

# Evaluation of Strained Silicon MOSFETs for RF and Analog Circuit Applications

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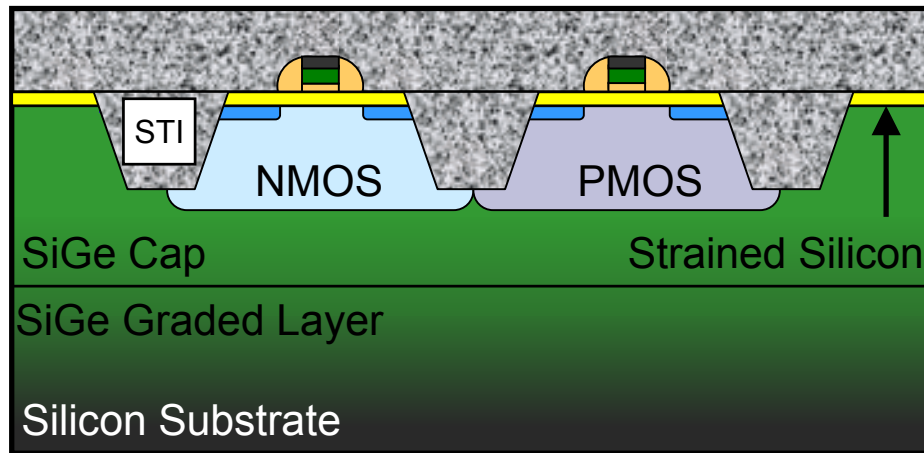
# Outline

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- Introduction
- Broad evaluation of RF/Analog Figures-of-Merit
- Assessment of strained silicon for specific RF/Analog functions
- Conclusion

# Introduction

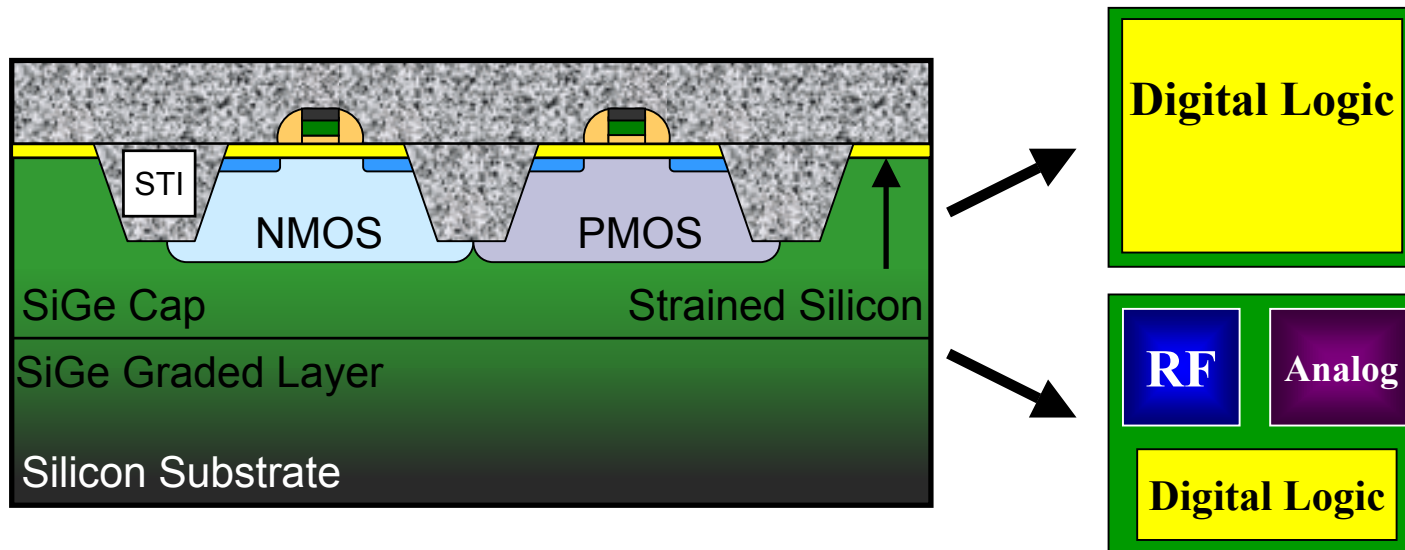
- Strained silicon CMOS is emerging
  - Very promising ITRS option
  - Enhanced performance from digital logic perspective



**Digital Logic**

# Introduction

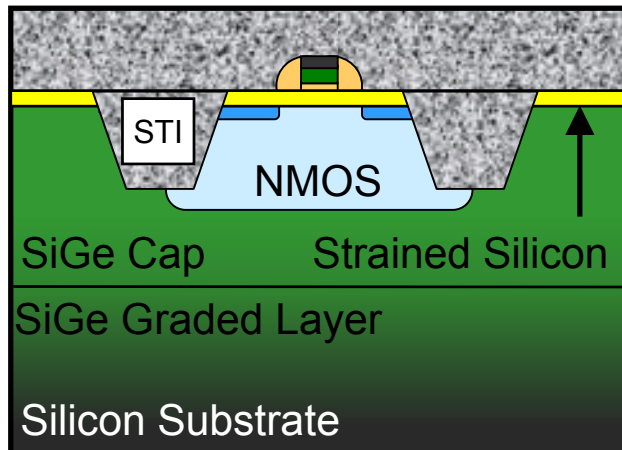
- Strained silicon CMOS is emerging
  - Very promising ITRS option
  - Enhanced performance from digital logic perspective



- Modern CMOS process must also support RF/Analog
  - Communications is driver of semiconductor industry
- **This work:** Evaluation of RF/Analog potential of strained silicon CMOS

# Introduction

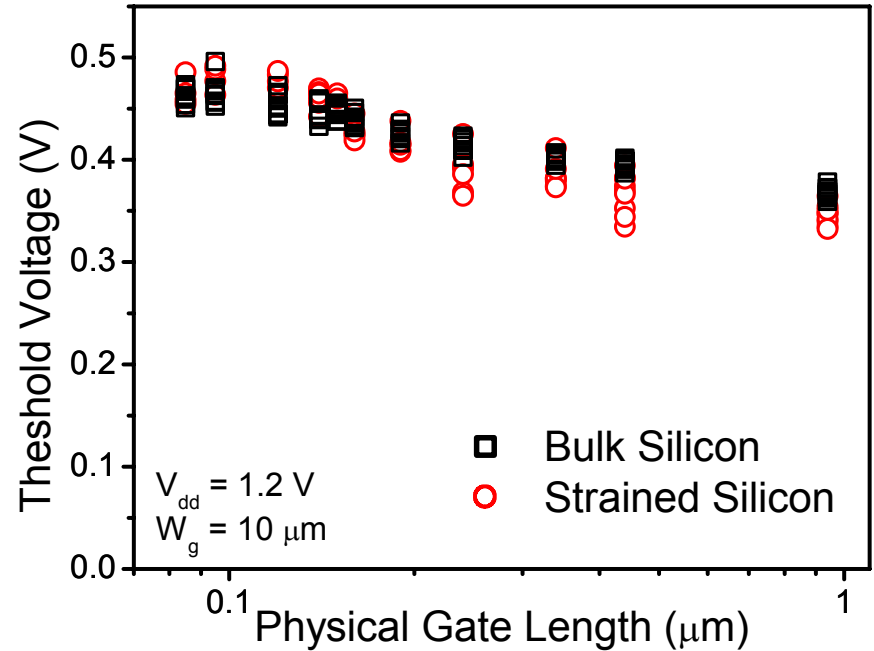
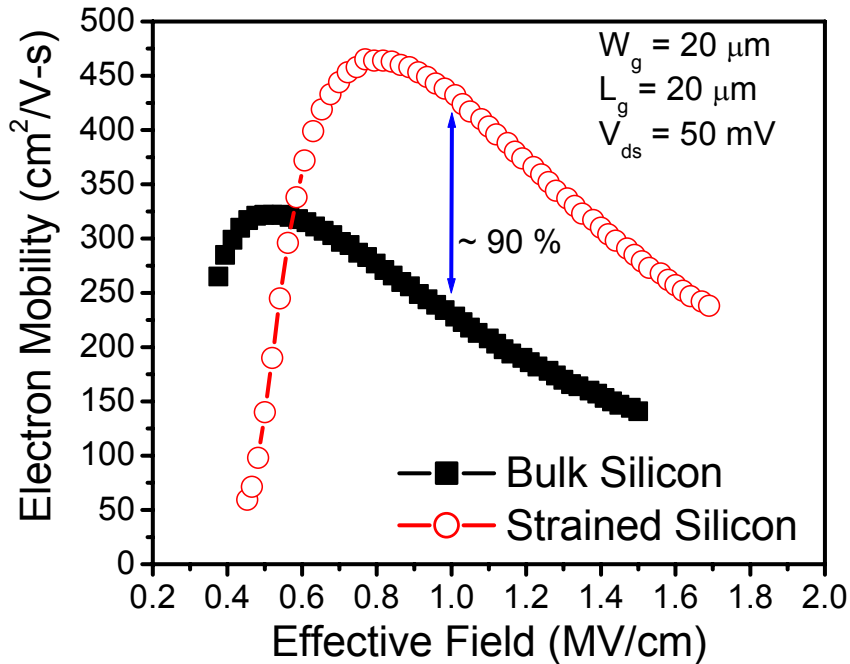
- Prior work on RF/Analog strained silicon MOSFETs:
  - G. Tenet et al. (2000), M. H. Lee et al. (2003)
    - Demonstrated  $f_t$ , noise characteristics of strained Si MOSFETs
    - Excellent early work
    - Limitations: Non-standard MOSFET processes, Large  $L_g$
- **This Work:**
  - First demonstration of RF/Analog properties of a standard digital MOSFET process
  - Evaluation through direct comparison of strained Si and silicon



## Fabrication Process

- $L_g = 85$  nm,  $t_{gox} = 20$  Å
- STI, spacers, salicide
- $V_t$  matched Strained Si to silicon
- Ge. Comp. = 20 %, CMP,  $t_{Si} = 17.5$  nm

# Introduction



- Low field electron mobility enhancement of 90 %
- $V_t$  matched from  $L_g = 1 \mu\text{m}$  to 85 nm for fair comparison

# Introduction

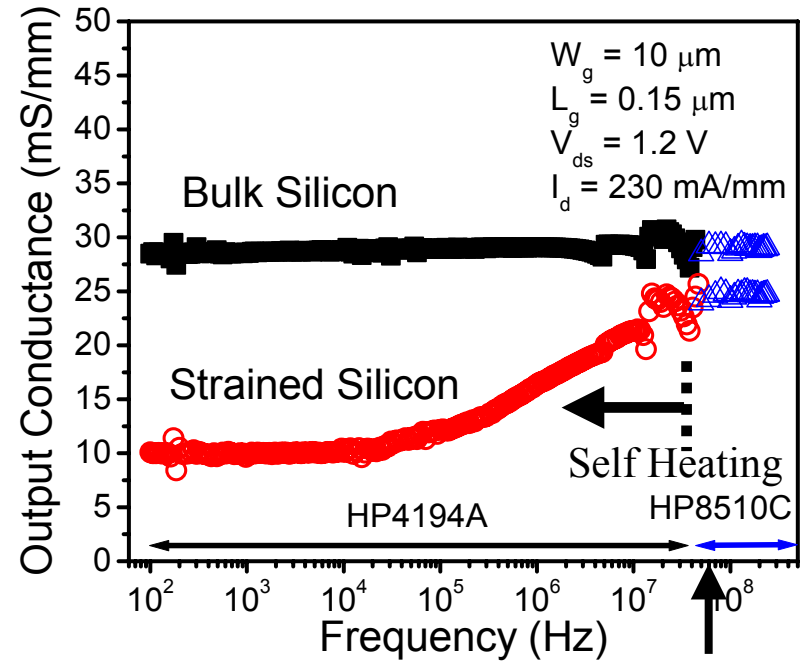
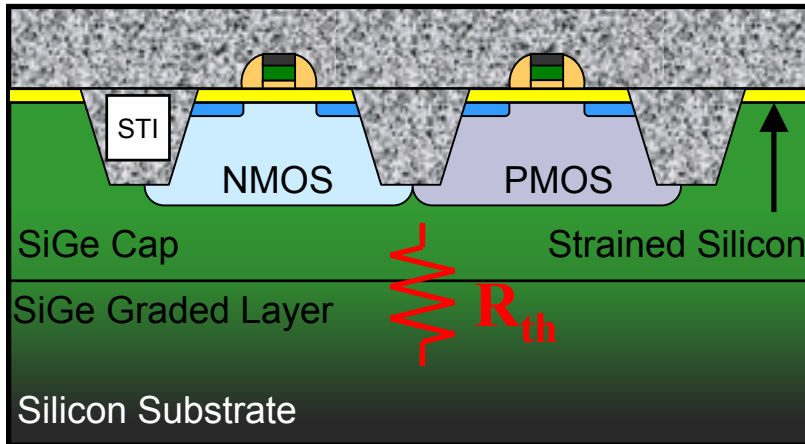
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- Broad evaluation for RF/Analog difficult
  - Diverse building-block circuits with varying requirements:

Analog Amplifiers	RF switch
LNA	Mixer
PA	VCO
Switched capacitor	
- Methodology:
  1. Examine Figures-of-Merit
    - General Figures-of-Merit: Relevant to all functions
      - $g_m$ ,  $g_o$ ,  $A_v = g_m/g_o$ ,  $f_t$
    - Specific Figures-of-Merit: Relevant to specific functions
      - $1/f$  noise,  $R_{on}$ : VCO, RF/Analog switches and PA
  2. Use results to assess suitability of strained silicon for specific functions

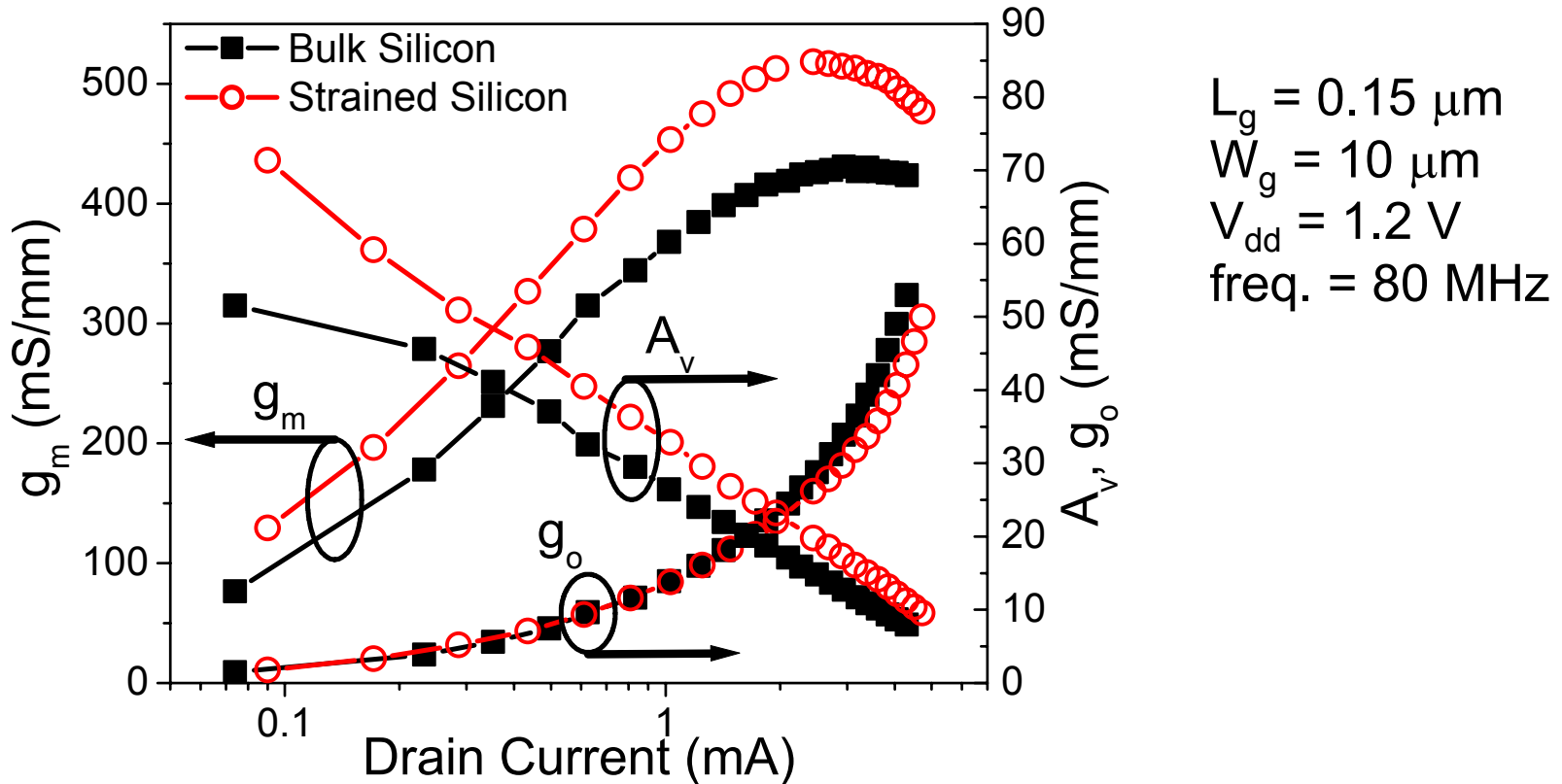
# General RF/Analog Figure-of-Merit Evaluation

- First evaluate  $g_m$ ,  $g_o$ ,  $A_v$
- Must properly consider self-heating



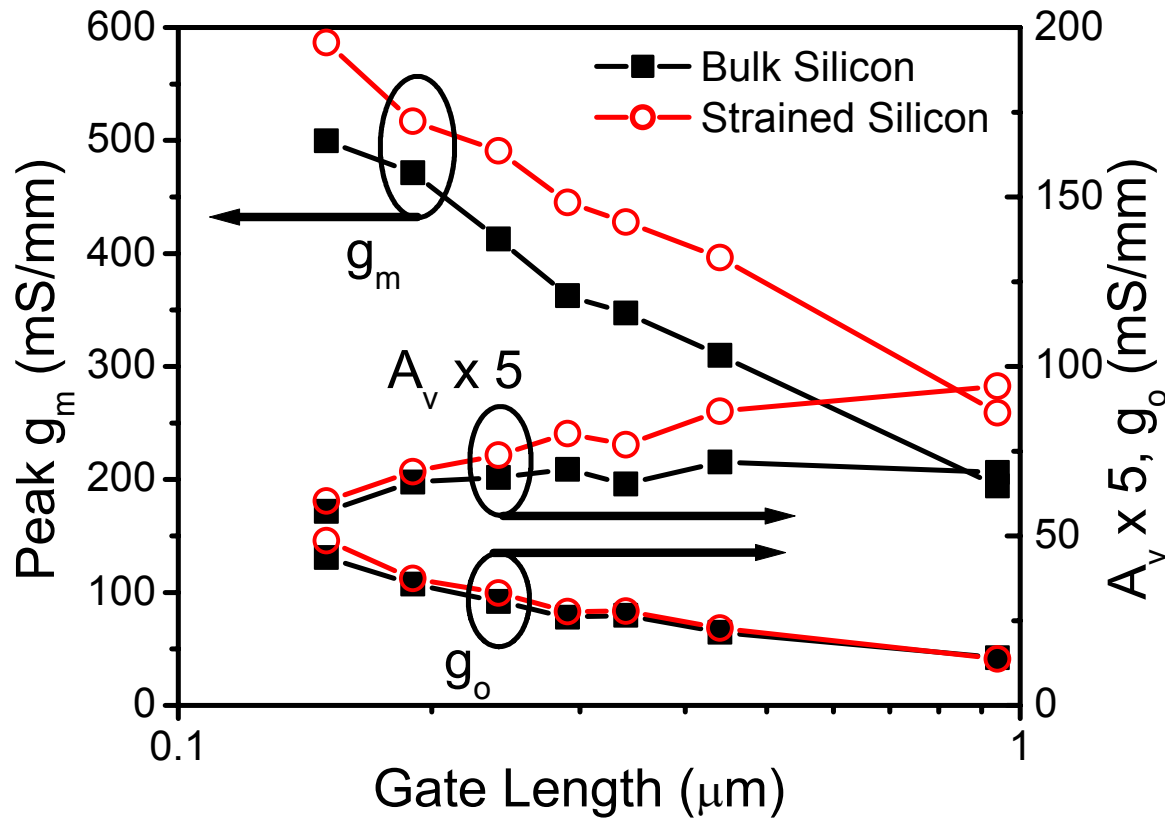
- Self-heating must be taken into account for proper analog evaluation
- Need freq.  $> 1/\tau_{SH}$  to avoid artificially low  $g_o$
- All  $g_m$ ,  $g_o$ ,  $A_v$  data taken at freq. = 80 MHz

# General RF/Analog Figure-of-Merit Evaluation



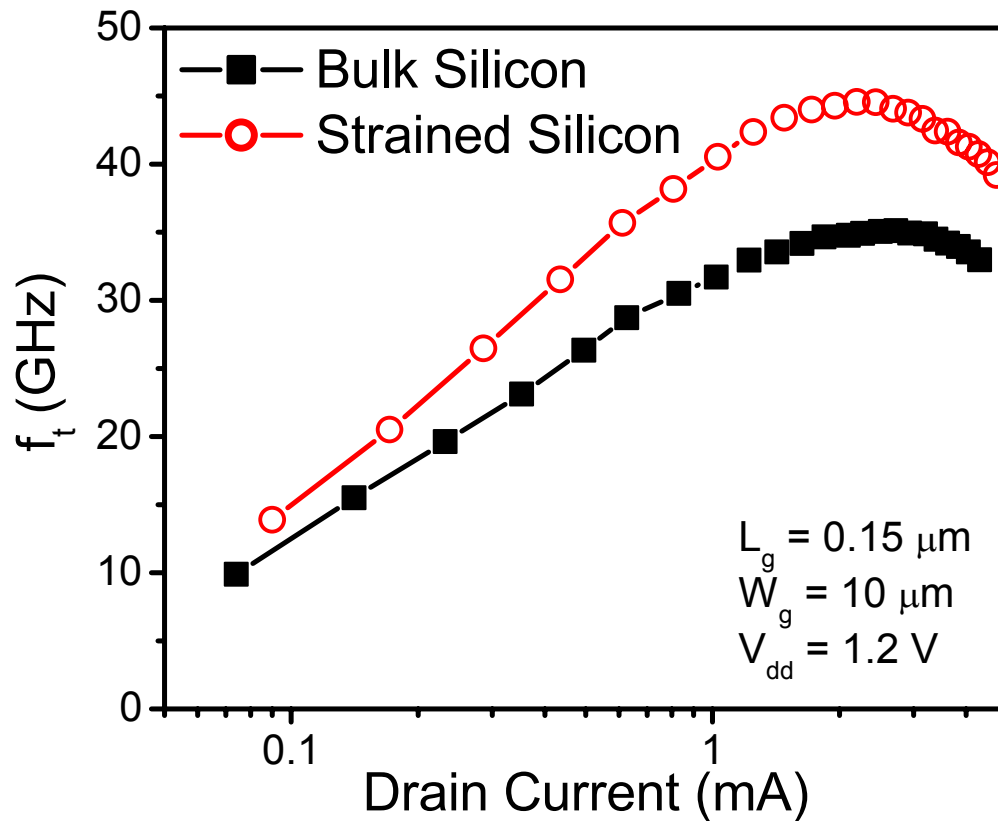
- $g_m, A_v$  enhanced by 20 % with same  $g_o$

# General RF/Analog Figure-of-Merit Evaluation



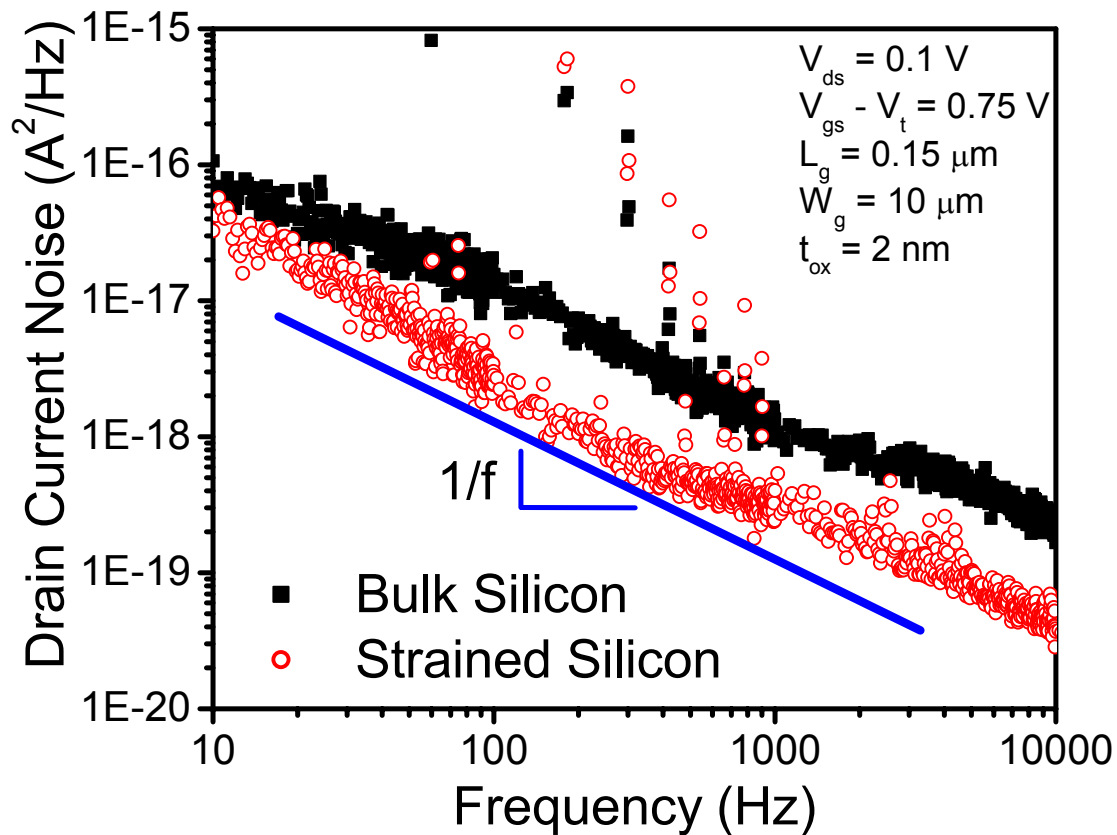
- Both short and long gate lengths important for analog
- Peak  $g_m$  enhanced with matched  $g_o$ 
  - $L_g \sim 0.5 \mu\text{m}$ : 30-35 %,  $L_g \sim 0.2 \mu\text{m}$ : 20-25 %

# General RF/Analog Figure-of-Merit Evaluation



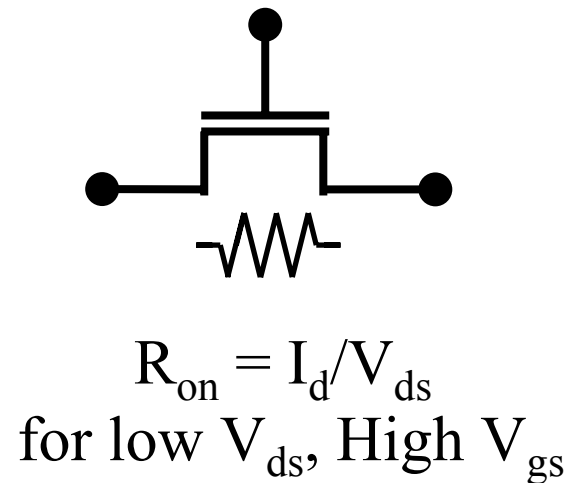
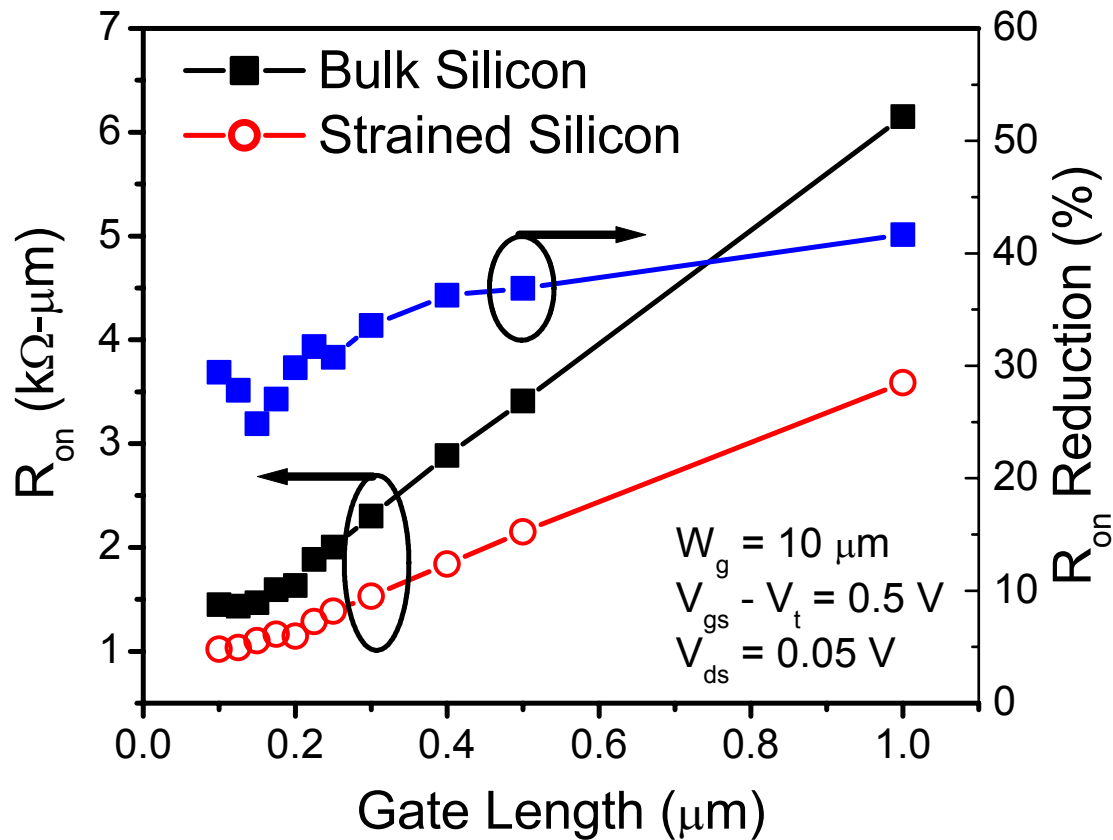
- $f_t$  silicon = 34 GHz,  $f_t$  strained Si = 44 GHz
- $f_t$  enhanced by 25 % at  $L_g = 0.15 \mu\text{m}$

# Specific RF/Analog Figure-of-Merit Evaluation



- $1/f$  noise of strained silicon, silicon comparable

# Specific RF/Analog Figure-of-Merit Evaluation



- Greatly reduced  $R_{on}$ :
  - $L_g \sim 0.5 \mu\text{m}$ : 40 %
  - $L_g \sim 0.2 \mu\text{m}$ : 25-30 %

# Assessment for specific RF/Analog Functions

- Properties of strained silicon
  - Self-heating has effect on  $g_o$
  - Increased  $g_m$ ,  $A_v$ ,  $f_t$ , similar 1/f noise, reduced  $R_{on}$ ,

	Increased Self-Heating	Increased $g_m$ , $A_v$ and $f_t$	Reduced $R_{on}$	<b>Strained Silicon Suitability</b>
Analog Amplifier	-	+	No Impact	<i>Good</i>
Analog Switch	No Impact	+	++	<i>Excellent</i>
RF LNA	-	+	No Impact	<i>Good</i>
RF Power Amplifier	--	+	++	<i>Uncertain</i>
RF Switch	No Impact	+	++	<i>Excellent</i>

- Strained silicon offers significant advantages for a wide variety of RF/Analog functions

# Conclusion

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- Broad evaluation of standard strained silicon MOSFET technology for RF/Analog circuit applications
- Strained silicon demonstrated to offer significant advantages for RF/Analog circuits:
  - Self-heating affects  $g_o$
  - Enhanced  $g_m$
  - Enhanced  $f_t$
  - Similar  $1/f$  noise
  - Greatly reduced  $R_{on}$
- Strained Silicon CMOS has tremendous potential for RF and Analog circuit applications

# Acknowledgements

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