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# Mechanical loss of silica film on silicon cantilever deposited by PECVD method

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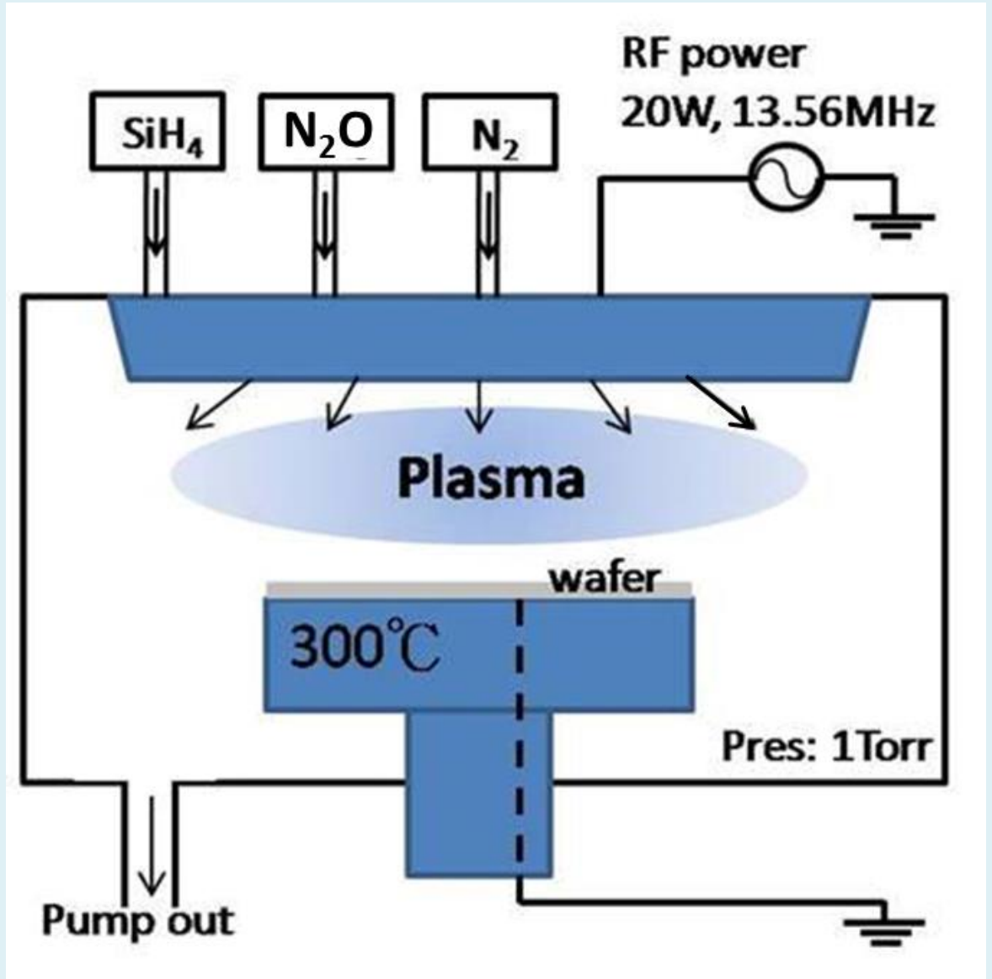
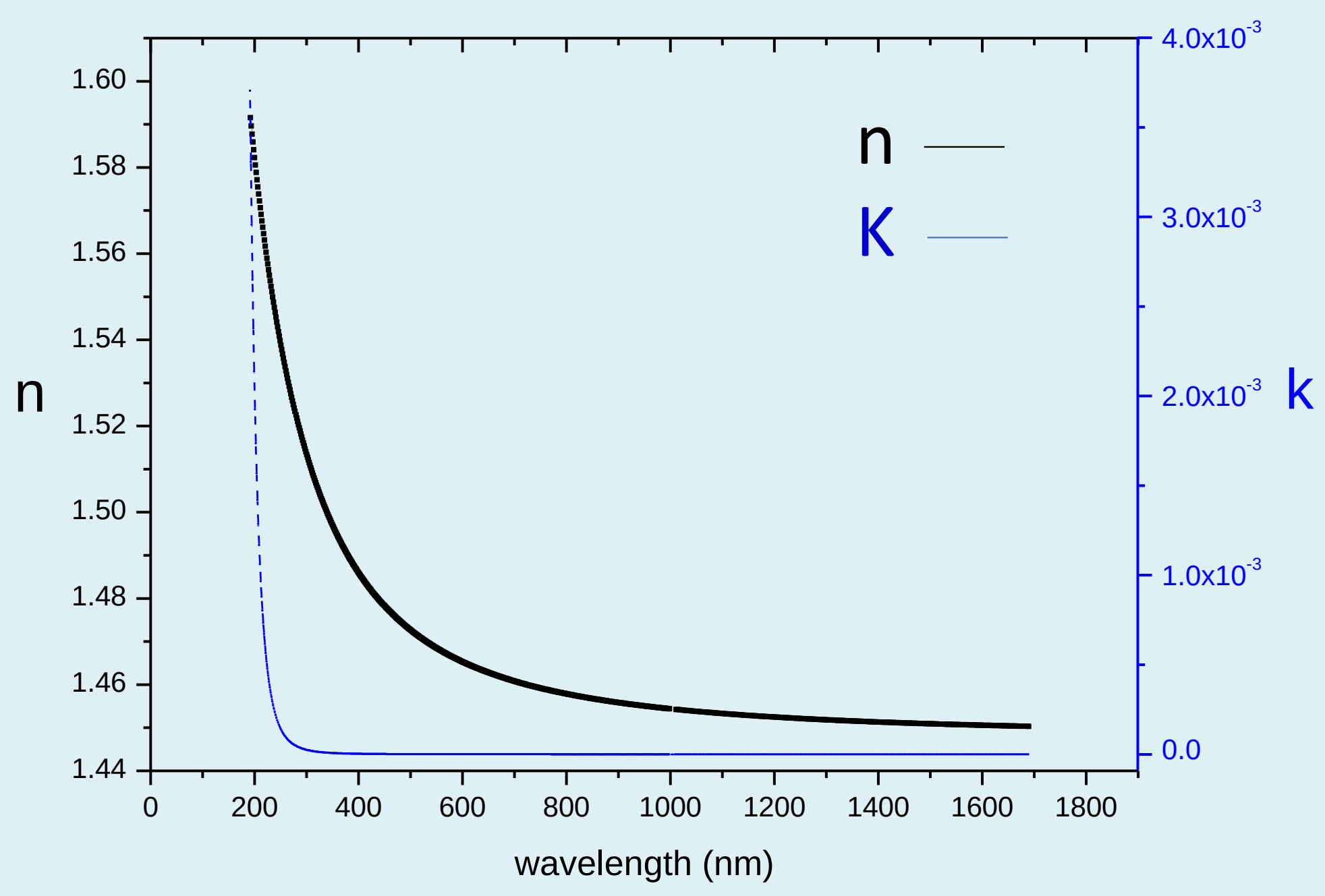
Chemical Vapor Deposition (CVD) method is well-established in silicon IC industry. Deposition of silica($SiO_2$) , silicon-nitride($SiN_x$) and amorphous silicon(α-Si) films on 16” (40 cm) silicon wafer by CVD is a common practice nowadays. All-CVD process for depositing quarter-wave (QW) stacks for dielectric mirror that consists of high index layer, e.g. α-Si and $SiN_x$, and low index layer, e.g. $SiO_2$ and $SiN_x$, has advantages for LIGO application and yet not been realized. In this poster, we present results of optical and mechanical properties of un-annealed $SiO_2$ film deposited by Plasma-enhanced Chemical Vapor Deposition (PECVD) on silicon substrate. Refractive index of the film was 1.45 and extinction coefficient was less than detection limit (~$10^{-3}$ for ellipsometry) at 1550 nm wavelength. Young’s modulus and stress of the film were 83.8±1.3 GPa and -158.2±6.0 MPa respectively. Un-annealed mechanical loss was $(4.76\pm1.16)\times10^{-4}$ , this value is close to that of the $SiO_2$ film deposited by ion beam sputter in our laboratory. Study of the annealing effect is on-going.

## Fabrication and Optical property of PECVD $SiO_2$





$SiH_{4(g)}+2N_2O_{(g)} \rightarrow SiO_{2(s)}+2N_{2(g)}+2H_{2(g)}$

$SiO_2$ film was deposited by PECVD with mixture of $SiH_4$, $N_2O$ and $N_2$ at 300 °C. The deposition rate was about 170 nm/min. This rate was faster than ion beam sputters (~8 nm/min). The refractive index was 1.45 and the extinction coefficient was less than detection limit (~$10^{-3}$ for ellipsometry) at 1550 nm wavelength. Those optical constants showed that PECVD $SiO_2$ is suitable 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.

## Young’s modulus and stress of PECVD $SiO_2$

| | Deposition method | Young’s modulus(GPa) |
|---|---|---|
| This work | PECVD 300°C | 83.8±1.3 |
| Jeremy Thum[1] | PECVD 250°C | 81.5±3.3 |
| Zhiqiang Cao [2] | PECVD 400°C | 74.8±3.3 |
| Yeon-Gil Jung [3] | Thermal Wet oxidation at Atm. 1100°C | 72.5±1.5 |
| Steve Wang [4] | Ion beam sputter | 71.9±5.8 |
| W. C. Oliver [5] | Bulk fused silica substrate | 69.3±0.39 |
| Technical data* | Bulk fused silica substrate | 72 |
| J. A. Taylor [6] | Bulk fused silica substrate | 75.9±0.6 |

*General Electric Fused Quartz Products Technical Data, general catalog number 7705—7725, 1985

In this work, Young’s modulus of the $SiO_2$ film was 83.8±1.3GPa measured by using nano-indentation. This value is close to but a little higher to that of [1] which was deposited at 250°C.

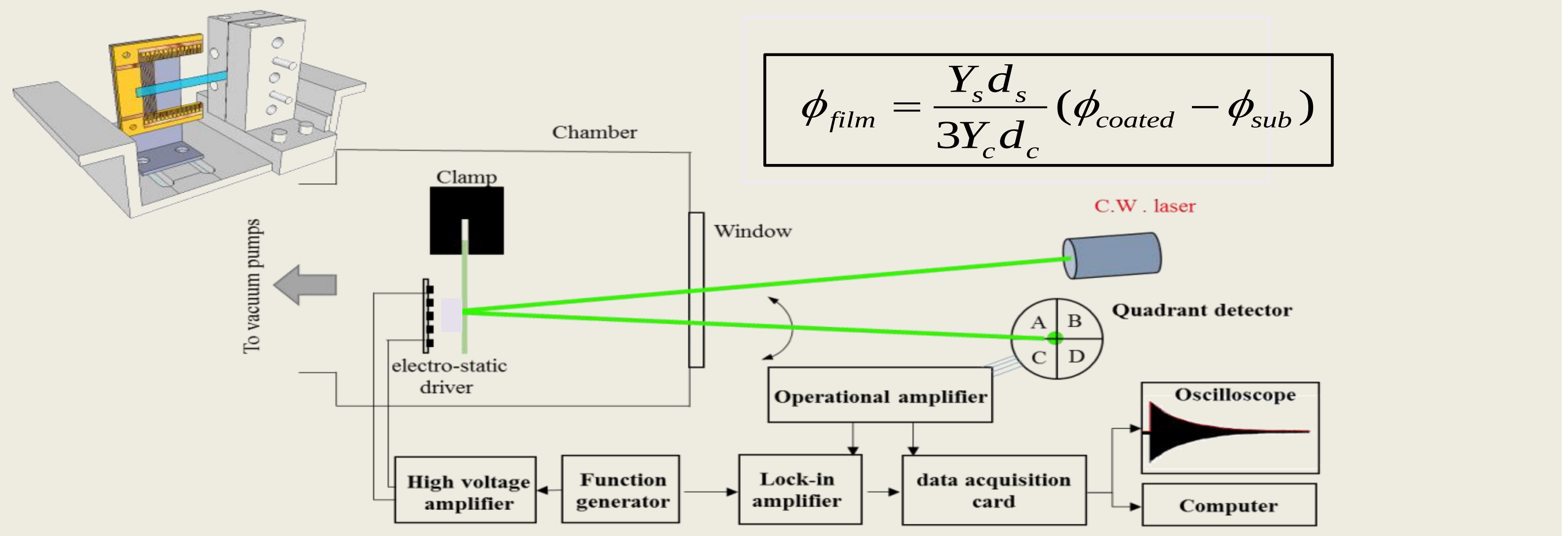
| | $SiH_4$ (sccm) | $N_2O$ (sccm) | $N_2$ (sccm) | RF (W) | Temp (℃) | Stress* (MPa) |
|---|---|---|---|---|---|---|
| This work | 8.5 | 710 | 161.5 | 20 | 300 | -158.2±6.0 |
| Zhiqiang Cao [2] | 300 | 9500 | 1500 | NA | 400 | -155±17 |
| Jin-Kyung Choia [7] | 5 | 10 | NA | 75 | 230-270 | 60.5~-257 |
| Jin-Kyung Choia [7] | 5 | 2.75-5.75 | NA | 75 | 270 | -62.5~-159 |

*Tensile stress is expressed in + value ◡ , and compressive stress is expressed in – value. ◠

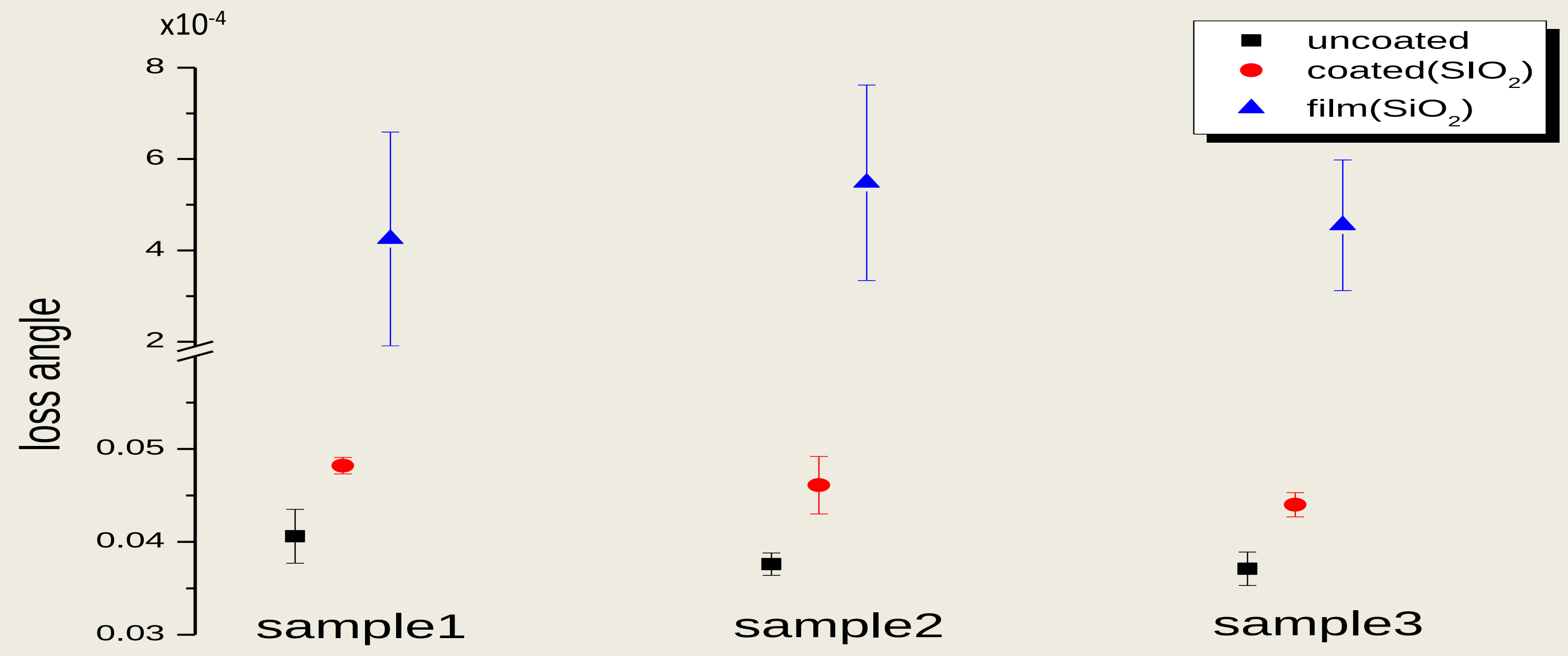
The stress of $SiO_2$ film was measured by curvature scanner in this work and it was -158.2±6.0 MPa. It is a compressive stress and could be compensated by the tensile stress of the high index film, such as $SiN_x$, in the QW stack. Correlations between the stress and the process parameters are summarized as follows:

**1. As deposition temperature is higher, stress is more compressive (-) [7]**
**2. As gas flow ratio of $N_2O/SiH_4$ increases, stress is more compressive(-) [7,8]**
**3. When a higher RF power is applied, stress gets more compressive(-) [8]**

## Mechanical loss of PECVD $SiO_2$

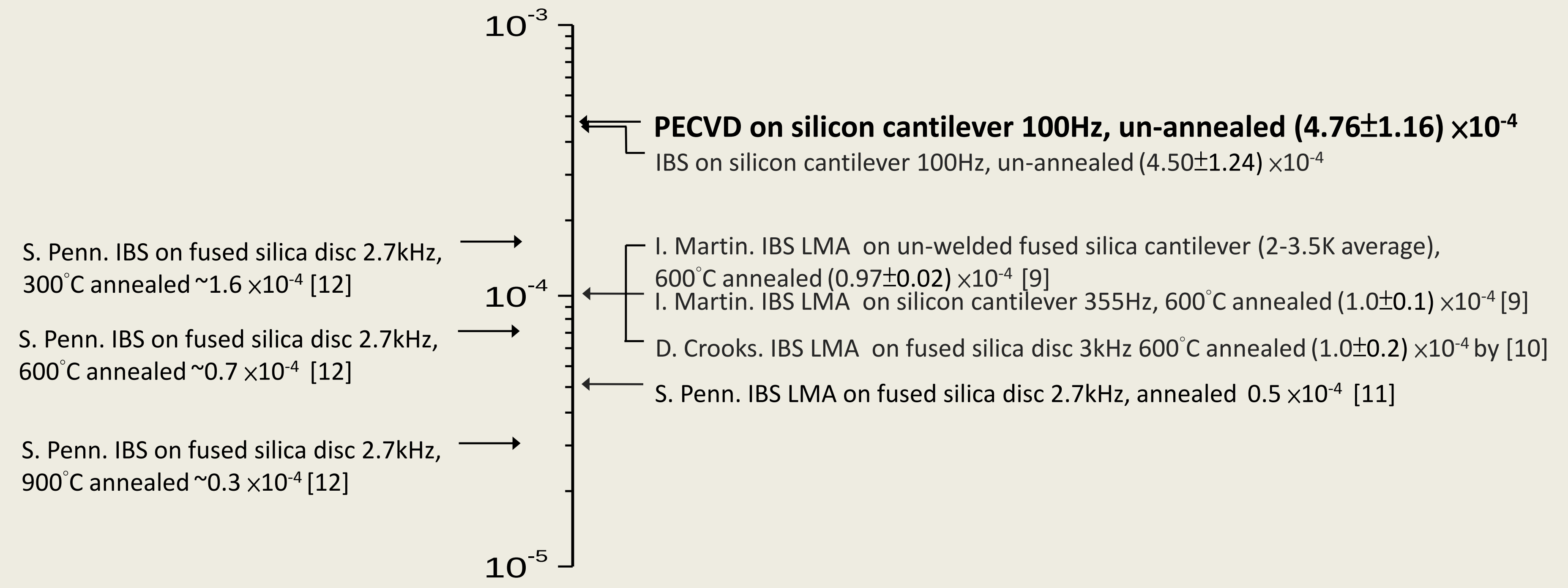


$$\phi_{film} = \frac{Y_s d_s}{3Y_c d_c}(\phi_{coated} - \phi_{sub})$$



The room temperature ring-down system was used to measure the loss angle of the films. The fundamental mode (~100Hz) of silicon cantilever was excited and free damped, the loss angle was obtained from the ring-down time constant. Each cantilever was measured for several times of re-clamping and the lowest loss angle among the re-clampings was counted. Three samples fabricated by the identical process are shown in the figure above. As can be seen that loss angle of PECVD $SiO_2$ films are in the range between $4.25\times10^{-4}$ to $5.48\times10^{-4}$ and the average of these three samples is $(4.76\pm1.16)\times10^{-4}$.

### $SiO_2$ Loss angle comparison (room temperature)



**PECVD on silicon cantilever 100Hz, un-annealed $(4.76\pm1.16)\times10^{-4}$**
IBS on silicon cantilever 100Hz, un-annealed $(4.50\pm1.24)\times10^{-4}$

S. Penn. IBS on fused silica disc 2.7kHz, 300°C annealed ~$1.6\times10^{-4}$ [12]
I. Martin. IBS LMA on un-welded fused silica cantilever (2-3.5K average), 600°C annealed $(0.97\pm0.02)\times10^{-4}$ [9]
I. Martin. IBS LMA on silicon cantilever 355Hz, 600°C annealed $(1.0\pm0.1)\times10^{-4}$ [9]
S. Penn. IBS on fused silica disc 2.7kHz, 600°C annealed ~$0.7\times10^{-4}$ [12]
D. Crooks. IBS LMA on fused silica disc 3kHz 600°C annealed $(1.0\pm0.2)\times10^{-4}$ by [10]
S. Penn. IBS LMA on fused silica disc 2.7kHz, annealed $0.5\times10^{-4}$ [11]
S. Penn. IBS on fused silica disc 2.7kHz, 900°C annealed ~$0.3\times10^{-4}$ [12]

## Conclusion

1. $SiO_2$ films deposited by PECVD method has approximately the same un-annealed loss angle as that of the ion beam sputtered $SiO_2$ film.
2. Heat treatment was proven to be an effective method to reduce the mechanical loss of $SiO_2$, which will be the major subject of investigation for our future work on PECVD $SiO_2$.
3. Compressive stress of the PECVD $SiO_2$ could be adjusted by process parameters such as $N_2O/SiH_4$ ratio, RF power and deposition temperature.
4. In a QW stack, films with tensile stress, e.g. $SiN_x$, could be used as the high index layer to compensate the compressive stress of the $SiO_2$ layer.

Reference : [1] J. Thum, J. Appli. Phys. **91**, 2002, [2] Zhiqiang Cao , J. Appli. Phys.**97**, 2005, [3] Yeon-Gil Jung , J. Mater. Res. **19**, 2004, [4] Shun-Jin Wang, master. Thesis, NTHU,2013, [5] W. C. Oliver , J. Mater. Res. **7**,1992, [6] J. A. Taylor , J. Vac. Sci. Technol.A, **9**, 1991, [7] J. K. Choia , Surface and Coatings Technology **131** 2000., [8] Oxford Instruments Plasma Technology pic 2003, [9] I.Martin, PhD thesis, Glasgow, 2009, [10] D. Crooks , Class. Quantum Grav. **23** (2006), [11] S. Penn, Class. Quantum Grav. **20** (2003), [12] S. Penn, Proc. Amaldi 2009,LIGO Document-G0900600,