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Cryogenic Mechanical Loss of SiO_2 film Deposited by Plasma Enhanced Chemical Vapor Deposition Method

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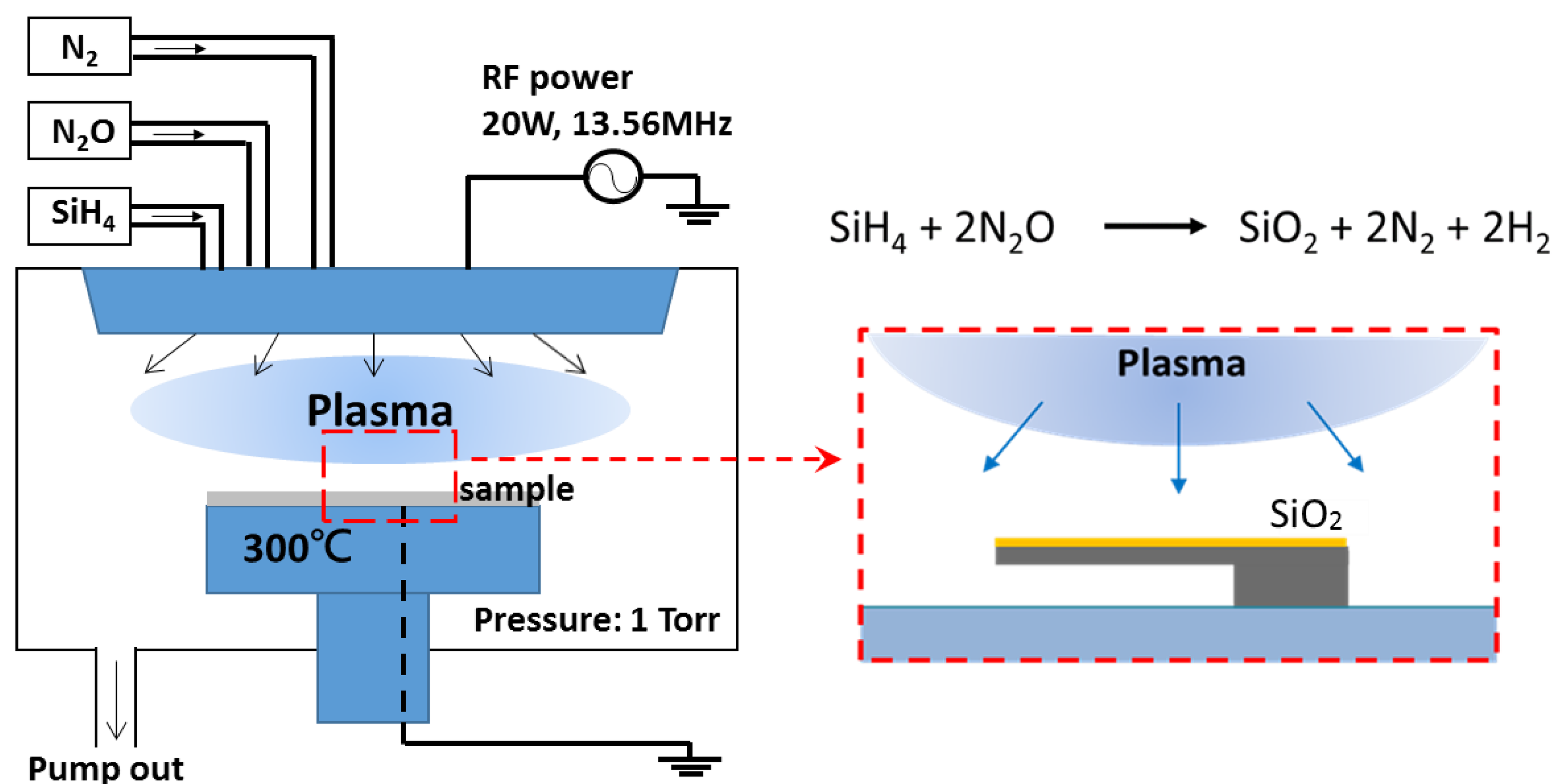
Introduction

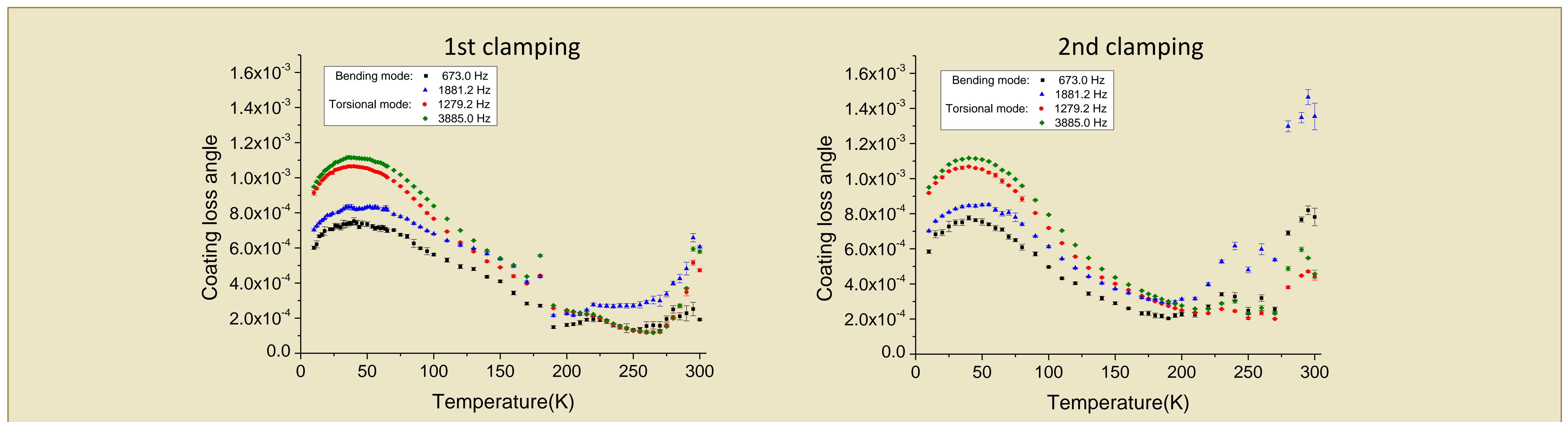
Chemical vapor deposition (CVD) is a common method in semiconductor IC industry to fabricate thin films. Large area deposition, close to the size of mirrors for laser interference gravitational waves detector, on silicon wafer with diameter up to 12" is a common practice and 18" is in the state of the art. Many thin film materials for optical purpose can be deposited by using CVD. We have been exploring the possibility of using CVD for the GW detector mirror coatings[1]. Mechanical loss of these materials are of prime interest. Here we report cryogenic mechanical loss of SiO_2 films fabricated by using plasma enhanced CVD (PECVD). Comparison to the SiO_2 films fabricated by others means, e.g. ion beams sputter, is also given.

PECVD process



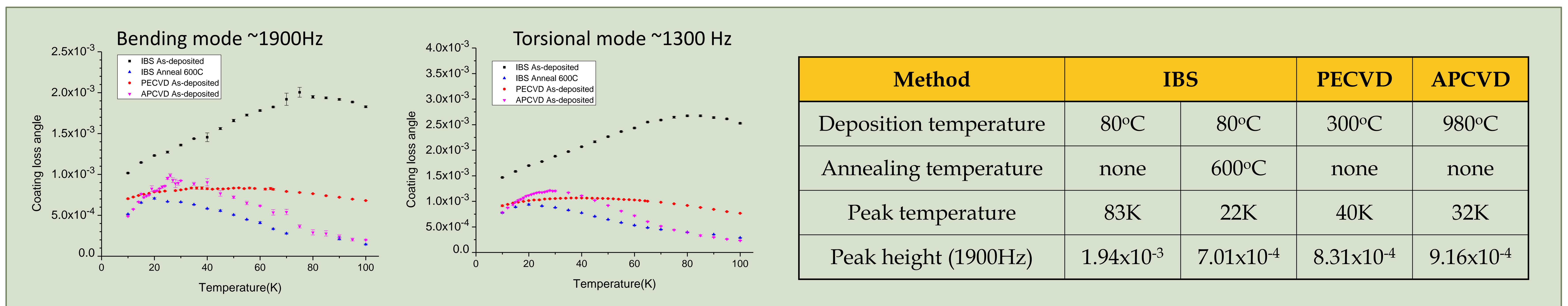
SiH_4, N_2O and N_2 gases were fed into the reaction chamber at 1 torr pressure and 20W RF power was used to generate plasma. Chemical reaction took places and SiO_2 film was condensed on the substrate, i.e. a silicon cantilever, that was held at 300°C. The deposition rate was about 65 nm/min. This rate was faster than ion beam sputters (~8 nm/min). Refractive indices were 1.45 at 1550 nm and 1064 nm, respectively. Extinction coefficient was below the detection limit ($\sim10^{-3}$) of ellipsometry. The film is suitable optically to serve as the low index layer in the QW stack where PECVD α-Si(n=3.4) or SiN_x(n=1.7-2.3) serve as the high index layer such that a complete QW high reflector stack could be fabricated continuously in the PECVD chambers.

Results of cryogenic mechanical loss measurement



The figures above show the cryogenic loss angle of the SiO_2 film measured by using cantilever ring-down method. Results for 2 times clamping, measured once and re-clamped for the second measurement, are shown. As reported in LIGO-G1700301, the peaks at high temperature are false peaks from re-clamping and should be disregarded. Values at mid-temperature range were affected by the tails of the false peaks and were not accurate. Values below ~100K are consistent for the two measurements. A profound cryogenic peak exists at ~40K.

Comparison of the cryogenic loss of SiO_2 films deposited by different methods at different temperature



Method	IBS		PECVD	APCVD
Deposition temperature	80°C	80°C	300°C	980°C
Annealing temperature	none	600°C	none	none
Peak temperature	83K	22K	40K	32K
Peak height (1900Hz)	1.94×10^{-3}	7.01×10^{-4}	8.31×10^{-4}	9.16×10^{-4}

Here we compiled data from our previous reports [2][3] and shown in the figures above to compare the loss angle of SiO_2 deposited by different methods from our lab. IBS: ion beam sputter, APCVD: atmospheric pressure CVD. PECVD: plasma enhanced CVD.

Characteristics of the loss peak for each deposition method are listed in the table above. It is apparent that the peak temperature shifts to lower temperature with higher deposition or annealing temperature. Peak height decreases with higher deposition or annealing temperature up to 600°C.

Reference:

[1] S Chao et al., "Mechanical loss of PECVD SiNx films and quarter-wave $SiN_{0.40}/SiO_2$ stack and scaling-up the CVD process for large mirror coatings ", LIGO document: G1700304 (2017)

[2] S Chao et al., "A closed loop cryogenic mechanical loss measurement system for cantilever samples", LIGO document: G1501048 (2015)

[3] L C Kuo et al., "Preliminary Results of Cryogenic Losses for Titania, Silica, Silicon Nitride Films and Silicon Substrate", LIGO document: G11601703 (2016)