OPTICAL ABSORPTION MEASUREMENTS ON SION COATING FABRICATED BY LOW PRESSURE CHEMICAL VAPOR DEPOSITION

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OUTLINE

- Motivations: SiON Coating with LPCVD
- New Fabrication Gas Line in TSRI
- Results
- Comparison with PECVD
- Future Plans

INTRDUCTION

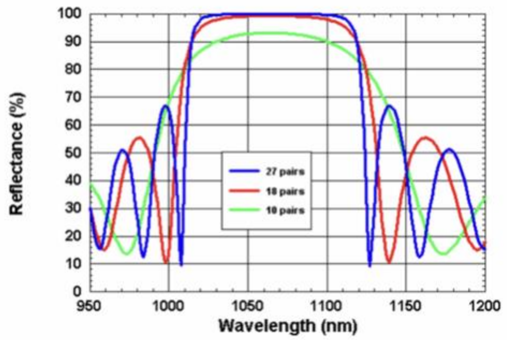
- CONCEPT
  - WE ARE LIGO MEMBER. IN ORDER TO HAVE FUTURE LIGO VIRGO LIKE THE CRYOGENICS VIRGO, CURRENT COATING NOISE IS LIMITED BY LIGO SENTIVITY AND ALSO EFFECTED BY LOW FREQUENCY.
  - TO SLOVE THESE PROBLEMS, WE HAVE TO DEVELOPE THE NEW COATING MATERIAL IN TSRI, WHERE THE PLACE THAT WE CAN MAKE THE NEW SAMPLE.
  - NOWADAYS WE USE THE TSRI LOW PRESSURE CHEMICAL VAPOR DEPOSITION (LPCVD) TO HAVE STACK COATING, USING HIGH REFLECT AND LOW REFLECT LIKE SIN AND SION.
  - IN THE FUTURE, WE'LL ADD AMORPHOUS SILICON TO BECOME HIGH REFLECT MATERIAL AND THEN ADDING SIN AND SION TO HAVE THREE LAYER MATERIAL.

HIGH LOW COATING

- **INDEX REFRACTION:**

- IN STACK COATING, WE USE TWO LAYER WITH HIGH-LOW INDEX REFLECTION TO COAT ON THE GLASS SUBSTRATE.

- FIRST WE COAT THE LOW REFRACTIVE INDEX LAYER LIKE SIN (INDEX REFLECTION:1.62), THEN WE COAT HIGH REFLECTIVE INDEX LAYER LIKE SION (INDEX REFLECTION:2.68).



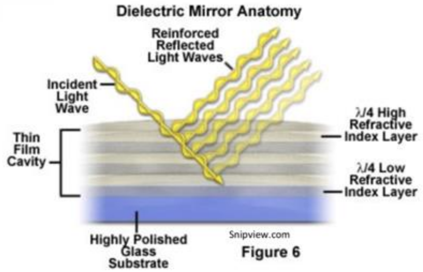
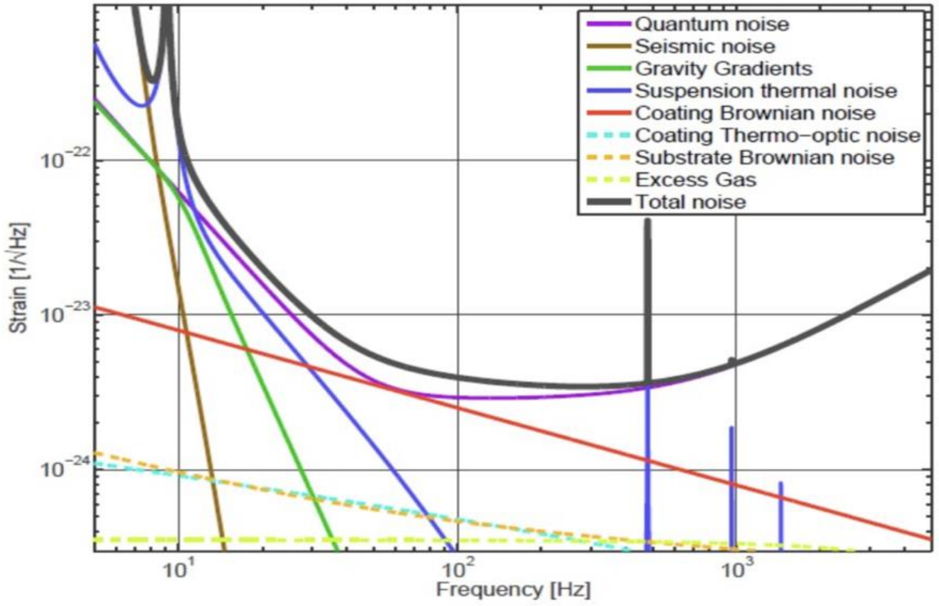


Figure 6



WHY CHANGING SION COATING FROM PECVD TO LPCVD

- **ABSORPTION LOSS IN PECVD SION:**
  - NITRIDE-LIKE SION HAD LOWER MECHANICAL LOSS THAN IBS SIO_2 ANNEAL & SILICA-LIKE SION @ 10K
  - SILICA-LIKE SION HAD LOWER MECHANICAL LOSS THAN IBS SIO_2 ANNEAL & NITRIDE-LIKE SION @120K
  - IBS SIO_2 ANNEAL HAD LOWER ABSORPTION THAN SILICA-LIKE SION AND NITRIDE-LIKE SION
- **THICKNESS REDUCTION PROBLEM**
  - PECVD SION WITH HIGH TEMPERATURE ANNEALING GIVES RISE TO THICKNESS REDUCTION.
  - AT STACKING IT WITH A HIGH-REFRACTIVE-INDEX MATERIAL, EXPECTS PECVD SION HAVE NUMEROUS THERMAL EFFECTS, MAKING IT DIFFICULT TO PRECISELY CONTROL THE THICKNESS OF EACH LAYER.

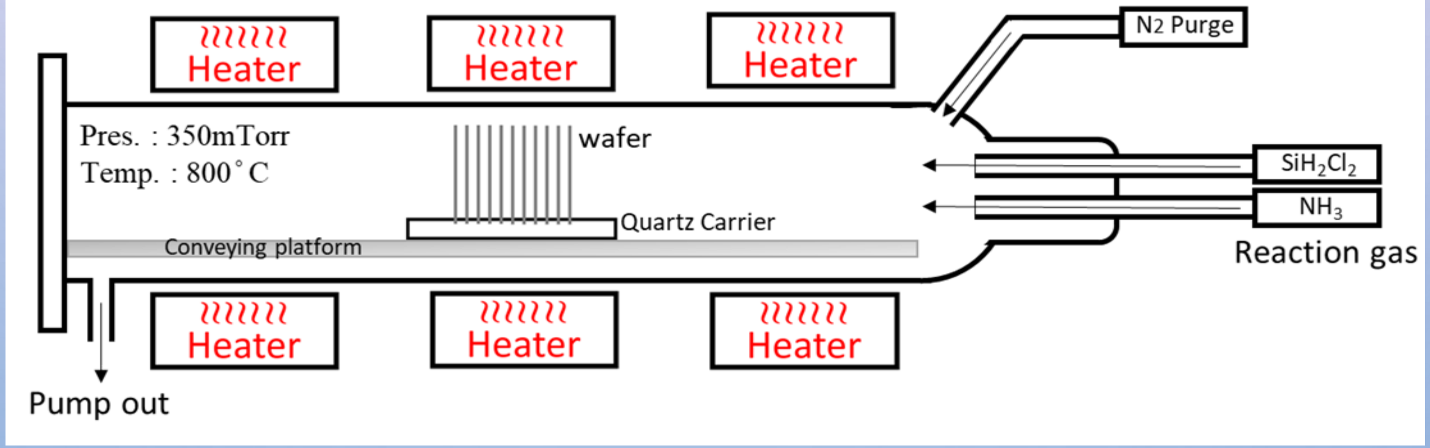
TSRI LPCVD Facility

- **Project funded by AS for LSC Program;**
  - Proposal endorsed by OWG Convener, October 2022;
  - Facility commissioned April 2024.

TSRI LPCVD

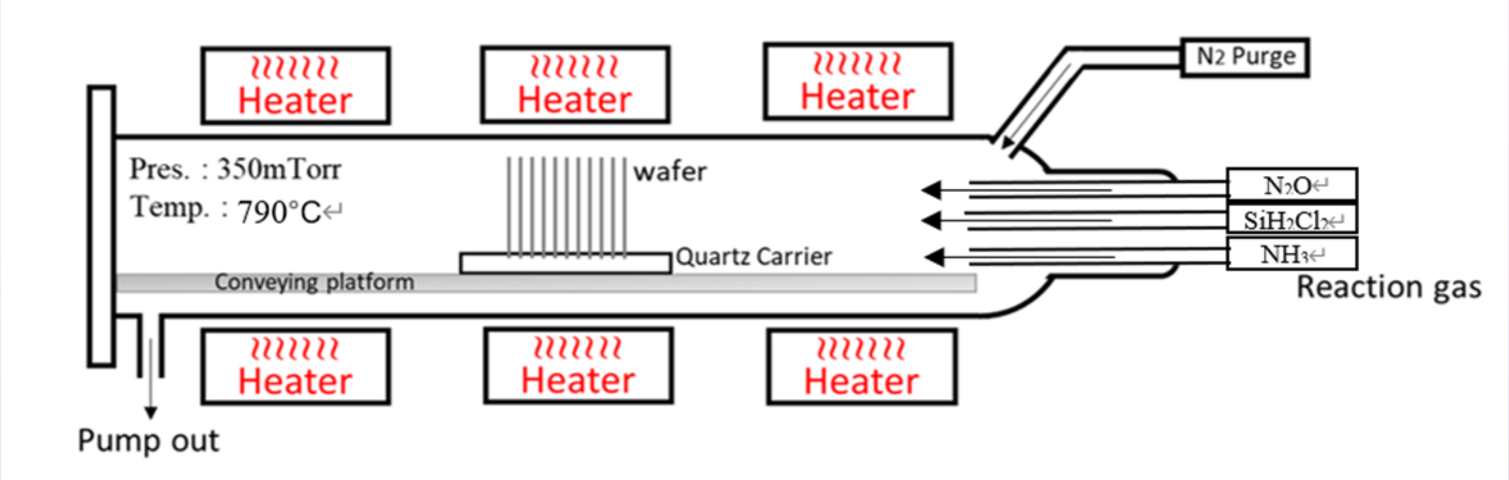
LOW PRESSURE CHEMICAL VAPOR DEPOSITION (LPCVD)

- LOW PRESSURE CHEMICAL VAPOR DEPOSITION (LPCVD) IS A HIGH TEMPERATURE DEPOSITION PROCESS (HENCE AVOIDING ANNEALING) AND PROVIDES LARGE AREA UNIFORM DEPOSITION.
- LOWER STRESS, LOWER N-H BOND DENSITY AND LOWER H ATOMIC DENSITY IN THE LPCVD FILMS THAN IN PECVD WAS REPORTED.
- WE EXPECT N-H BONDS CAN BE SIGNIFICANTLY REDUCED AND SI- BONDS BE LESS INCREASED BY USING LPCVD FOR DEPOSITION OF SION FILMS AND HENCE REDUCING EXTINCTION COEFFICIENTS.

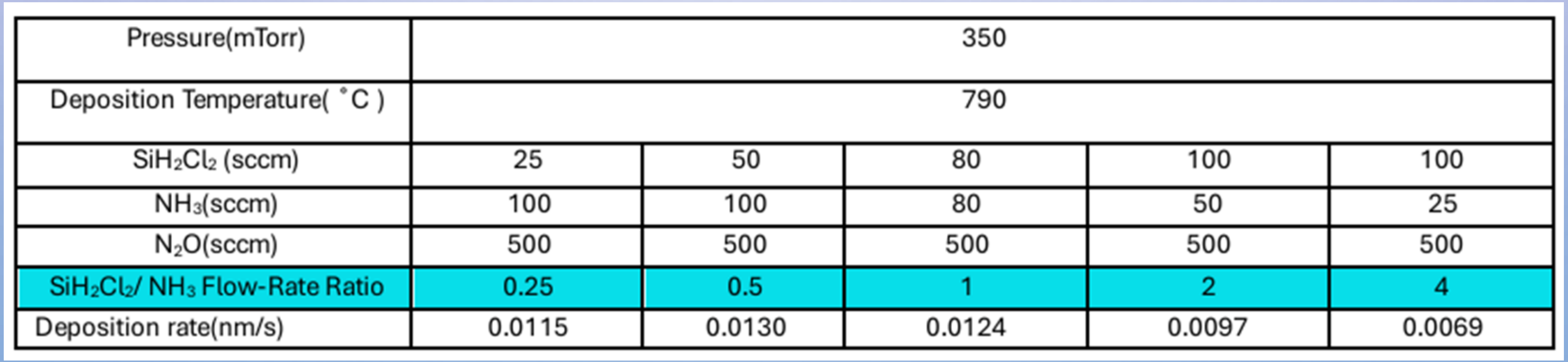


LPCVD PROCESS

LPCVD SION: $SIH_2CL_{2(G)} + N_2O_{(G)} + NH_{3(G)} \longrightarrow SIO_XN_YH_{Z\,(S)}$ + RESIDUAL GAS



PARAMETER OPTIMIZATION: EFFECT OF CHANGING THE [SIH_2CL_2/NH_3 FLOW RATE RATIO] TO THE EXTINCTION COEFFICIENTS.



Pressure(mTorr)	350				
Deposition Temperature(˚C)	790				
SiH_2Cl_2 (sccm)	25	50	80	100	100
NH_3(sccm)	100	100	80	50	25
N_2O(sccm)	500	500	500	500	500
SiH_2Cl_2/ NH_3 Flow-Rate Ratio	0.25	0.5	1	2	4
Deposition rate(nm/s)	0.0115	0.0130	0.0124	0.0097	0.0069

RESULTS

Pressure (mTorr)		350				
Temperature (°C)		790				
SiH_2Cl_2 (sccm)		25	50	80	100	
NH_3 (sccm)		100	100	80	50	25
SiH_2Cl_2/NH_3 Flow-Rate Ratio		1/4	1/2	1/1	2	4
Deposition Rate (nm/s)		0.0115	0.0130	0.124	0.0097	0.0069
Bond Concentration	Dangling Bond Density (10^{18} cm^{-3})	0.34±0.04	0.35±0.23	0.39±0.08	0.60±0.04	1.32±0.05
	N-H (10^{21} cm^{-3})	3.33	3.75	2.35	0.57	0.28
	Si-H (10^{21} cm^{-3})	<DL	<DL	<DL	<DL	< DL
	Si-N (10^{21} cm^{-3})	43.78	46.62	43.69	32.55	19.91
	Si-Si (10^{21} cm^{-3})	18.58	18.79	17.90	16.00	11.50
	Si-O (10^{21} cm^{-3})	47.51	44.92	48.57	59.69	73.84
Atomic Density	Si (10^{21} cm^{-3})	32.11	32.28	32.01	31.06	29.19
	O (10^{21} cm^{-3})	23.75	22.46	24.29	29.84	36.92
	N (10^{21} cm^{-3})	15.69	16.79	15.35	11.04	6.73
	H (10^{21} cm^{-3})	3.30	3.75	2.35	0.57	0.28
Composition		$SiO_{0.74}N_{0.49}H_{0.1}$	$SiO_{0.7}N_{0.52}H_{0.12}$	$SiO_{0.76}N_{0.48}H_{0.07}$	$SiO_{0.96}N_{0.36}H_{0.02}$	$SiO_{1.26}N_{0.23}H_{0.01}$
Refractive Index, n	1064 nm	1.673	1.698	1.676	1.624	1.564
	1550 nm	1.670	1.695	1.674	1.621	1.562
	1950 nm	1.669	1.694	1.673	1.620	1.561
κ (10^{-5})	1064 nm	0.36±0.06	0.46±0.05	0.30±0.04	0.11±0.04	0.23±0.05
	1550 nm	0.49±0.07	0.57±0.02	0.35±0.07	0.28±0.09	0.22±0.07
	1950 nm	0.90±0.08	0.96±0.10	0.78±0.07	0.71±0.07	0.89±0.08
E_g (eV)		5.482	5.245	5.198	5.176	3.481

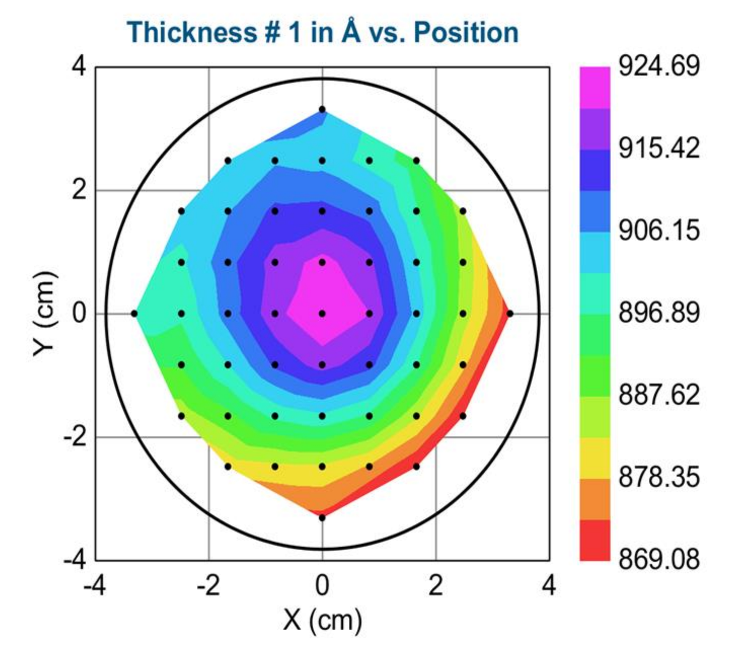
* Detection Limit (DL) of bond concentration and atomic density is 10^{20} cm^{-3}

- By changing the ratio of LPCVD to find the different result:
  - The ratio of SiH_2Cl_2 (25, 50, 80, 100 sccm) and NH_3 (100, 80, 50, 25 sccm)
  - We can compare the result of Refractive Index and Extinction Coefficient

COATING THICKNESS UNIFORMITY

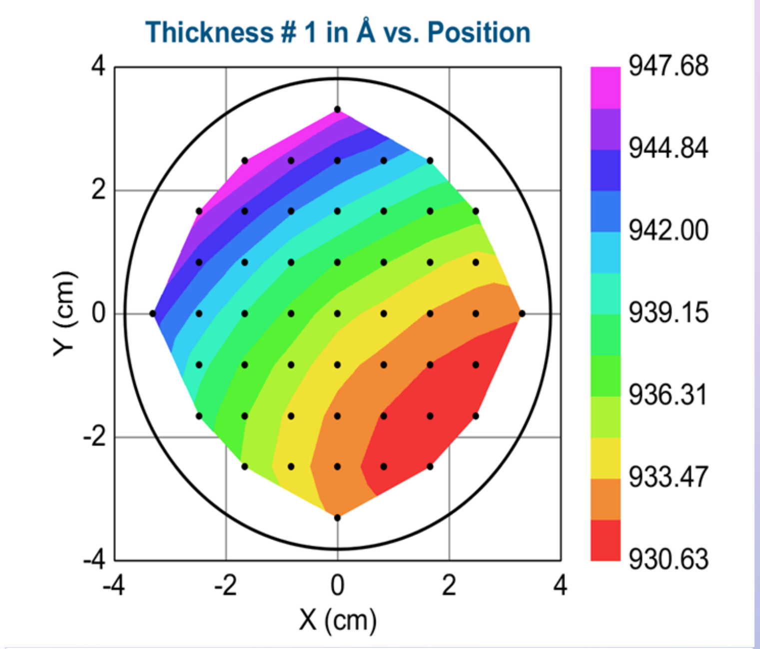
- MEASURED BY SPECTROSCOPIC ELLIPSOMETER.
- DETECT 49 POINTS ON 3INCH WAFER
- LPCVD IMPROVED OVER PECVD
- RESIDUAL SYSTEMATIC DEVIATIONS IN UP-DOWN DIRECTION

PECVD SiON



Position (cm)	Thickness # 1 (Å)
Average	898.53
Min.	869.08
Max.	924.69
Std. Dev.	**14.7**
% Range	**6.189**

LPCVD SiON



Position (cm)	Thickness # 1 (Å)
Average	937.33
Min.	930.63
Max.	947.68
Std. Dev.	**4.81**
% Range	**1.8188**

SUMMARY

- LPCVD, a high temperature low pressure deposition method, was demonstrated to deposit SiON thin films with lower extinction coefficients than the PECVD methods.
  - The best extinction coefficients are

    1.1×10^{-6} at 1064nm, 2.8×10^{-6} at 1550nm and 7.1×10^{-6} at 1950nm
- LPCVD SiON shows improved characteristic properties over PECVD SiON:
  - Much lower hydrogen content and N-H bond density → **lower optical loss**
  - Better thickness uniformity → **promising prospects on stacking**
- Future Plans
  - Amorphous silicon is a strong candidate as high-index material for future gravitational-wave detectors, both at room temperature (1064 nm) in multimaterial mirror designs and at cryogenic temperatures (1550 and 2000 nm) in standard mirror designs.
  - We’ll stack three layers with high-low method, it similar with before but we add amorphous silicon in high refractive index.