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國立清華大學 National Tsing Hua University

Silicon-nitride Films Deposited by PECVD Method on Silicon Substrate for Next Generation Laser Interference Gravitational Wave Detector

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LIGO-G1600363
LIGO-G1601298

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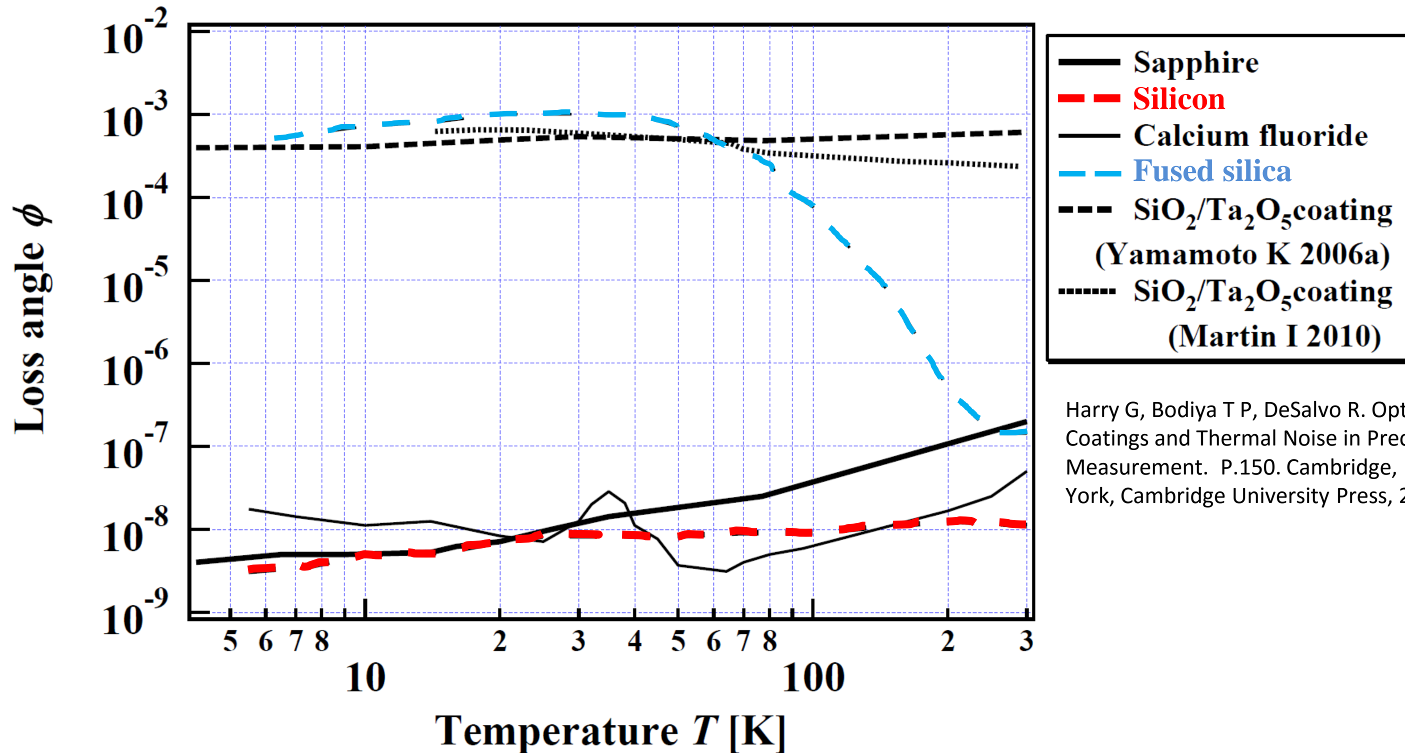
Silicon for Next Generation Cryogenic LIGO Mirror Substrate



Harry G, Bodiya T P, DeSalvo R. Optical Coatings and Thermal Noise in Precision Measurement. P.150. Cambridge, New York, Cambridge University Press, 2012.

Silicon is a good candidate for next generation cryogenic LIGO mirror substrate due to its low cryogenic mechanical loss

→ **Seeking for silicon compatible dielectric multi-layer HR coatings**

Chemical Vapor Deposition (CVD) for multi-layer dielectric mirror coating

PECVD system

http://www.examiner.com/article/transition-to-450mm-silicon-wafers-impact-on-analog-chips

CVD deposition for 18“ silicon wafer. Large area uniform coating up to 18" is not an issue.

SiH_4
NH_3
N_2
300℃, 1 Torr
RF power 20W 13.56MHz
Transfer chamber
Load-lock chamber
Wafer in
SiH_4
N_2O
N_2
300℃, 1 Torr

Process chamber 1 ： SiNx

$SiH_4 + 4NH_3 \xrightarrow{plasma} Si(NH_2)_4 + 4H_2$

$3Si(NH_2)_4 \xrightarrow{heat} Si_3N_4 + 8NH_3$

Process chamber 2 ： SiO_2

$SiH_4 + 2N_2O \longrightarrow SiO_2 + 2N_2 + 2H_2$

Si

Silicon substrate side view

Chemical Vapor Deposition (CVD) for multi-layer dielectric mirror coating

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Large size is not an issue.

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300˚C, 1 Torr

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20W 13.56MHz

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Load-lock chamber

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SiH_4

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Process chamber 2 : SiO_2

$SiH_4 + 2N_2O \rightarrow SiO_2 + 2N_2 + 2H_2$

Si

Silicon substrate side view

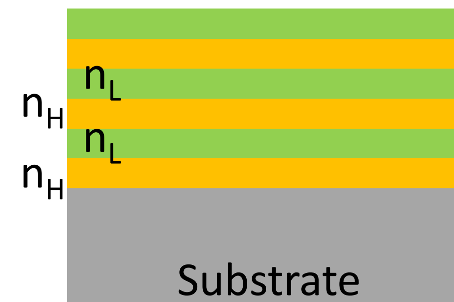
Candidate Silicon IC-Compatible CVD Thin Films for Optical Purpose

	a-Si	SiC	SiNx	SiO_2
Refractive index @ 1550 nm	3.5[1]	3.2-2.6[11,12]	2.6-1.8[16][30]	1.45[19,20]
Absorption range	<700 nm[2]	<380 nm [13]	<510 nm[17]	<200 nm[21]
Young's modulus (GPa)	100 ~ 150[3-5]	392 ~ 694[14]	85~210[16]	72~83[20,22-25]
Stress# (MPa)	-400 ~ -900[6,7]	-160 ~ -510[15]	+600 ~ 1200 [16]	+60 ~ -257[25]
Loss angle at RT	$3.3x10^{-4}$ e beam[8] $5x10^{-4}$ sputter[8]	--	~$2x10^{-6}$ high stress [18] ~$3x10^{-4}$ stress relief [18] $1.4x10^{-5}$ $SiN_{0.87}$ @107Hz[30]	$4.76x10^{-4}$ [20] $1x10^{-4}$ [26-28]
Cryogenic peak	？？*[8-10]	--	No**[18]	$5x10^{-4}$ @20K[29]

\# - : compressive +: tensile

* Existence of cryogenic peaks depends on hydrogen content [8,9] and heat treatment [9,10].

** No cryogenic peak at MHz range [18]

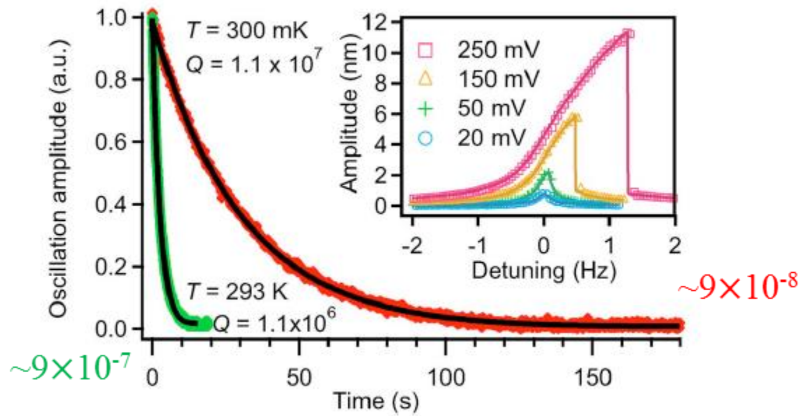


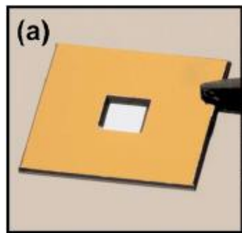
For LIGO application, the films need to be low-losses.

i.e. Low optical loss and Low mechanical loss

Silicon Nitride Films

Lower mechanical loss at cryogenic





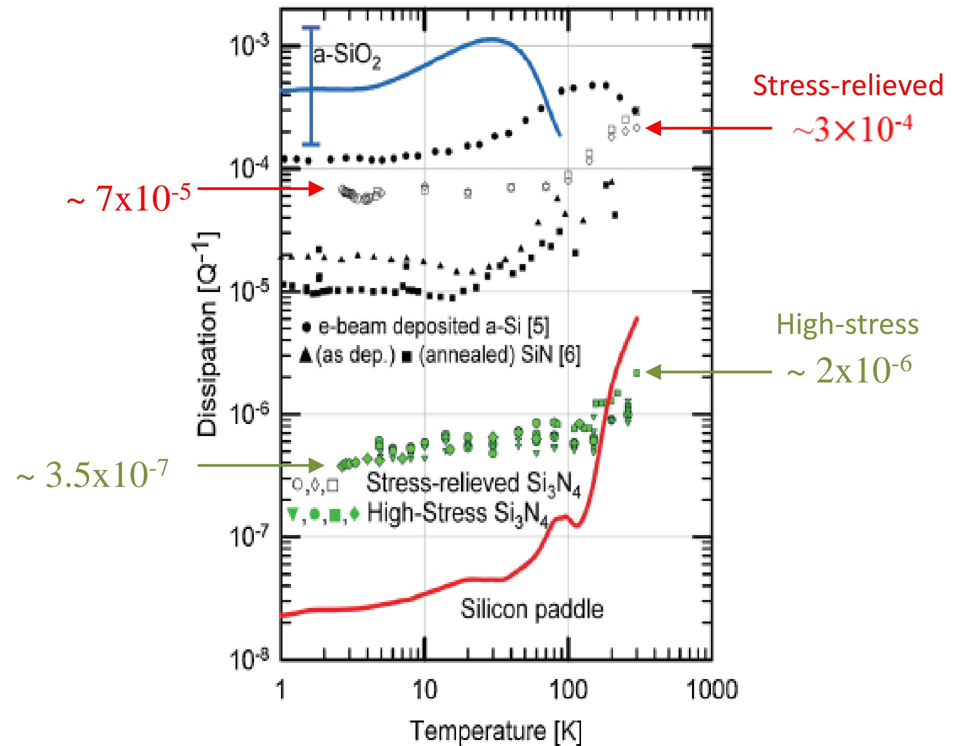
1 mm ×1 mm × 50 nm
Norcada x-ray membrane.

Ref. 2: B. M. Zwickl, et al. Appl. D Phys. Lett. **92**, 103125 (2008)

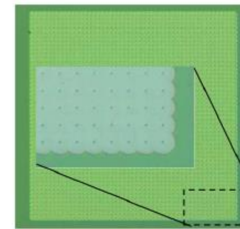
These results were for MHz range.

How about frequency in GW range, i.e. 10Hz ~1000Hz ?

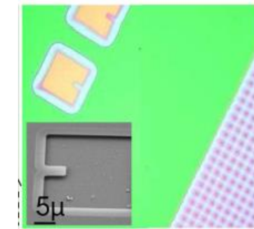
Stress reduces mechanical loss



high-stress Si_3N_4 membrane

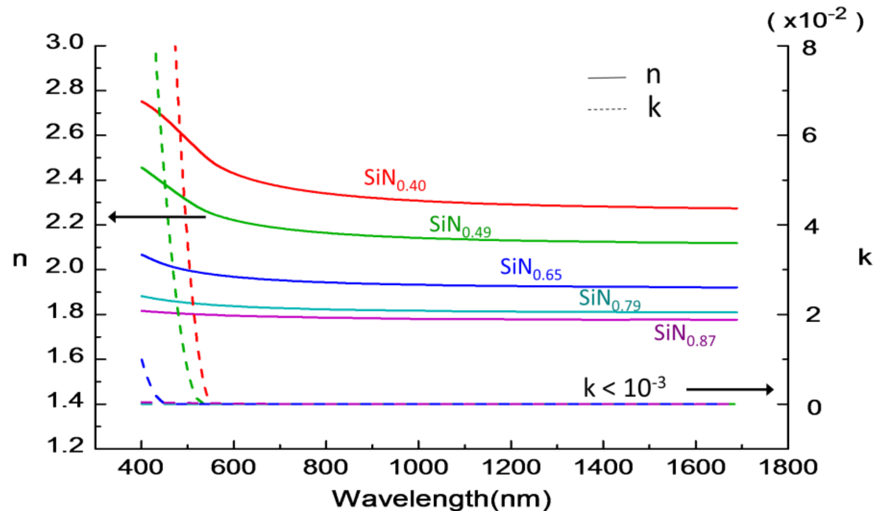


Si_3N_4 stress–relieved cantilever

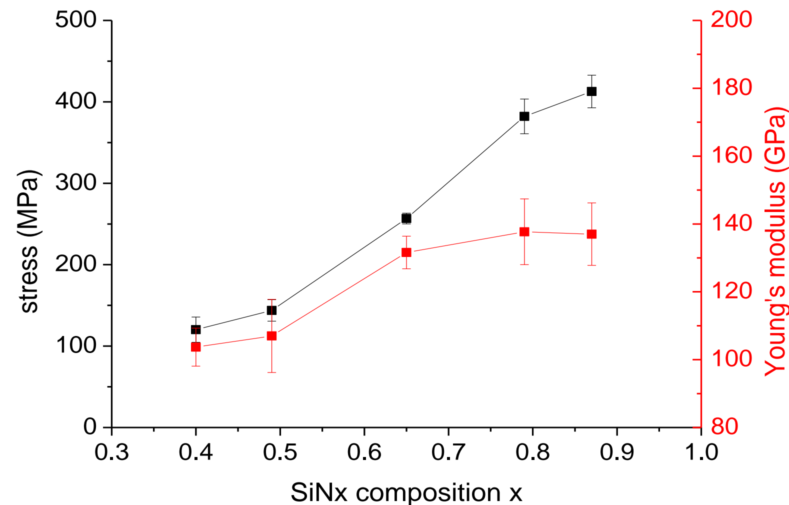


Ref. 1: D. R. Southworth , et al.PhysRevLett.**102**.225503(2009)

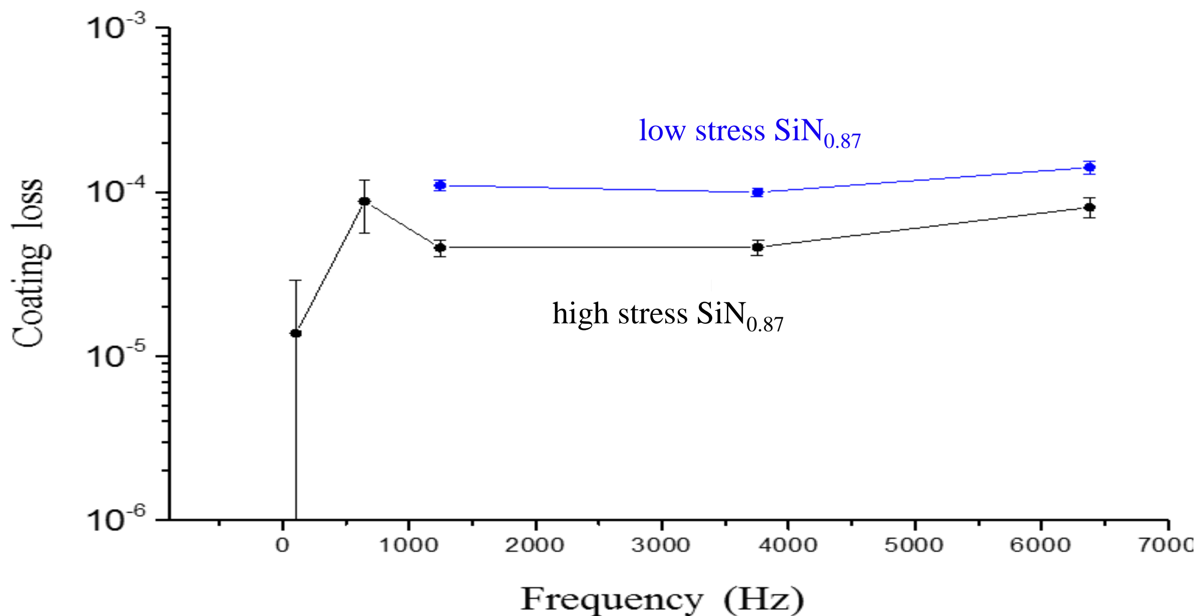
Material Properties of PECVD amorphous SiNx from NTHU



Refractive index and extinction coefficient



Stress and Young's modulus



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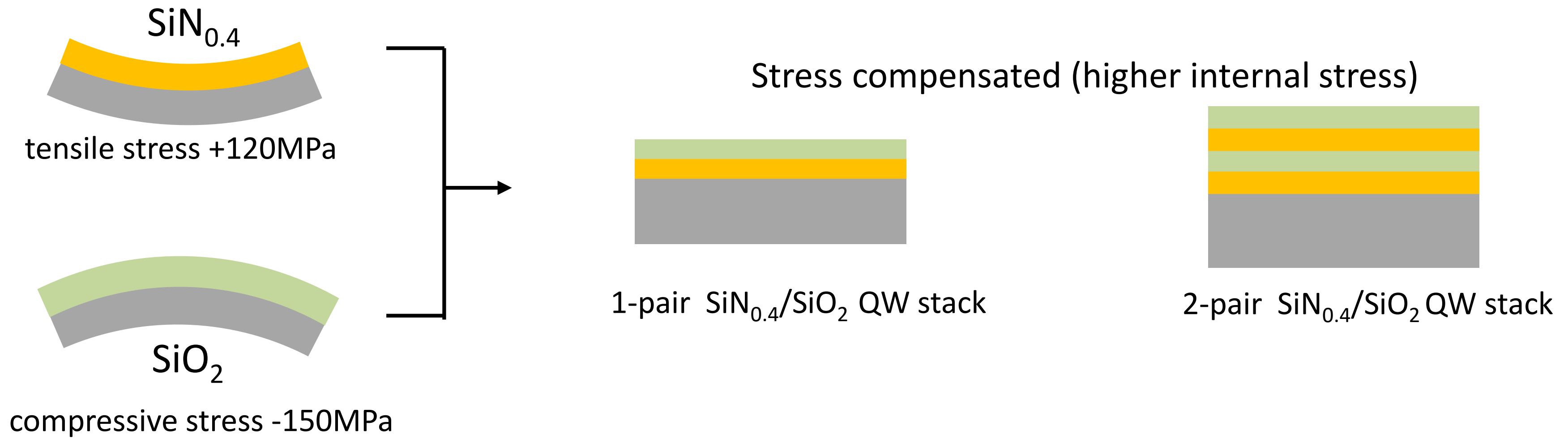
Mechanical Loss of QW $SiN_{0.4}/SiO_2$ Stacks Deposited by PECVD



	1-pair (2-layer)	2-pair (4-layer)
High tress (measured)	$(4.42 \pm 1.83)\times10^{-5}$	$(9.28 \pm 0.55)\times10^{-5}$
Low stress (calculated)	$(3.08 \pm 0.74)\times10^{-4}$	$(3.16 \pm 0.77)\times10^{-4}$

Preliminary results of the mechanical loss for QW stacks of 1-pair and 2-pair

Conclusion

- Dual-reactor CVD in conventional silicon-IC process can be used for HR optical coating.
- SiN_x films showed stress-reduced mechanical loss in GW frequency range.
- $SiN_{0.4}/SiO_2$ QW pairs deposited by all-CVD process showed room temperature mechanical loss in 10^{-5}, lower than Ta_2O_5-TiO_2/SiO_2 in current GW detector.

References for the table in page 5

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