Measurement of nanometric deformations of thin membranes under controlled mechanical loads

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ABSTRACT

We have measured the mechanical deformation of a 500nm thick Si_3N_4 membrane under normal loads between 10uN and 5mN. The loads were applied with a nanoindentor whose tip location onto the membrane surface can be positioned within 5 um. The deformation was measured at nanometer vertical resolution with a home-made interferometric microscope. Deformations were completely reversible without any residual strain for loads up to 0.1 mN.

Keywords: membrane, MEMS, interference microscope, phase shift, nanomechanics, silicon nitride

1 MOTIVATION

The accurate mechanical characterisation of thin membranes is recognized to be of prime importance for the development of membrane-based MEMS. To address this issue, we have built a measurement system which uses a nanoindentor to apply a well controlled force on one side of the membrane, while the deformation is recorded simultaneously on the other side with a home-made interferometric microscope [1]. Such a combination to study the mechanical properties of membrane has been pioneered by Espinosa [2]. The use of a nanoindentor ensures both a very well controlled force and a highly localised load on the membrane, while the use of the interferometric microscope allows us to measure deformations down to nanometric scale. The available forces of our nanoindentor [3] enable deformations from nanometers range to membrane rupture.

2 SAMPLES AND INSTRUMENTATION

2.1 Membrane

A SEM image of the membranes we have used is shown in the inset of Fig. 1. It is a 250um x 250um silicon nitride membrane, with a thickness of 500nm [4]. As seen on the binocular picture, the membrane is optically transparent, which greatly simplify the alignment of the nanoindenter tip with the membrane : as soon as the tip is correctly above the membrane window, the light coming from the interferometric objectives scatter onto the tip and is easily perceived.

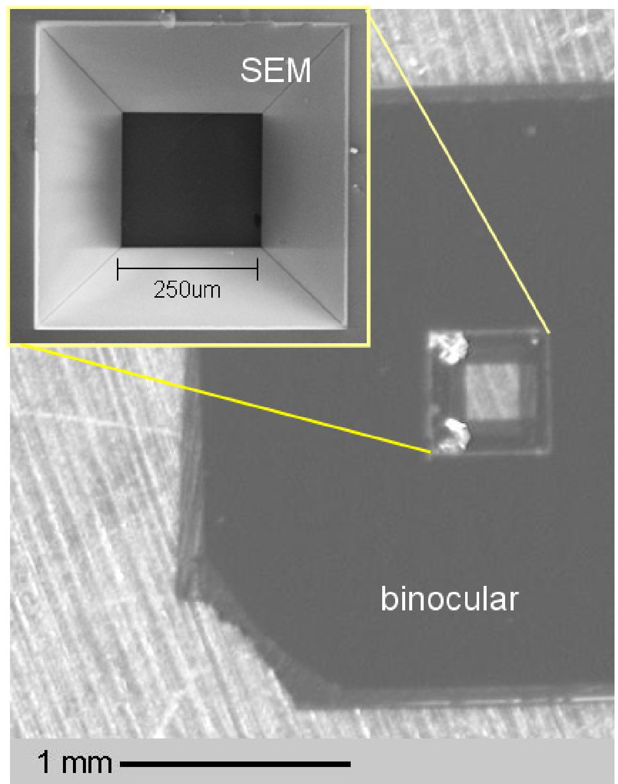

Figure 1: Si_3N_4 membrane used in this paper, showing its optical transparency and its geometry

2.2 Integrated Interferometric Micro-scope/Nanoindentor

Fig 2 is a picture of the actual instruments. The nanoindenteor is placed on top of the setup and the inverted interferometric microscope is below the membrane holder. Three micrometer screws are used to tilt the sample and to approach it up to contact to the nanoindentor tip (diamond cube corner). Once the tip is approached up to contact to the membrane, a slight force (10uN) is applied on the membrane. The resulting deformation is easily seen on the interferogram, which allows for a precise (5um) lateral positioning of the tip on the membrane.

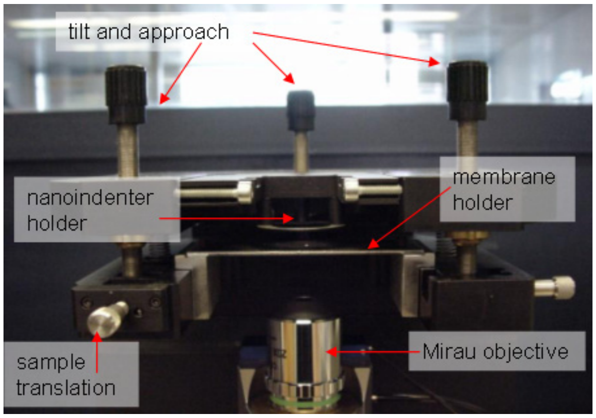

Figure 2 : Picture of the combined nanoindentor and interference microscope

A set of successive loads is applied on the membrane by the nanoindentor tip. During the 3 seconds when the force was held constant (plateau), the topography of the membrane is monitored in phase shift mode (details can be found in Ref [5]) with the interferometric microscope.

A typical interferogram of a deformed membrane is shown in Fig 3, for a load of 70uN in the center of the membrane. In case of accidental rupture of the membrane, this can be unambiguously seen on the interferogram (inset), preventing then erroneous measurement on damaged membranes.

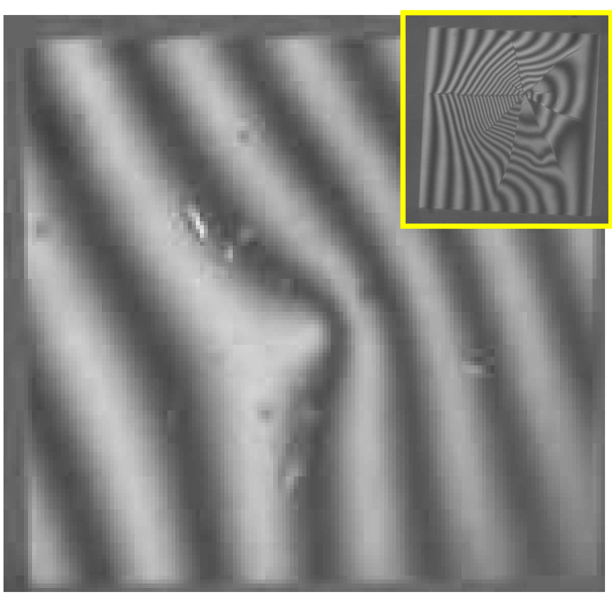

Figure 3 : Inteferogram for 70uN applied in the center of the membrane. Inset : interferogram immediately after the rupture

3 MEMBRANE DEFORMATION

3.1 Force curve

To investigate the mechanical properties of the membrane, we first performed force-distance curves with the nanoindentor on two membrane's locations: in the center and close (20um) from a corner. The ramp loads we used are shown in the inset of Fig. 4. This type of ramp is standard in nanoindentation. In our case, it allows to investigate the possible permanent deformation and creep of the membrane. We have verified by Atomic Force Microscopy that during such experiment, we do not actually indent the membrane with the nanoindentor tip.

The F-d curves are shown in Fig.4. We see that the deformation is totally reversible without any measurable residual strain for loads up to 100 uN. We measured rupture for loads ranging from 1600uN to 1700uN.

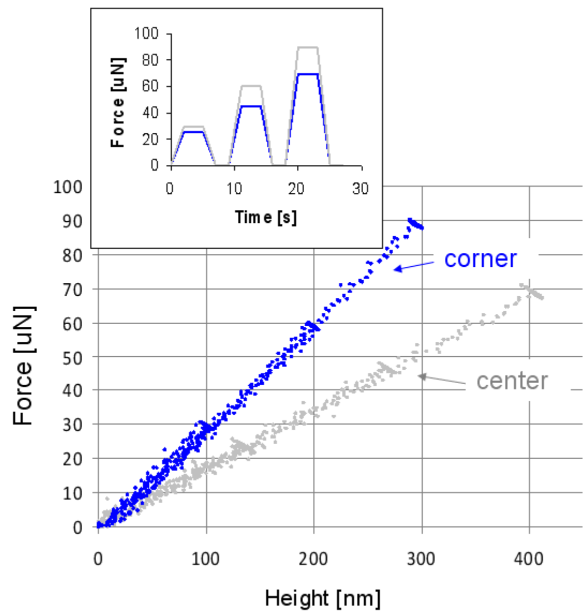

Fig 4 : Force curve in the center and close to a corner of the membrane. Inset : ramp loads.

3.2 Membrane deformation

The actual 3D deformation of the membrane has been measured with the interferometric microscope in Phase Shift Mode (PSM) and a 10x Mirau objective. Five successive $\pi/2$ phase shifted interferograms were acquired during the 3 seconds of constant force (see ramp in inset of Fig 4). The phase map was then constructed with the Hariharan [6] algorithm and the final topography is computed after standard unwrapping procedure.

NSTI-Nanotech 2008, www.nsti.org, ISBN 978-1-4200-8503-7 Vol. 1

Fig 5 is the membrane deformation for a 70uN load applied in the center, as measured with the interferometric microscope in Phase Shift Mode.

Fig 5 : Unwrapped topography of deformed membrane under a central load of 70 uN (Field of view : 260um x 260um)

The cross section (Fig 6) is not completely symmetric and shows a maximum deflection of 420nm. The measured membrane spring constant at the center of the membrane is 169 N/m, close to the expected 140 N/m given by the formula :

$$k = \frac{66Et^3}{a^2(1-\nu^2)},$$

where E=250 [MPa] is the Young modulus of Si_3N_4, υ=0.24 is the Poisson coefficient of Si_3N_4, t is the membrane thickness (500nm) and a its lateral dimension (250um). The measured spring constant increases up to 301 N/m when the tip is brought close to a corner. The inset of Fig 6b shows the nanometric deformation of the membrane, as a flattened portion of the cross section,. As our interferometric microscopes allows for atomic step imaging [7], it can be used to monitor efficiently the nanotopographies of such deformed membranes.

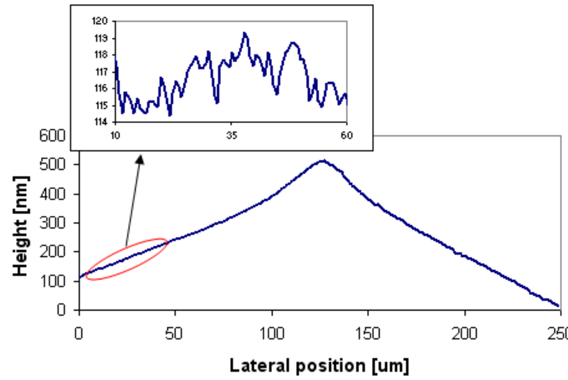

Fig 6 : Corresponding cross section of Fig 5.

4 CONCLUSIONS

We have setup an combined nanoindentor / interferometric microscopes devoted to the investigation at nanometer scale of the deformation of membranes under controlled loads in the range of 10-100uN.

REFERENCES

[1] M. Jobin et al., *NSTI Nanotech* ***2**, 695 (2005)*
[2] H.D. Espinosa et al., *J. Appl. Phys.* **94**, 6076 (2003)
[3] Hysitron, model Triboscope
[4] SPI Supplies, http://www.2spi.com
[5] M. Jobin et al., *Proc. SPIE* ***6188**, 61880T (2006)*
[6] P. Hariharan et al., *Appl. Opt* **26**, 2504 (1987)
[7] M. Jobin, R. Foschia, *Measurement* (2008), doi:10.1016/j.measurement.2007.12.006