1995

A simple technique to measure stress in ultrathin films during growth

D. Sander
Max-Plan&-Institut fur Mikrostrukturphysik, Weinberg 2, 06120-Halle, Germany

Axel Enders
University of Nebraska at Lincoln, a.enders@me.com

J. Kirschner
Max-Plan&-Institut fur Mikrostrukturphysik, Weinberg 2, 06120-Halle, Germany

NOTES

BRIEF contributions in any field of instrumentation or technique within the scope of the journal should be submitted for this section. Contributions should in general not exceed 500 words.

A simple technique to measure stress in ultrathin films during growth

D. Sander, A. Enders, and J. Kirschner
Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120-Halle, Germany

(Received 17 April 1995; accepted for publication 17 May 1995)

We demonstrate an easy implementation of the cantilever bending beam approach to measure stress during film growth in ultrahigh vacuum. Using a simple and compact optical deflection technique, film stress with sub-monolayer sensitivity can be detected. A stress measurement during $FeSi_2$ formation on Si(111) is presented.

The goal of this note is to show how film stress can be measured during growth with sub-monolayer sensitivity at basically any window of an ultrahigh vacuum (UHV) chamber. Just an unobstructed sight of the sample during growth must be possible through this window. Thus, the often somewhat elaborate and specialized experiments described previously[1–4] are not necessarily the only ways to measure stress. Especially, the *long* optical path of 1–3 m, with its inherent vibrational problems, employed by others[1,2] is *not* required in our setup. Of course, the simplicity of our approach does not give the outstanding sensitivity nor the thermal stability of the designs mentioned above. But in such cases where thin (≈0.1 mm) substrates are readily available (e.g., glass, mica, Si) and the expected stress values are of the order of 1 N/m per monolayer deposition, stress measurements can be performed quite easily. The only tribute that has to be paid to the stress measurement in terms of *in vacuo* modifications is the use of a sample holder, that clamps only one end of the sample. The other end has to be free, as to allow for a free bending of the sample. Figure 1 shows a schematic of our setup. The basic idea of all stress measurements is that a sample will curve a little bit when exposed to film stress on *one* of its surfaces. We use an *e*-beam evaporator as an Fe source. This Fe evaporator is aligned in such a way that an Fe beam of ~8 mm diam. hits the *frontside* of the sample. There is no direct path for Fe atoms to reach the backside of the sample, thus any deposition of Fe on the backside can be excluded. Using an optical deflection technique, we monitor the curvature of the sample during the deposition of Fe from the atmospheric side of a UHV window. The film stress σ_F is then calculated from the sample curvature R by applying Stoney's formula:[5,6]

$$\sigma_F = \frac{E t_s^2}{6R(1-\nu)t_F}.$$

In the case of ultrathin films, the ratio of sample thickness t_s to film thickness $t_F, t_s/t_F$ is of the order 10^4, thus only

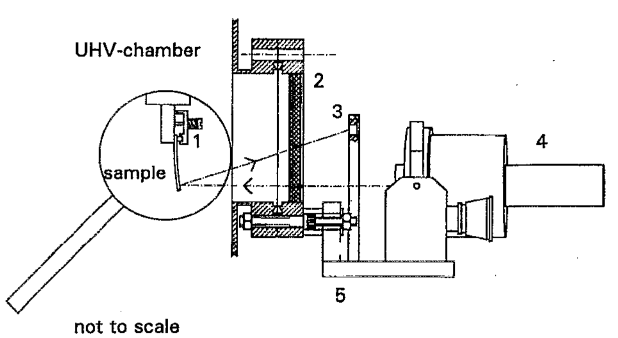

FIG. 1. Schematic of the optical deflection setup. The laser and split photodiode are mounted on *one* platform attached to a UHV flange. The laser beam is reflected from the sample to the photodiode. Note that the sample is clamped only at the top end to allow for a free bending. The distance sample photodiode is 240 mm. 1: sample holder; 2: UHV window flange; 3: split-photodiode; 4: HeNe laser; 5: platform with gimbal mount for convenient alignment of the laser.

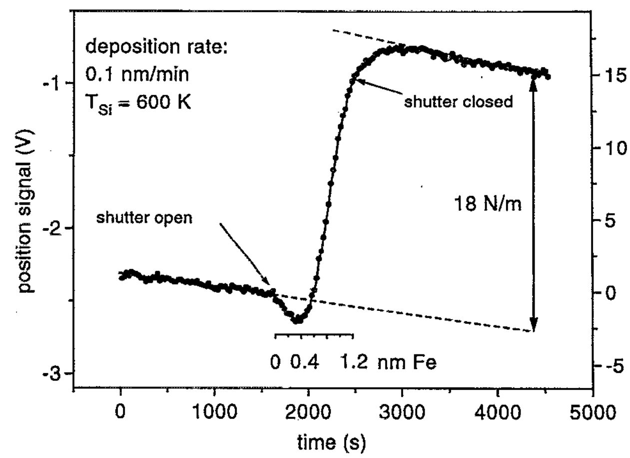

FIG. 2. Stress measurements taken during Fe deposition on Si(111) at $T_{Si}=600$ K. A compressive stress is measured for the first 0.3 nm of Fe deposition. The tensile stress of 18 N/m for 1.2 nm of Fe deposited is measured as the offset between the thermal drift lines.

 0034-6748/95/66(9)/4734/2/$6.00

Young's modulus E and Poisson's ratio ν of the *sample* enter the formula *via* $E/(1-\nu)$. In the ultrathin limit, the film thickness is hard to define, then the stress is given as $\sigma = \sigma t_F$, in units of N/m. Values for $E/(1-\nu)$ are calculated from the elastic constants of the substrate, e.g., $E/(1-\nu) = 2.29 \times 10^{11}$ N/m^2 for Si(111).[7] For a film stress of 1 N/m, typical for a 0.1 nm thick film, a sample curvature for $t_S = 0.15$ mm of $R = 860$ m is expected. For a sample length of 12 mm, this leads to a sample deflection of 84 nm at the bottom end. Using the bottom end as a mirror, this deflection causes a displacement of the reflected laser beam at the split photodiode of 10 μm. This displacement is easily measured using a difference and sum amplifier[8] for processing the signals from the split diode. To keep vibrational noise low, it is essential to mount laser and detector on a common platform, directly attached to a window flange. Thus, relative movements between laser and detector are easily minimized, which otherwise would severely interfere with the stress-induced signal.

In Fig. 2, we present a stress measurement during the growth of 1.2 nm Fe on a Si(111) substrate at $T_{Si} = 600$ K. From this measurement, it is obvious that a sub-monolayer sensitivity can be obtained for this extremely simple setup. Note how the stress, induced by depositing as little as 0.1 nm of Fe, is easily detected to be 0.5 N/m. Further deposition of Fe leads to the formation of β-$FeSi_2$. This silicide formation induces a huge tensile stress of 18 N/m. A detailed discussion of the stress during growth of Fe on Si can be found elsewhere.[9]

[1] A. J. Shell-Sorokin and R. M. Tromp, Phys. Rev. Lett. **64**, 1039 (1990).
[2] R. E. Martinez, W. A. Augustyniak, and J. A. Golovchenko, Phys. Rev. Lett. **64**, 1035 (1990).
[3] D. Sander and H. Ibach, Phys. Rev. B **43**, 4263 (1991).
[4] M. Weber, R. Koch, and K. H. Rieder, Phys. Rev. Lett. **73**, 1166 (1994).
[5] G. G. Stoney, Proc. R. Soc. London Ser. A **82**, 172 (1909).
[6] A. Brenner and S. Senderoff, J. Res. Natl. Bur. Stand. **42**, 105 (1949).
[7] W. A. Brantley, J. Appl. Phys. **44**, 534 (1972).
[8] United Detector Technology: Amplifier Model 307 DIV, through LASER 2000, Argelsrieder Feld 14, 82234 Wessling, Germany.
[9] D. Sander, A. Enders, and J. Kirschner, Appl. Phys. Lett. (submitted).