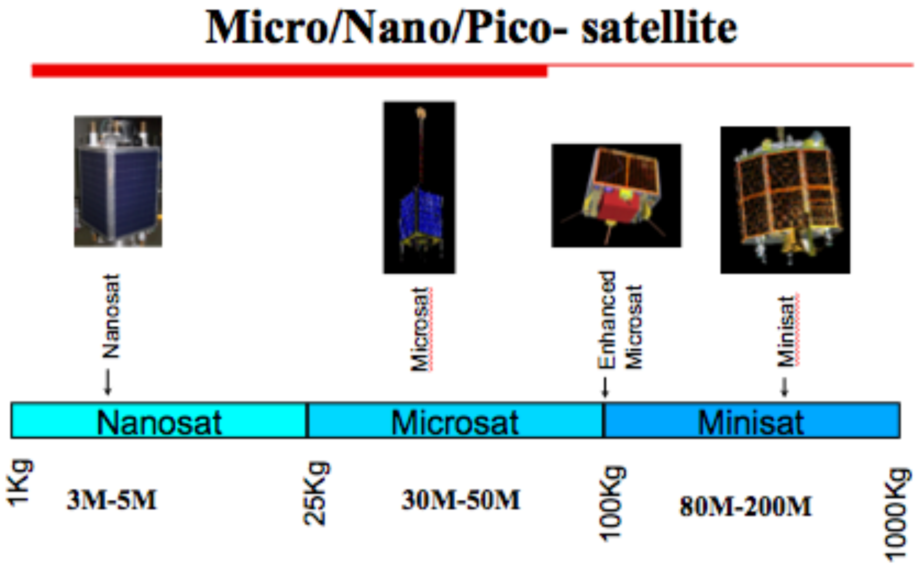
A Creative RF MEMS Capacitive Switch Based on MOS-type Co-Planar Waveguide for Space Applications

State Key Lab. of Precision Measurement Technology and Instruments
Department of Precision Instrument and Mechanics
Tsinghua University

ZHAO Jiahao, YOU Zheng, CHEN Junshou

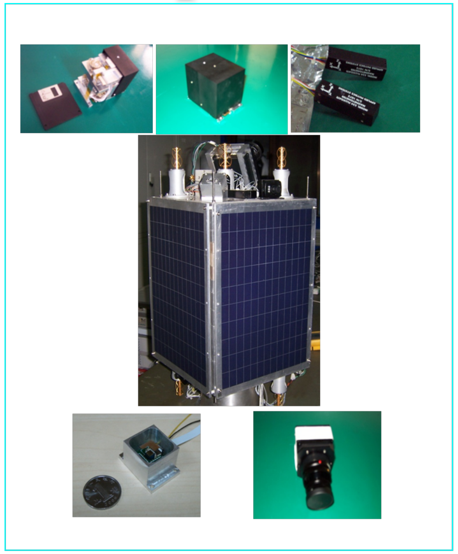
8th ESA Round Table on Micro and Nano Technologies for Space Applications
15 - 18 October 2012
ESA/ESTEC, Noordwijk, The Netherlands

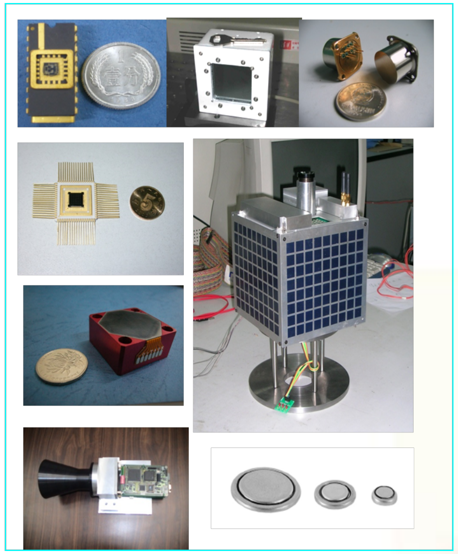
- **Microsatellite and Nanosatellite Research**



Smaller, Faster, Cheaper, Better (in some case)

- **Space MEMS Research**

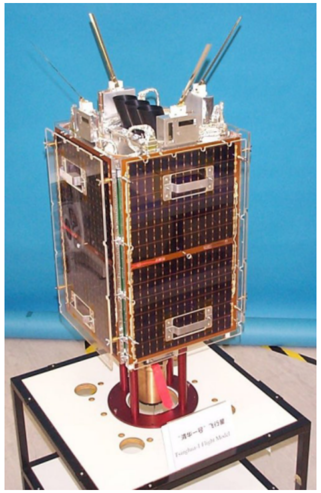




Microsatellite Research in Tsinghua University

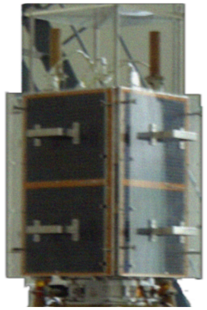
Successful Launched **Manufactured** **Waiting for Launch**

(2012-2013)

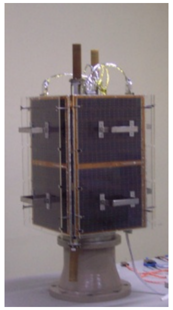


Tsinghua-1 **NS-1**

（50kg，2000）（25kg，2004）

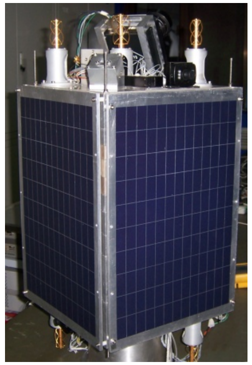


KT-PS
（35kg）



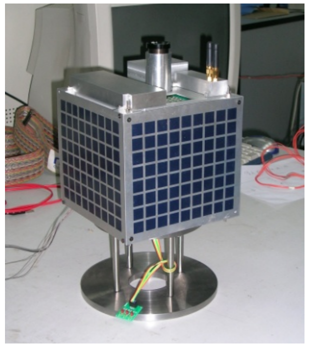
KT-PS1
（35kg）

2000-2004



NS-2

（25kg）



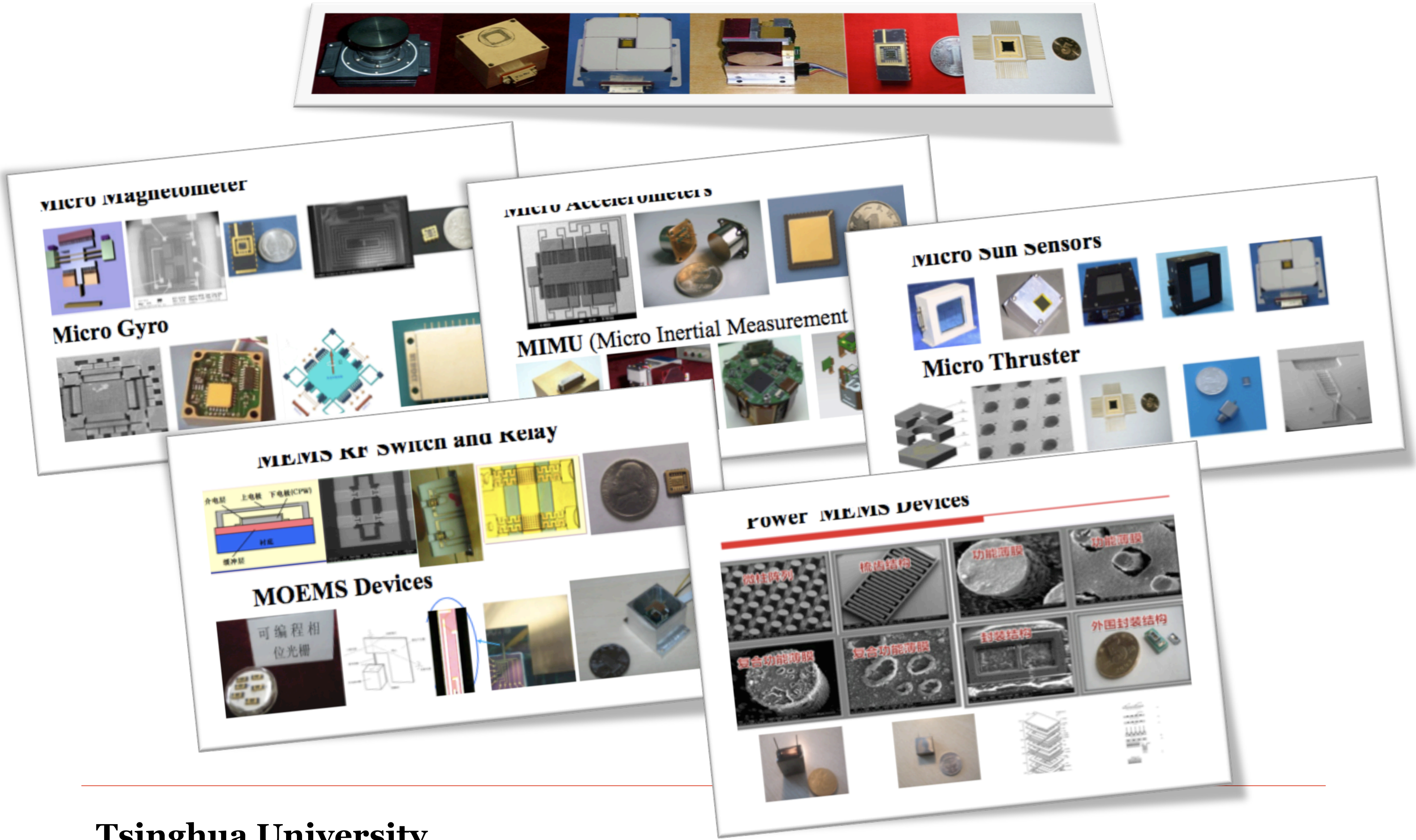
MEMSat

（7kg）

2006-2012

NS-1 is smallest and highest density launched 3 Axis stable Nano-satellite in china

Space MEMS Research in Tsinghua



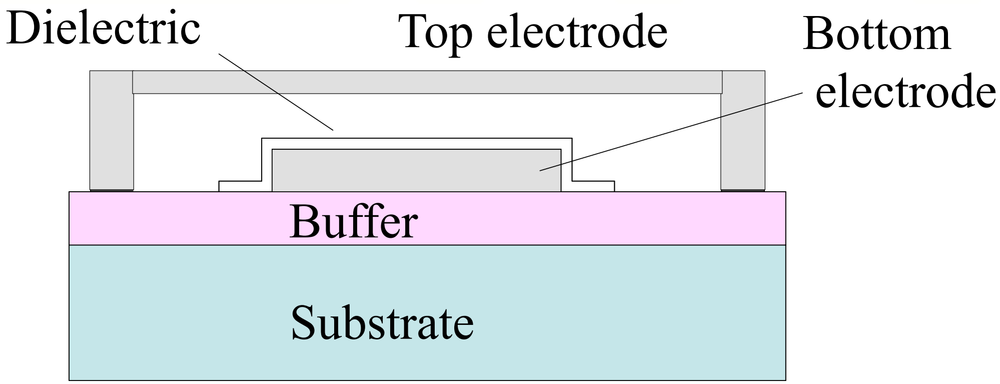
Outline

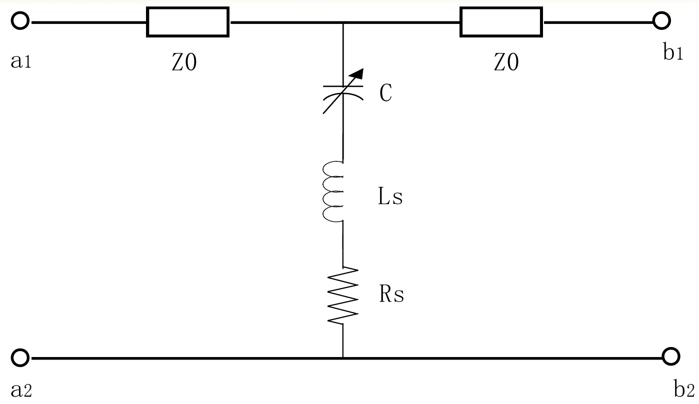
- **Background and Space Applications**
- **MOS-type Co-Planar Waveguide**
- **RF MEMS Capacitive Switch**
- **Conclusion**

Outline

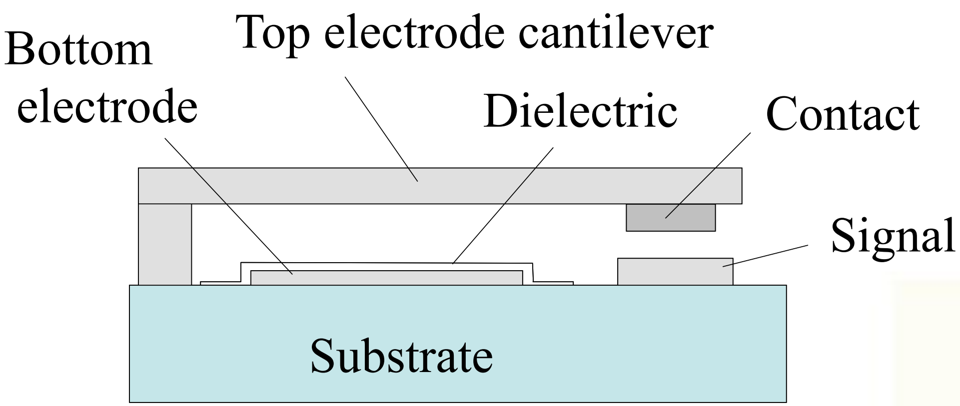
- Background and Space Applications
- MOS-type Co-Planar Waveguide
- RF MEMS Capacitive Switch
- Conclusion

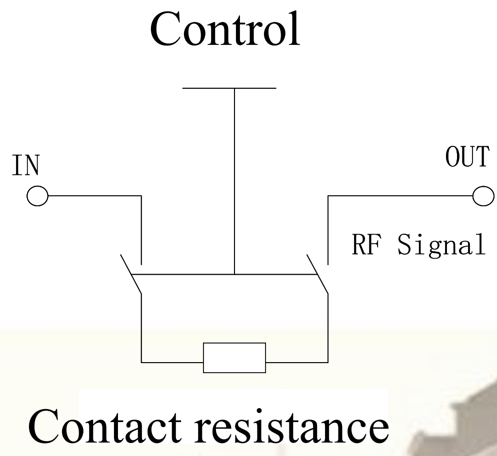
RF MEMS Switch





Capacitive Switch



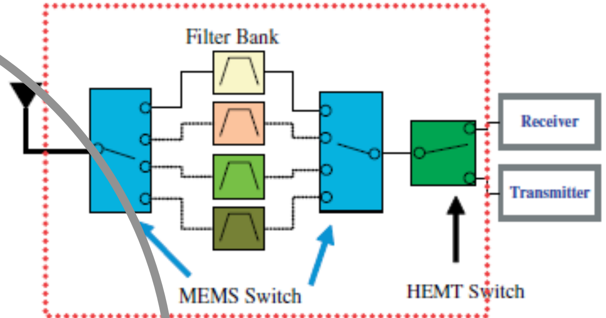


Resistive switch

RF MEMS Switch Research

	Main direction	Major approaching	Current development
Low driving voltage	Low-K design, low residual stress design, reduce the distance, increase the area	H-type beam, Elastic bending beam, Slotted beam	7~20V
Low insertion loss &. High isolation	Low losses CPW	CPW with suspending structure, Special substrate, Low loss conductor	<0.20dB@35GHz
High power	Varied driving types, Varied driving structures	Comb driving, Thermal driving, Disc structure, Sandwich structure	>10W
High reliability	Thermal stability, Radiation stability, Impact load stability	Reliability model, key factors, Reliability design	10^{11}

Applications of RF MEMS switch



RF MEMS SWITCH

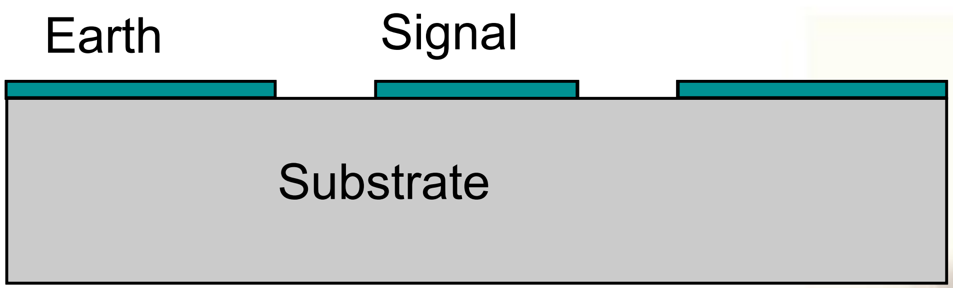
MORE

Outline

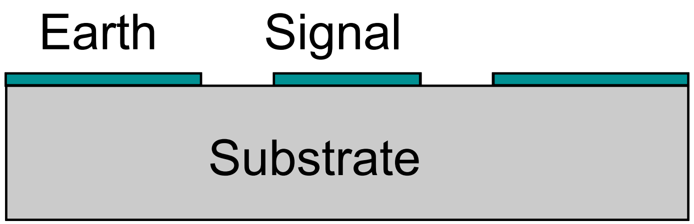
- **Background and Space Applications**
- **MOS-type Co-Planar Waveguide**
- **RF MEMS Capacitive Switch**
- **Conclusion**

Co-Planar Waveguides, CPW

- Key Component of RF MEMS switch
  - Important related to the losses of switch device
  - CPW with low losses ⇨ High performance device
- Advantages of CPW
  - No aperture inside the substrate - compared with micro-strip transmission line
  - All the wires located on the same layer- convenience for integration with MMIC



Losses of CPW



- Conductor Loss

$$\alpha_{cond} = 4.88\times10^{-4} R_s \varepsilon_q Z_0 \frac{P}{\pi w}\left(1+\frac{s}{w}\right)\times\frac{1+\frac{1.25t}{\pi s}+\frac{1.25}{\pi}\ln\frac{4\pi s}{t}}{\left(2+\frac{s}{w}-\frac{1.25t}{\pi w}\left(1+\ln\frac{4\pi s}{t}\right)\right)^2}$$

- Substrate Loss

$$\alpha_{sub} = 8.68\pi\frac{q\varepsilon_r}{\varepsilon_q}\cdot\frac{\tan\theta}{\lambda_g}$$

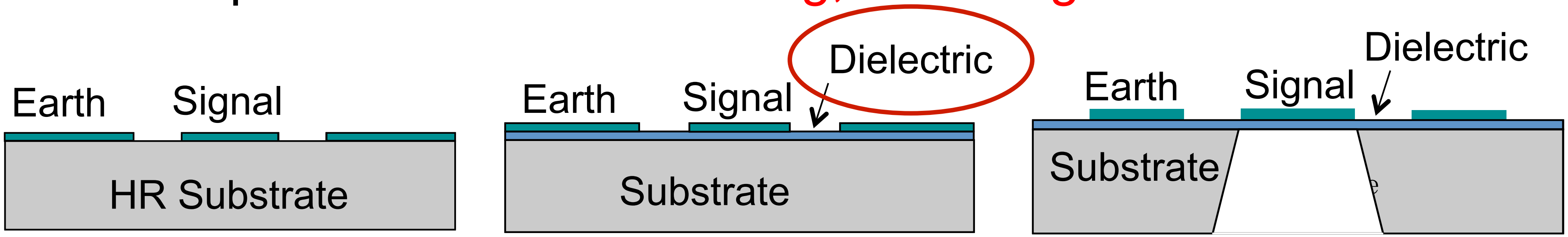
- Radiation Loss

$$\alpha_{rad} = \left(\frac{\pi}{2}\right)^5 2\left(\frac{\left(1-\varepsilon_{eff,f}/\varepsilon_r\right)^2}{\sqrt{\varepsilon_{eff,f}/\varepsilon_r}}\right)\frac{(s+2w)^2\varepsilon_r^{3/2}}{c^3K'(k)K(k)}f^3$$

[1] Liao C L, Tu Y M, Ke J Y, et al. Transient propagation in lossy coplanar waveguides. IEEE Transactions on Microwave Theory and Techniques, 1996,44(12 /2):2605-2611.
[2] K. C. Gupta R G A L. Microstrip Lines and Slotlines. New York: Artech House, 1979.
[3] Heinrich W. Quasi-TEM description of MMIC coplanar lines including conductor-loss effects. IEEE Transactions on Microwave Theory and Techniques, 1993,41(1):45-52.
[4] Frankel M Y, Gupta S, Valdmanis J A, et al. Terahertz attenuation and dispersion characteristics of coplanar transmission lines. IEEE Transactions on Microwave Theory and Techniques, 1991,39(6):910-916

Low losses CPW

- High resistance substrate: HRS, GaAs, InP
- Insulation layer adding between CPW &. Substrate:
  SiO_2, PI, Si_3N_4, Photoresist
- Suspended structure: etching, removing substrate



[1] Reyes A C, El-Ghazaly S M, Dorn S, et al. Silicon as a microwave substrate: Microwave Symposium Digest, 1994., IEEE MTT-S International, 1994 [C].23-27 May 1994.

[2] Reyes A C, El-Ghazaly S M, Dorn S J, et al. Coplanar waveguides and microwave inductors on silicon substrates. Microwave Theory and Techniques, IEEE Transactions on, 1995,43(9):2016-2022.

[3] Hu Z R, Fusco V F, Wu Y, et al. Contact effects on HF loss of CPW high resistivity silicon lines: Microwave Symposium Digest, 1996., IEEE MTT-S International, 1996[C].17-21 Jun 1996.

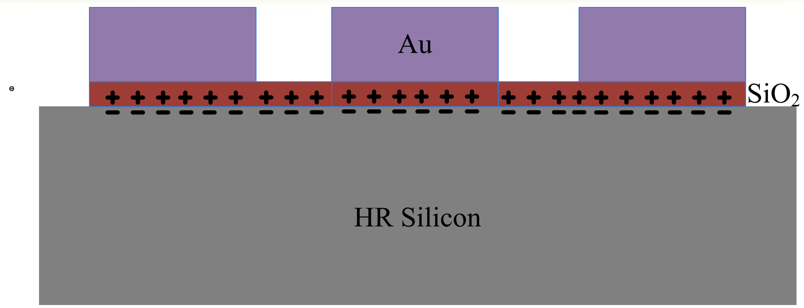
[4] Makita T, Tamai I, Seki S. Coplanar Waveguides on High-Resistivity Silicon Substrates With Attenuation Constant Lower Than 1 dB/mm for Microwave and Millimeter-Wave Bands. Electron Devices, IEEE Transactions on, 2011,58(3):709-715.

[5] Guillon B, Grenier K, Parra T, et al. Silicon micromachining for high performance passive structures at W band. Active and Passive Electronic Components, 2002,25(1):113-122.

AND SO ON…

Dielectric layer

- CPW with Insulation layer
  - Help to reduce DC loss
  - Bring Dielectric loss
- Dielectric Layer
  - Interface effect
  - Process quality
  - Crystal lattice mismatching with substrate



Work function difference → Interface state → Low resistance layer

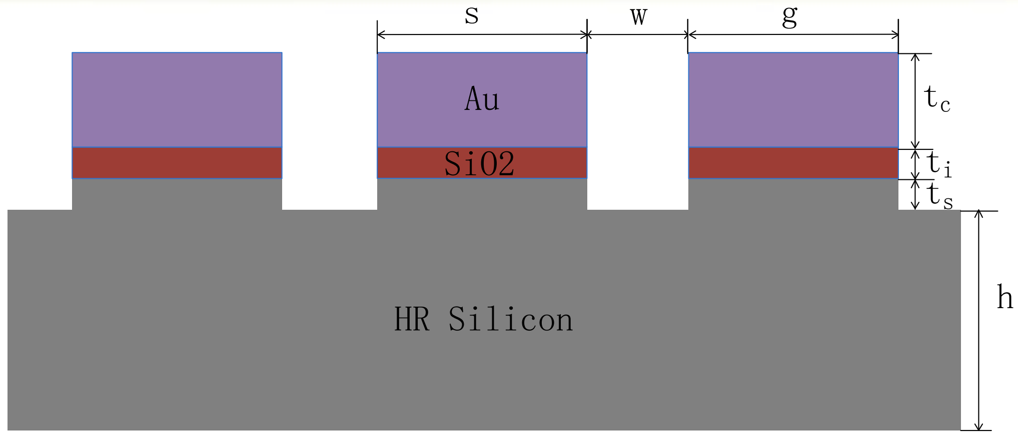
Carrier transporting → CPW Losses ↑

Substrate	HRS	
Insulation layer	↑	$\alpha = 0.10\text{dB/mm}$
Non-insulator	↓	$\alpha = 0.08\text{dB/mm}$

[1] Pfeifer T, Heiliger H M, Stein Von Kamienski E, et al. Charge accumulation effects and microwave absorption of coplanar waveguides fabricated on high-resistivity Si with SiO2 insulation layer. Applied Physics Letters, 1995,67(18):2624.
[2] Reyes A C, El-Ghazaly S M, Dorn S J, et al. Coplanar waveguides and microwave inductors on silicon substrates. Microwave Theory and Techniques, IEEE Transactions on, 1995,43(9):2016-2022.

Our CPW design

Raised MOS-type CPW

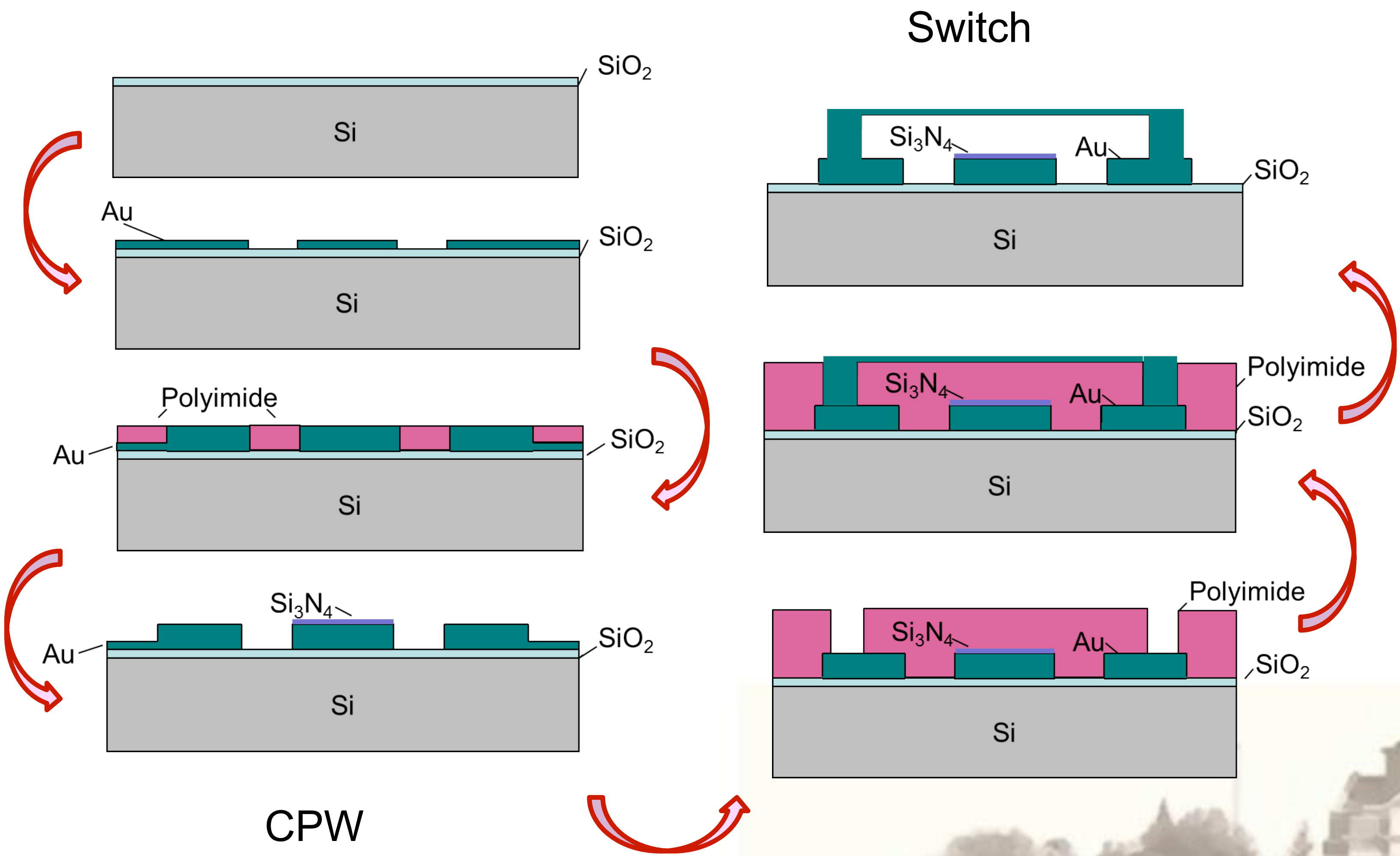


- Non-continuous Insulation layer
  - Etching silicon substrate
  - Half-suspending structure
- Objective
  - Reduce DC losses in bias working conditions
  - Carrier channels are broken to reduce dielectric losses

Outline

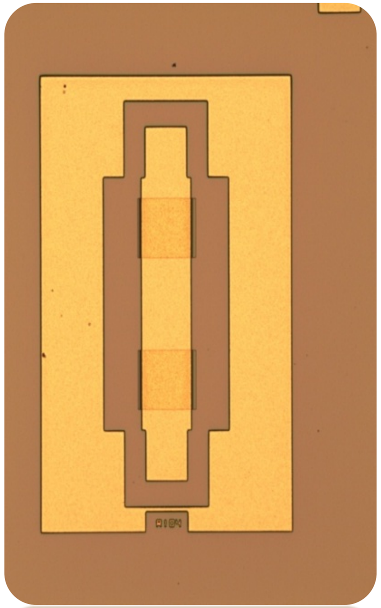
- **Background and Space Applications**
- **MOS-type Co-Planar Waveguide**
- **RF MEMS Capacitive Switch**
- **Conclusion**

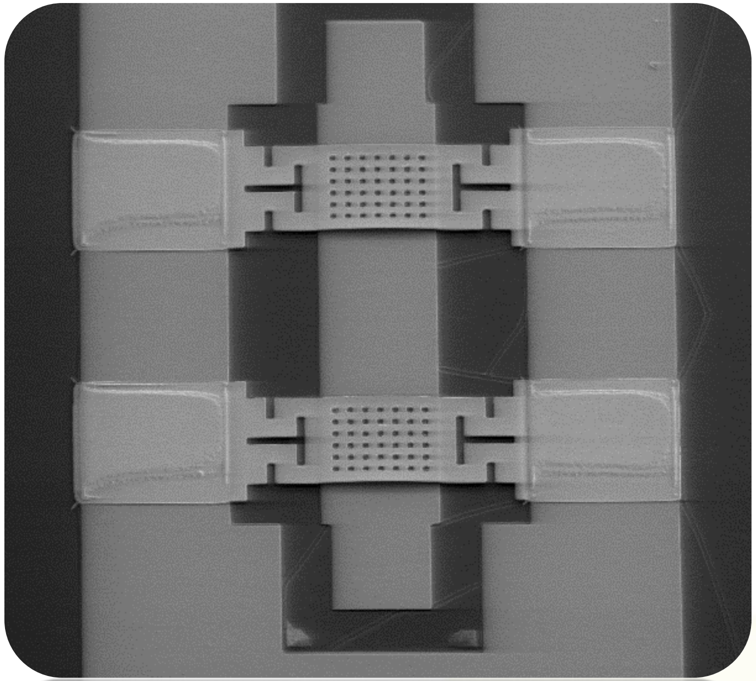
Process

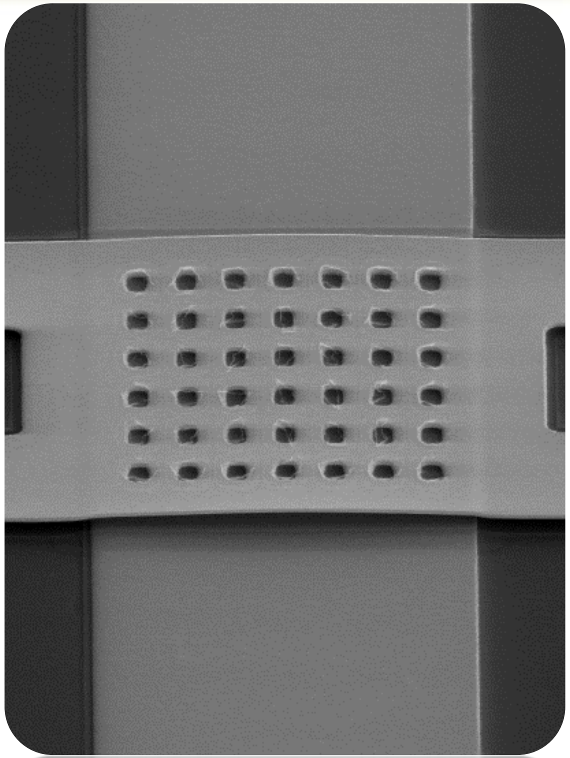


Switch
SiO2
Si
Au
SiO2
Si
Polyimide
Au
SiO2
Si
Si3N4
Au
SiO2
Si
CPW
Si3N4
Au
SiO2
Si
Si3N4
Au
Polyimide
SiO2
Si
Polyimide
Si3N4
Au
SiO2
Si

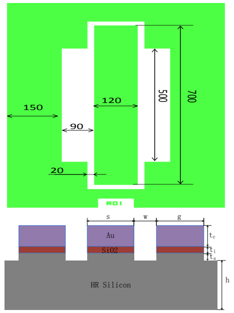
Fabricated CPW and Switch



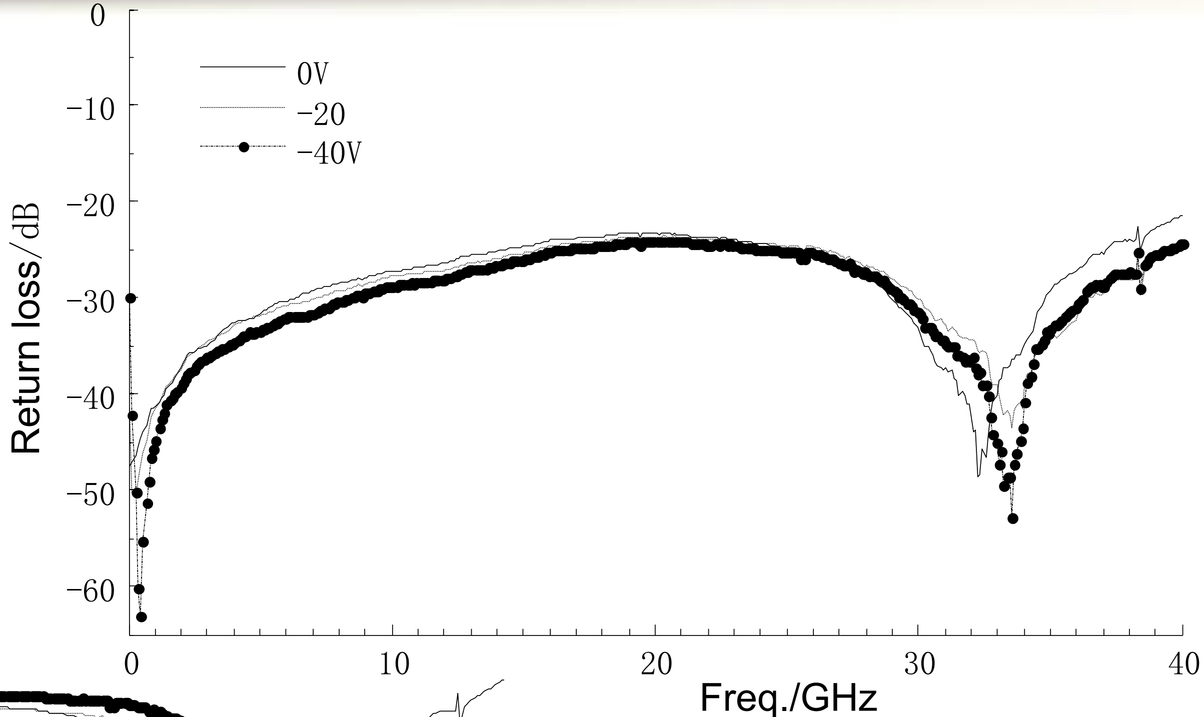




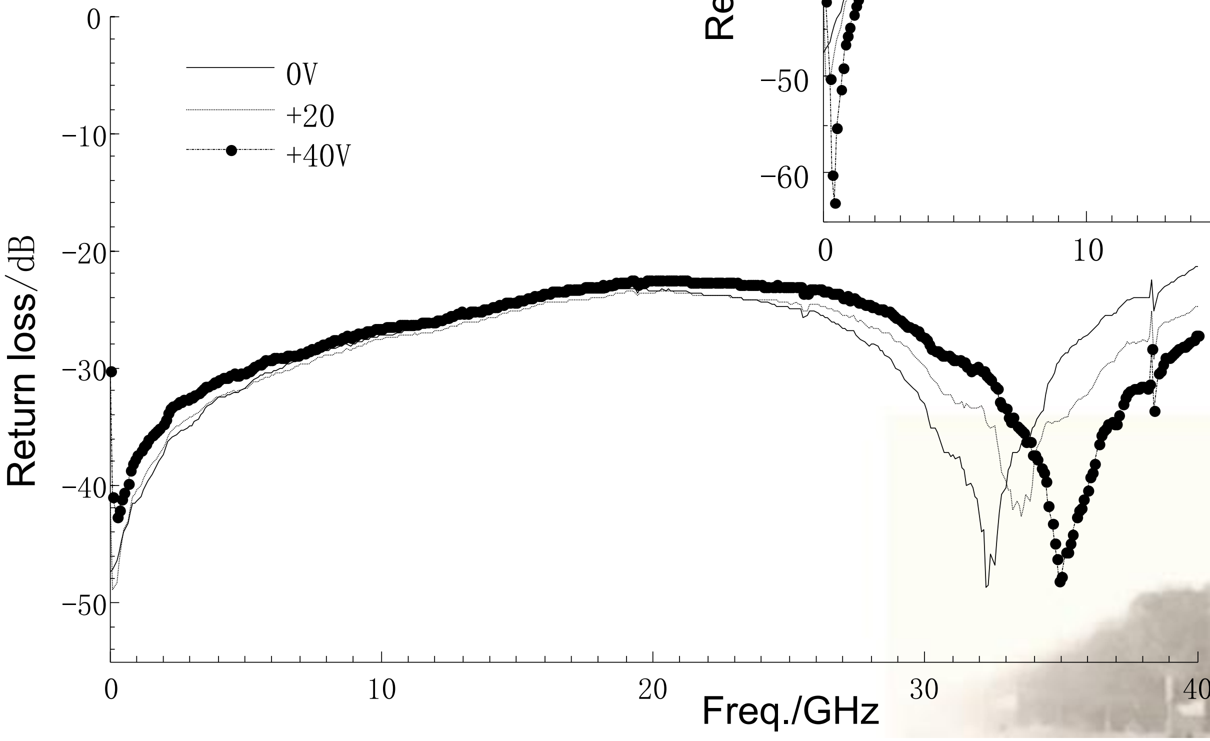
Return loss



150
120
90
20
500
700

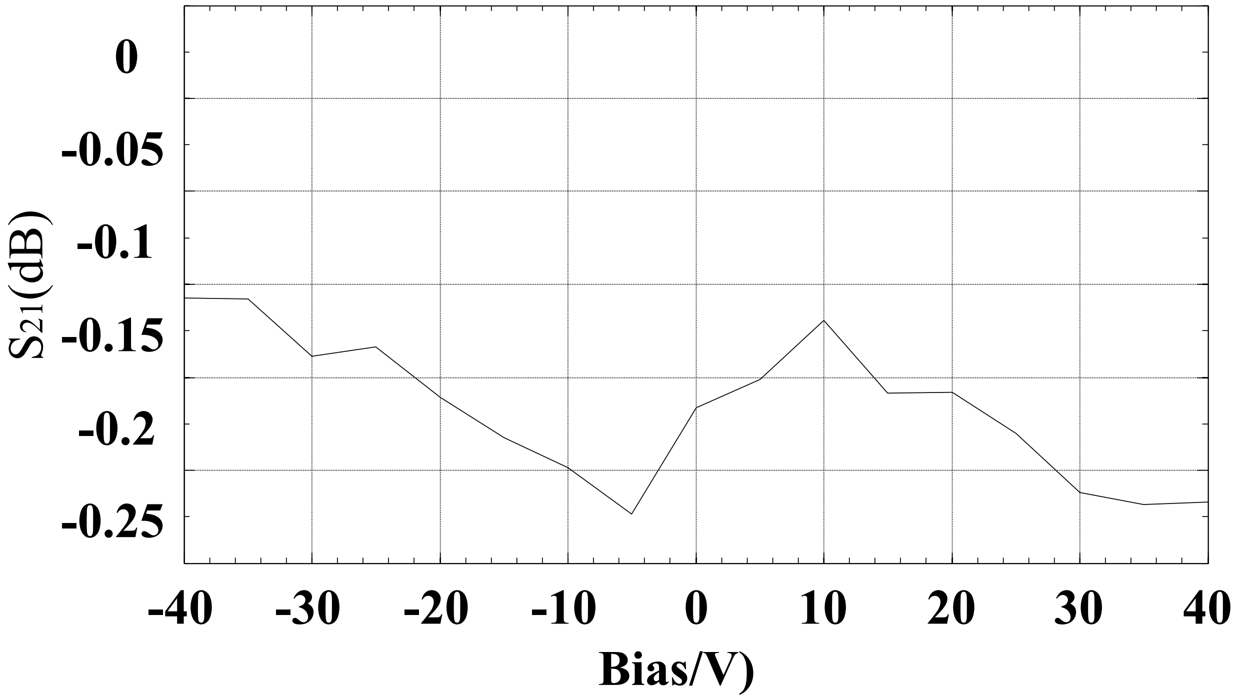


0V
-20
-40V
Return loss/dB
0
-10
-20
-30
-40
-50
-60
0
10
20
30
40
Freq./GHz

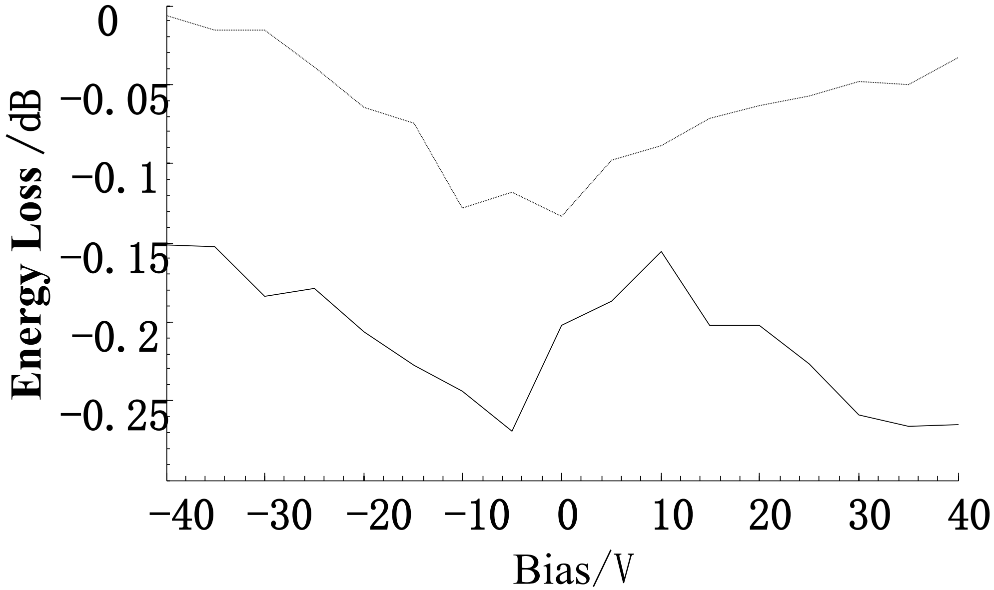


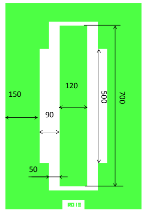
0V
+20
+40V
Return loss/dB
0
-10
-20
-30
-40
-50
0
10
20
30
40
Freq./GHz

Insertion loss@38.5GHz

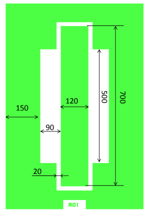


Energy loss





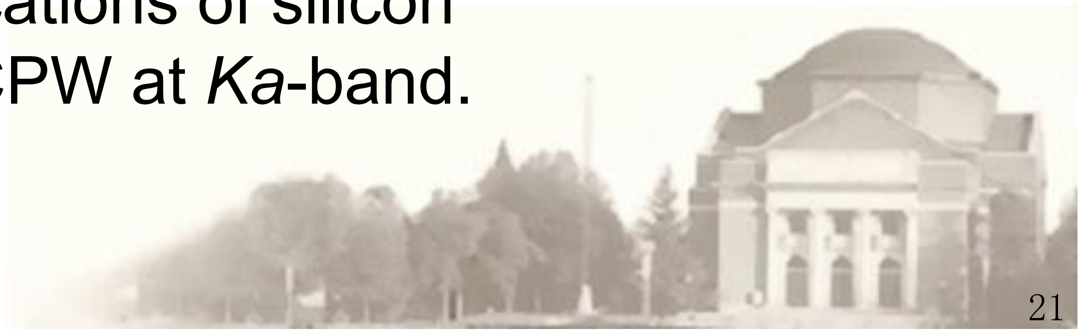
B@35. 0 GHz



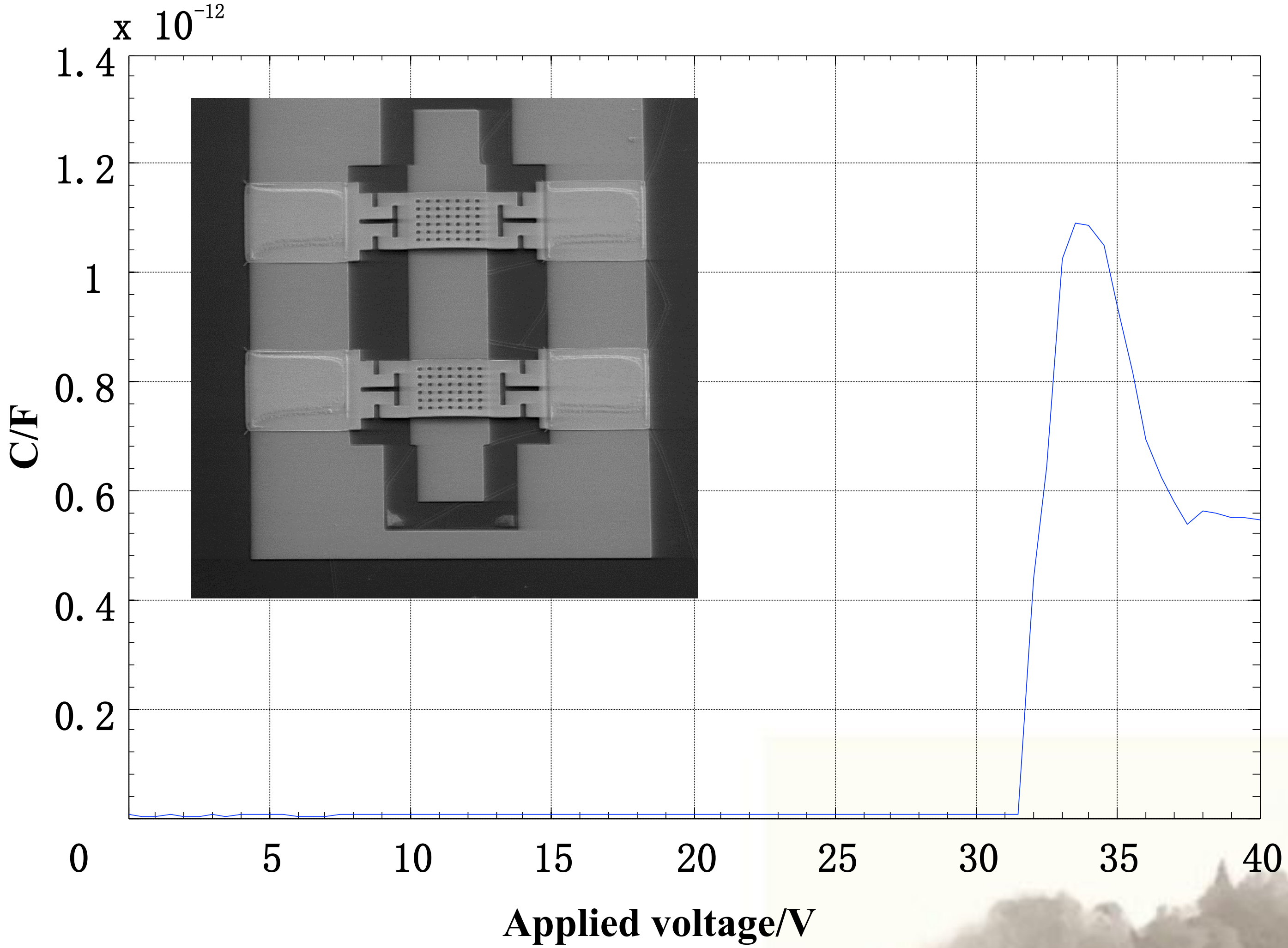
A@38. 5 GHz

$$|S_{11}|^2 + |S_{21}|^2$$

To our knowledge, this is the best result in the publications of silicon substrate based CPW at *Ka*-band.

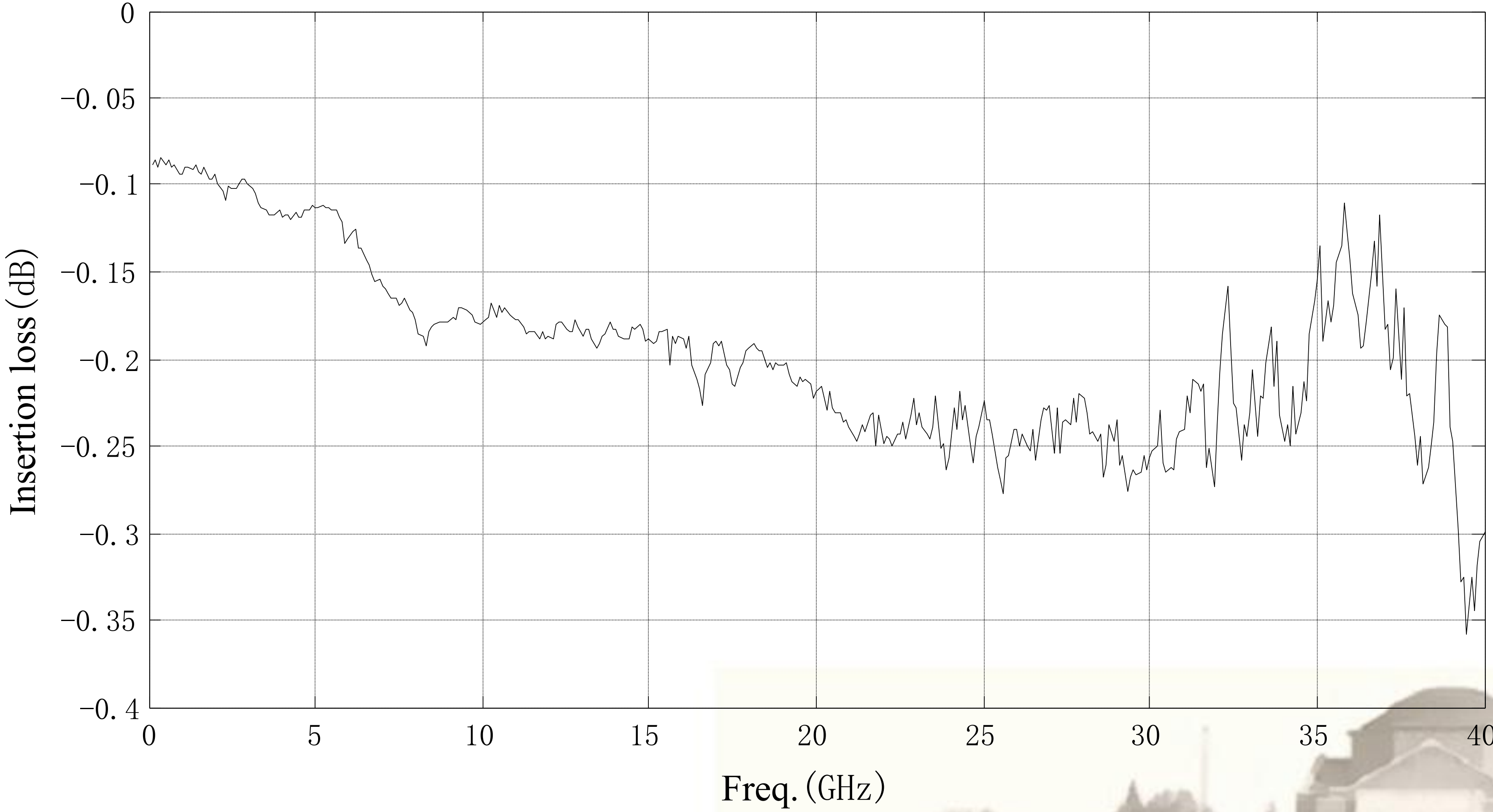


Driving Voltage of the Switch



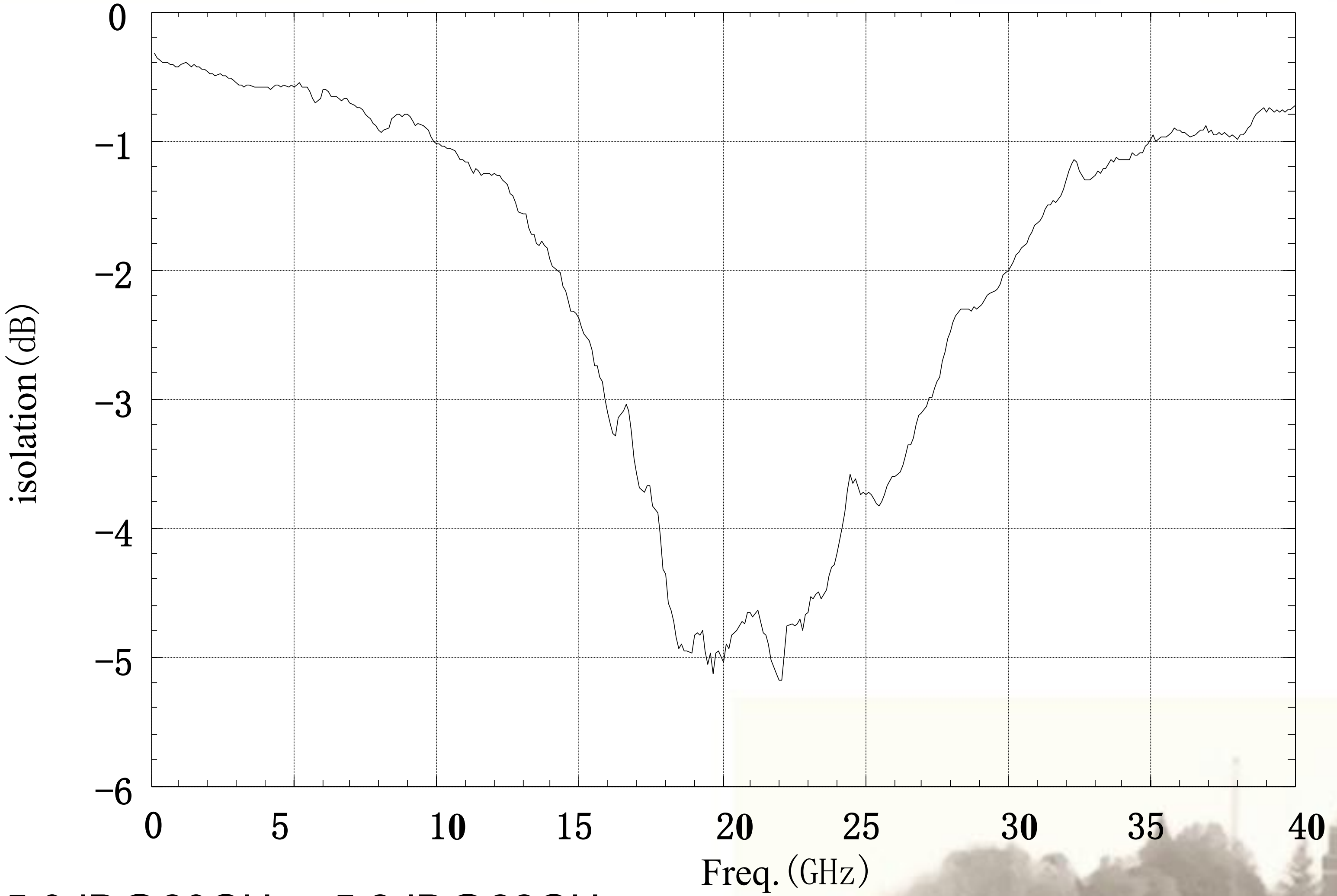
CV curve: 32V

Insertion loss



-0.14dB@35GHz， -0.28dB@0~37GHz， -0.36dB@0~40GHz

Isolation



-5.0dB@20GHz, -5.2dB@22GHz

Conclusion

- We discussed the raised MOS-type CPW with low losses and RF MEMS capacitive switch for aerospace applications.
- The fabricated CPW lines achieve an Energy loss

  lower than -0.010 dB/mm at 35GHz
- The RF MEMS switches achieves an insertion losses

  lower than -0.14dB at 35GHz

Thank You for Attention!

清華大學
Tsinghua University