STRESS ANALYSIS OF FREE-STANDING SILICON OXIDE FILMS USING OPTICAL INTERFERENCE

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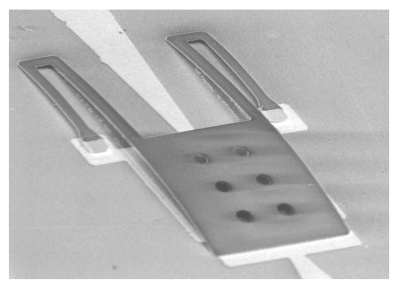
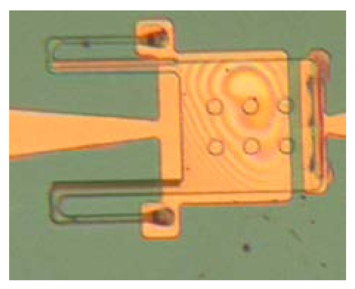
Introduction

We introduce a new method for stress measurement and topography analysis in silicon oxide thin films and variety of MEMS devices using optical interference. Optical interference occurs between reflections from the surface and the oxide slab, giving rise to light and dark fringes that may be imaged with a microscope. Position of dark and light fringes depends on the gap between slab and the substrate and that ultimately defines curvature of oxide slab which is a measure for stress induced in that layer. This method can also be used as a high resolution surface analysis for such devices.

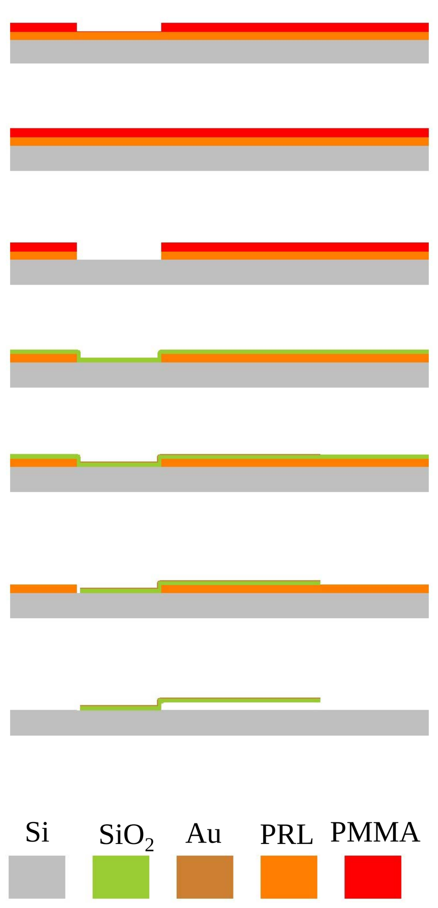
Fabrication

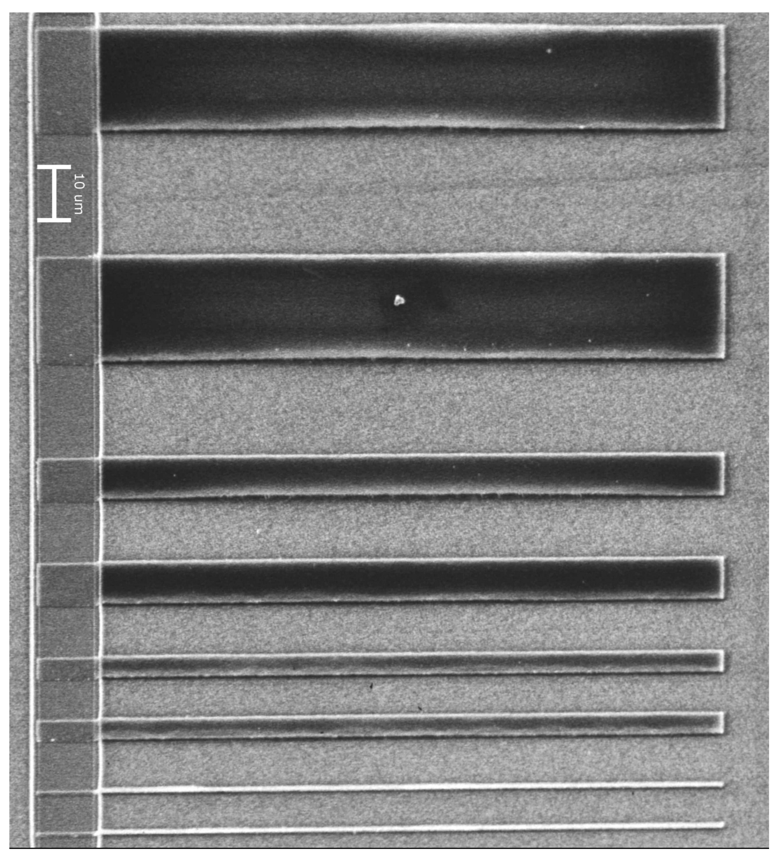
Initial observation of fringes was during our project of fabrication and analysis of a new type of MEMS cantilever IR detector.





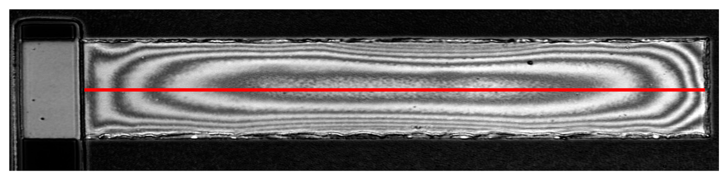
A simplified version of cantilever was designed and fabricated for demonstrate our technique :

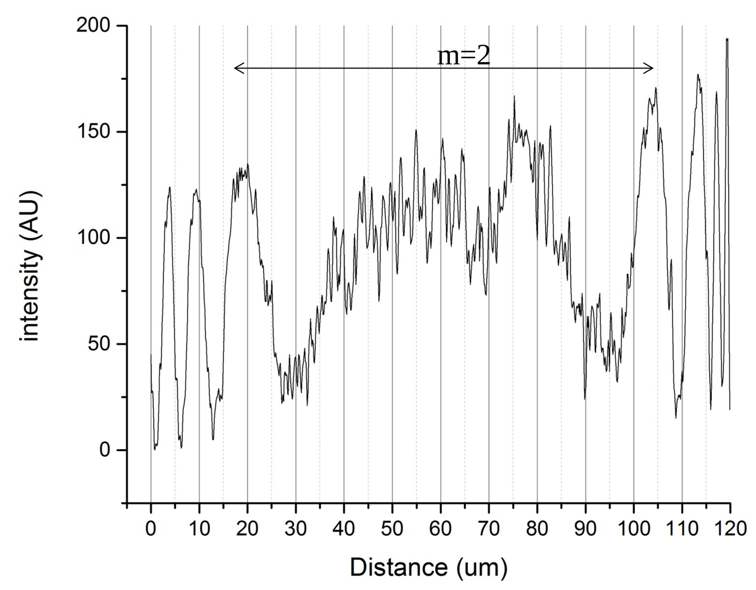




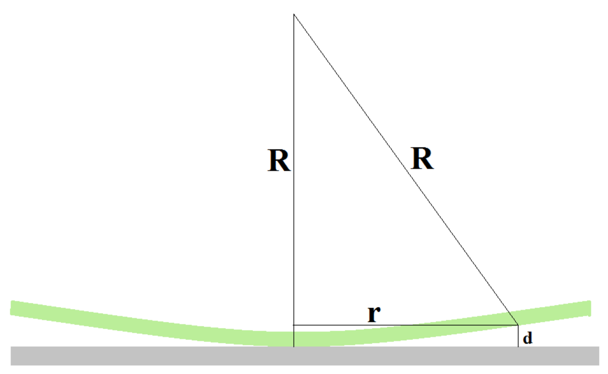
Measurement Method

A monochromatic source microscope capture fringes caused by interference of light reflected by Si substrate surface and Semi-reflected gold layer.





A monochromatic source microscope capture fringes caused by interference of light reflected at Si substrate surface and bottom surface of SiO_2 layer.



First ray reflected at bottom surface of SiO_2 has no phase shift at reflection, second ray reflected at substrate has a λ/2 at reflection point, considering additional path (twice the air gap) that it needs to travel, the total path difference between two rays is:

$$\Delta L \cong \frac{\lambda}{2} + 2d$$

To have constructive interference (bright fringe):

$$\Delta L = m\lambda \Rightarrow d = \frac{\lambda}{2}\left(m - \frac{1}{2}\right) \qquad m = 1,2,3,\ldots$$

Ex. For 2nd bright ring in top picture ($\lambda = 408\ nm$):

$$d = \frac{408\ nm}{2}\left(2 - \frac{1}{2}\right) = 306\ nm$$

Stress calculation

Surface radius of curvature at each point can be estimated based on radius of each dark/bright fringes at that point (r) and air gap thickness (d):

$$r^2 = 2Rd - d^2 \ \Rightarrow R = \frac{r^2 + d^2}{2d}$$

In our example:

$$R = \frac{(105\ um - 20\ um)^2 + (306\ nm)^2}{2 \times 306\ nm} \cong 11\ mm$$

Stoney's Equation relates this radius of curvature to stress in double layer structures like ours:

$$\sigma = \frac{E_O h_O^2}{6Rh_{Au}(1 - \nu_O)}$$

σ : *stress in film*
E_O : *oxide Young's modulus*
ν_O : *oxide Poisson's ratio*
h: *thickness*
In this case calculated R leads to :

$$\sigma = \frac{74\ GPa \times (500\ nm)^2}{6 \times 11\ mm \times 50\ nm \times (1 - 0.17)} = 6.3\ MPa$$

Topography

Meshing the surface and measuring d along each line for each fringe provides a 3D map of surface with high resolution: