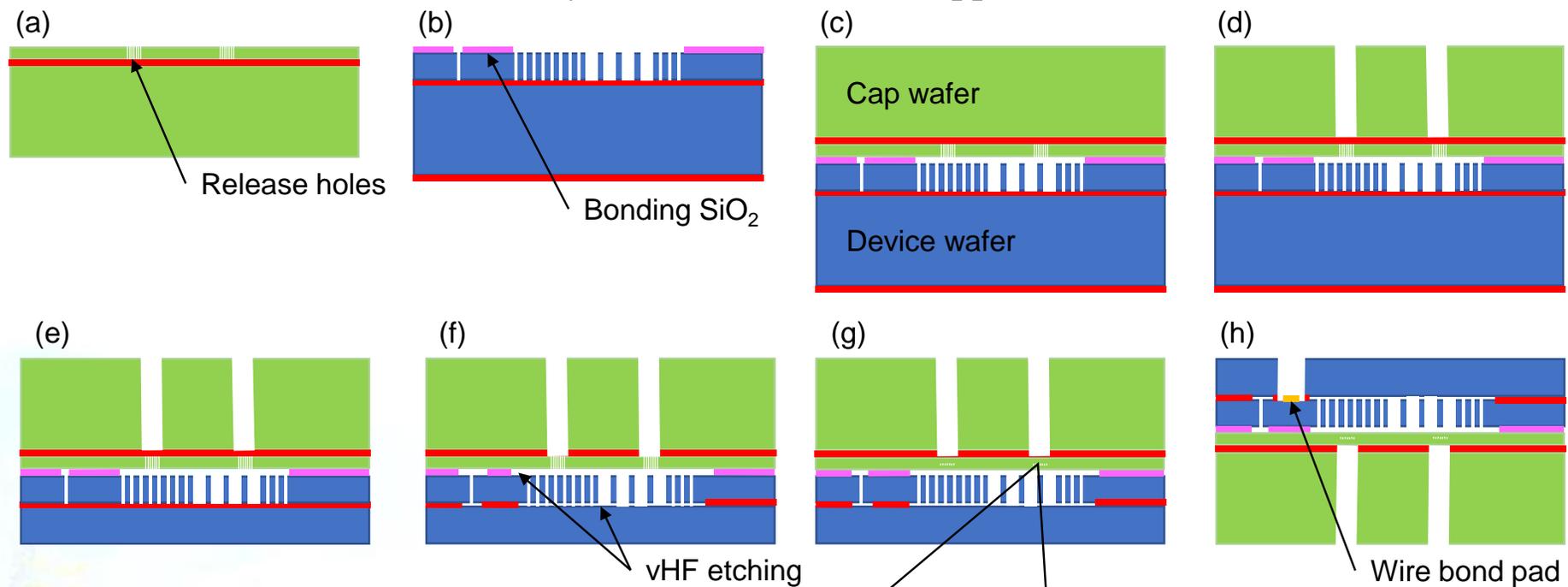


The diaphragm was mechanically broken in the chamber of TDS (thermal desorption spectroscopy) (ESCO, Japan).

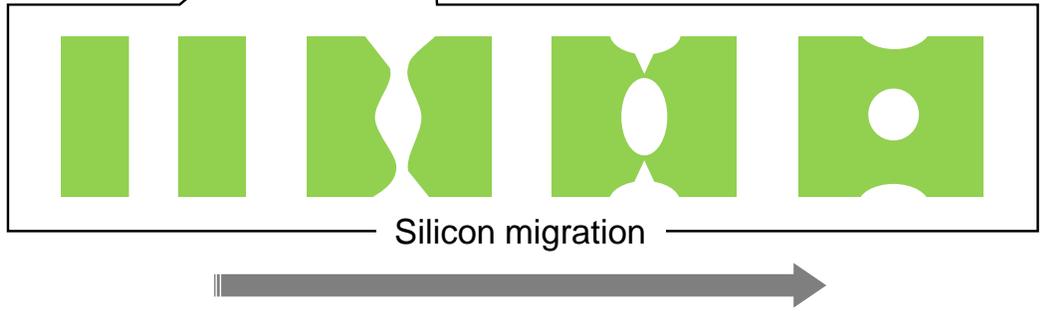


# Silicon Migration Sealing (SMS) WLPプロセス

Y. Suzuki *et al.* (Tohoku University), IEEE MEMS 2020, pp. 994-997



H<sub>2</sub> annealing at 1100°C for 20 min



# SMS WLPプロセスの開発



## 【東北大学】

- 4インチウェハを用いた研究開発を実施(フェーズA)
- SMS WLPを適用したデバイスの共同研究や試作を受注可能
- ソニーセミコンダクタマニュファクチャリングでの量産開発への移行支援を受注可能

## 【ソニーセミコンダクタマニュファクチャリング】

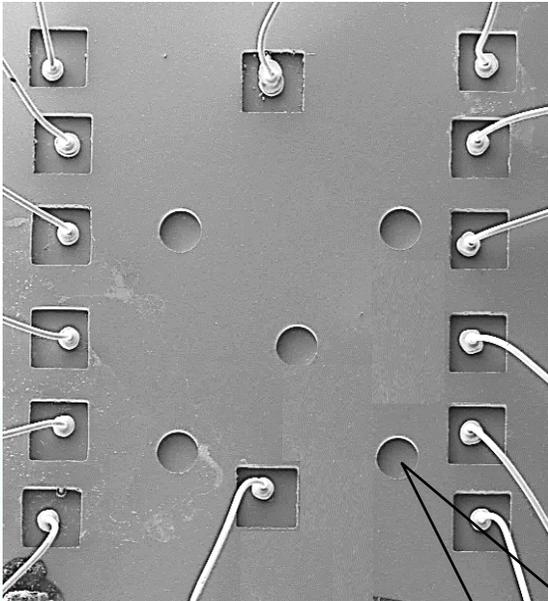
- 6インチウェハを用いた研究開発を実施(フェーズA)
- 8インチラインへの移行を準備
- 8インチウェハを用いた量産開発の営業を開始予定



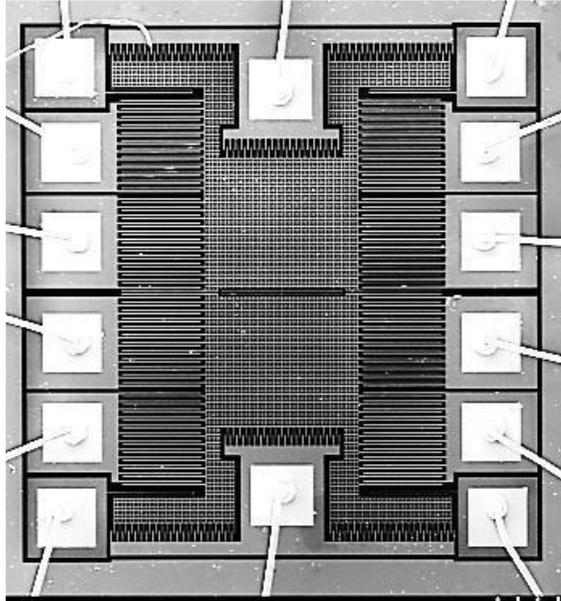
Micro Electro Mechanical Systems Lab  
Tanaka Shuji Laboratory

# 真空封止したMEMS共振子

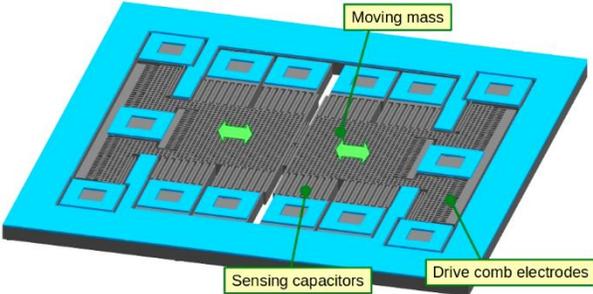
M. J. Khan *et al.* (Tohoku University), IEEE MEMS 2023



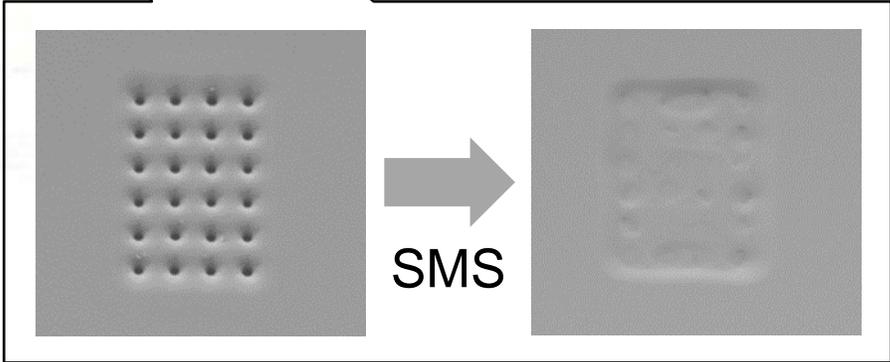
MEMS resonator with SMS WLP



MEMS resonator without cap



Tuning fork resonator

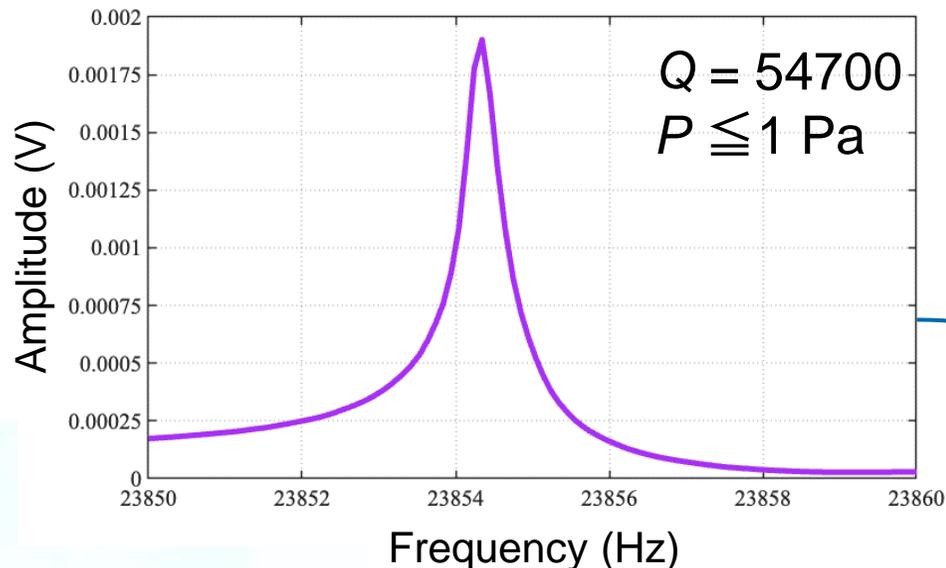


Release holes

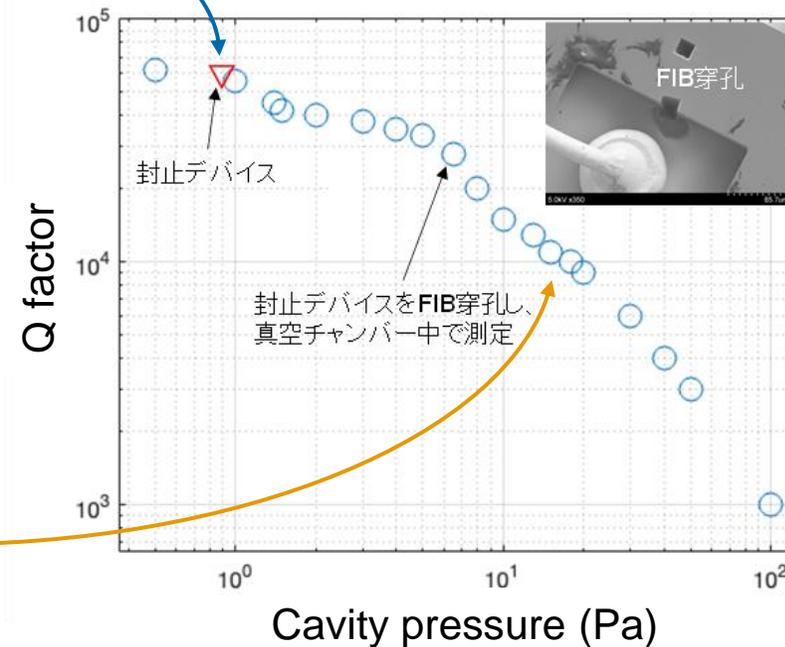
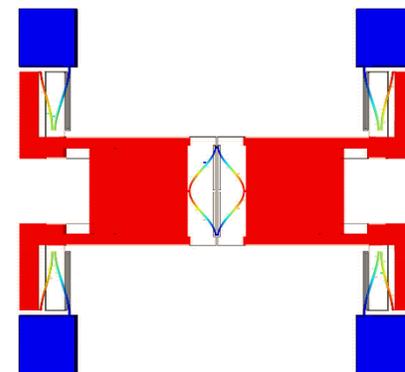


# MEMS共振子のQ値と封止圧力

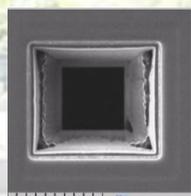
S. Suzuki *et al.* (Tohoku University), Transducers 2023



Frequency characteristic of SMS-WLP resonator



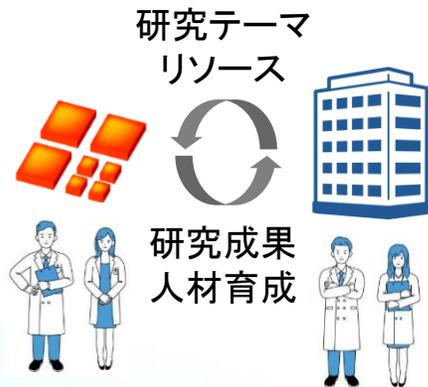
Cavity pressure vs. Q factor



The package was leaked by FIB drilling, and then Q factor was measured by changing pressure in a vacuum chamber.

# 本プロジェクト 成果の活用に向けて

## 共同研究



研究者受入れによる  
共同研究  
(学位取得も可能)

当研究室メンバーに  
よる分担・支援も可  
能

お客様の研究フェー  
ズに応じて、基礎研  
究から製品開発まで

## 委託研究



お客様の希望に応じ  
た委託研究

当研究室メンバーに  
よる研究の実施

研究テーマと状況に  
よっては共同研究を  
お勧めします

## 学術指導・コンサルティング



技術、業界動向、研  
究開発戦略、ビジネ  
スなどに関するアド  
バイスや情報提供

大学を通じた学術指  
導または個人による  
コンサルティング

顧問契約も可能

## プライベートセミナー、ワークショップ



お客様の希望に応じ  
た社内プライベート  
セミナー

お客様側の研究者・  
技術者との議論を行  
うワークショップ

お客様の会社を学生  
にアピールする学内  
セミナー

[mems tohoku](#)

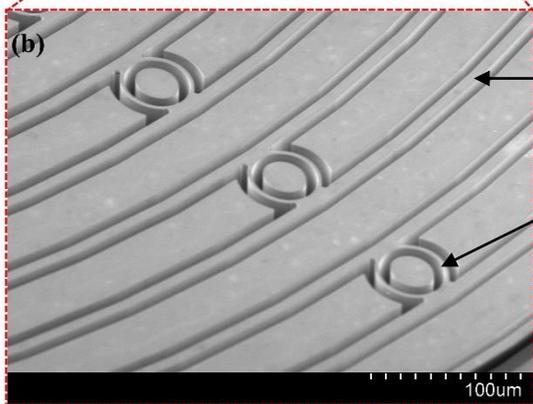
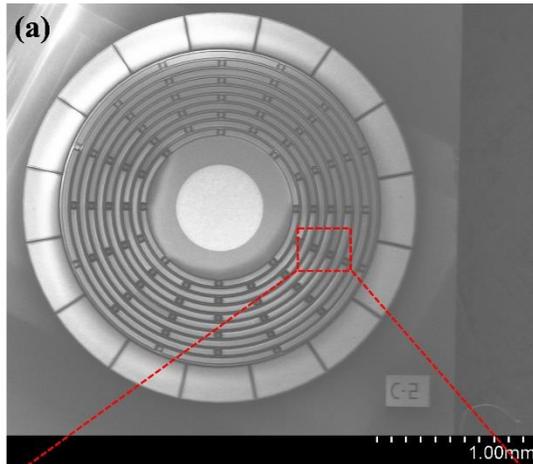
検索



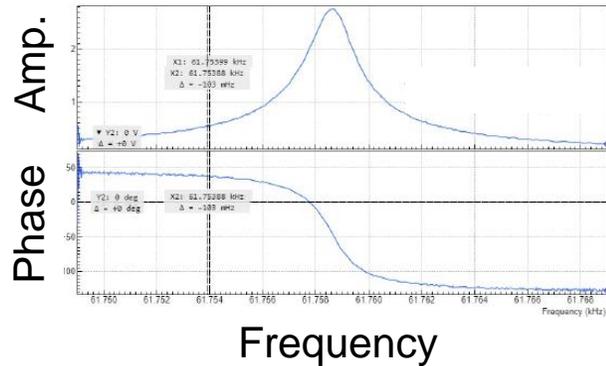
Micro Electro Mechanical Systems Lab

Tanaka Shuji Laboratory

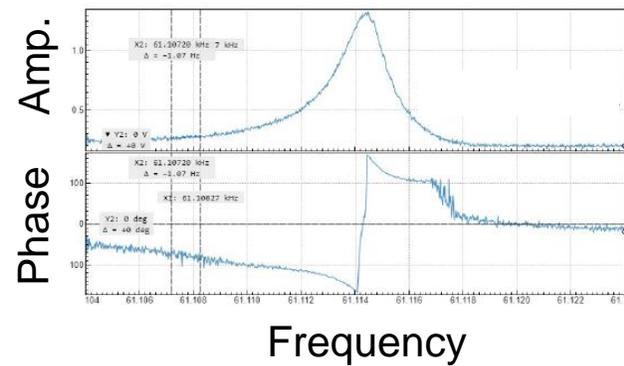
# パッケージの中身=デバイスの開発も支援可能



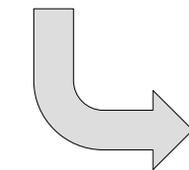
High performance (<1 %/h class) MEMS gyroscope



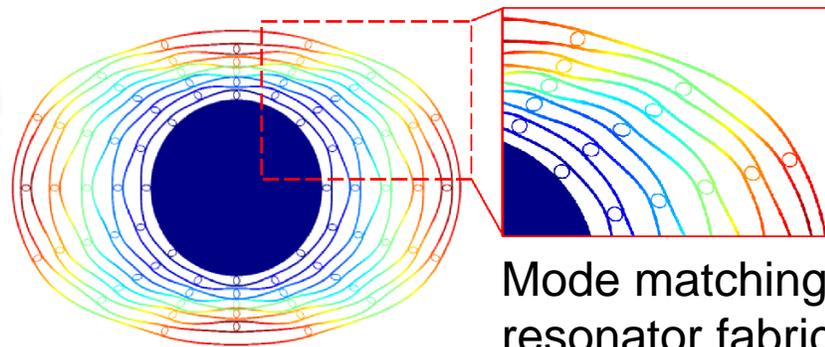
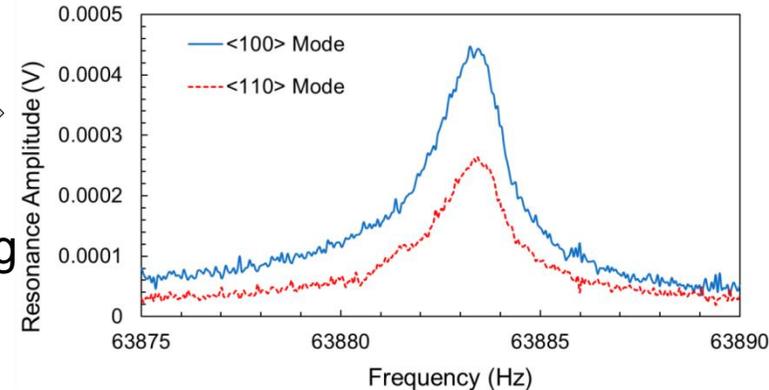
Mode 1 <100> 61.115 kHz



Mode 2 <110> 61.759 kHz



Mode matching



Mode matching of multiring resonator fabricated on (100) Si

# まとめ

- ウェハレベルパッケージングはMEMSのキー技術  
「パッケージを考えたから中身を考えよ」
- MEMSジャイロセンサー等の高性能化には、高真空パッケージングが必須
- 封止圧力1 Pa以下を達成できるウェハレベルパッケージングに選択肢なし
- SMSに基づくウェハレベルパッケージングを開発し、1 Pa以下の封止圧を実証
- 本ウェハレベルパッケージング技術は様々なSOI/Cavity SOI MEMSに適用可能
- 本ウェハレベルパッケージング技術の適用や中身のデバイスの開発について技術支援や量産支援が可能

mems tohoku

検索



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