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Electronic Supplementary Information

Ultra-flexible, conformal, and nano-patterned photonic surfaces via polymer cold-drawing

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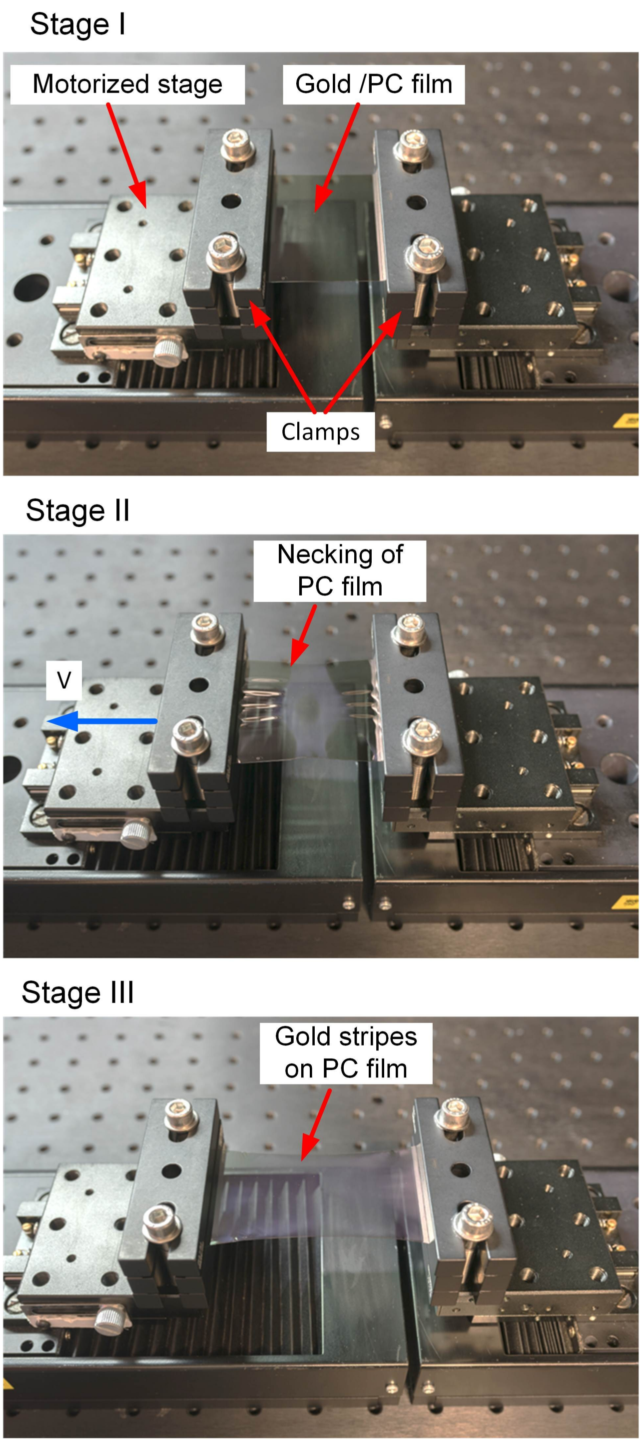

Fig. S1 Experimental setup and mechanical stretching process.

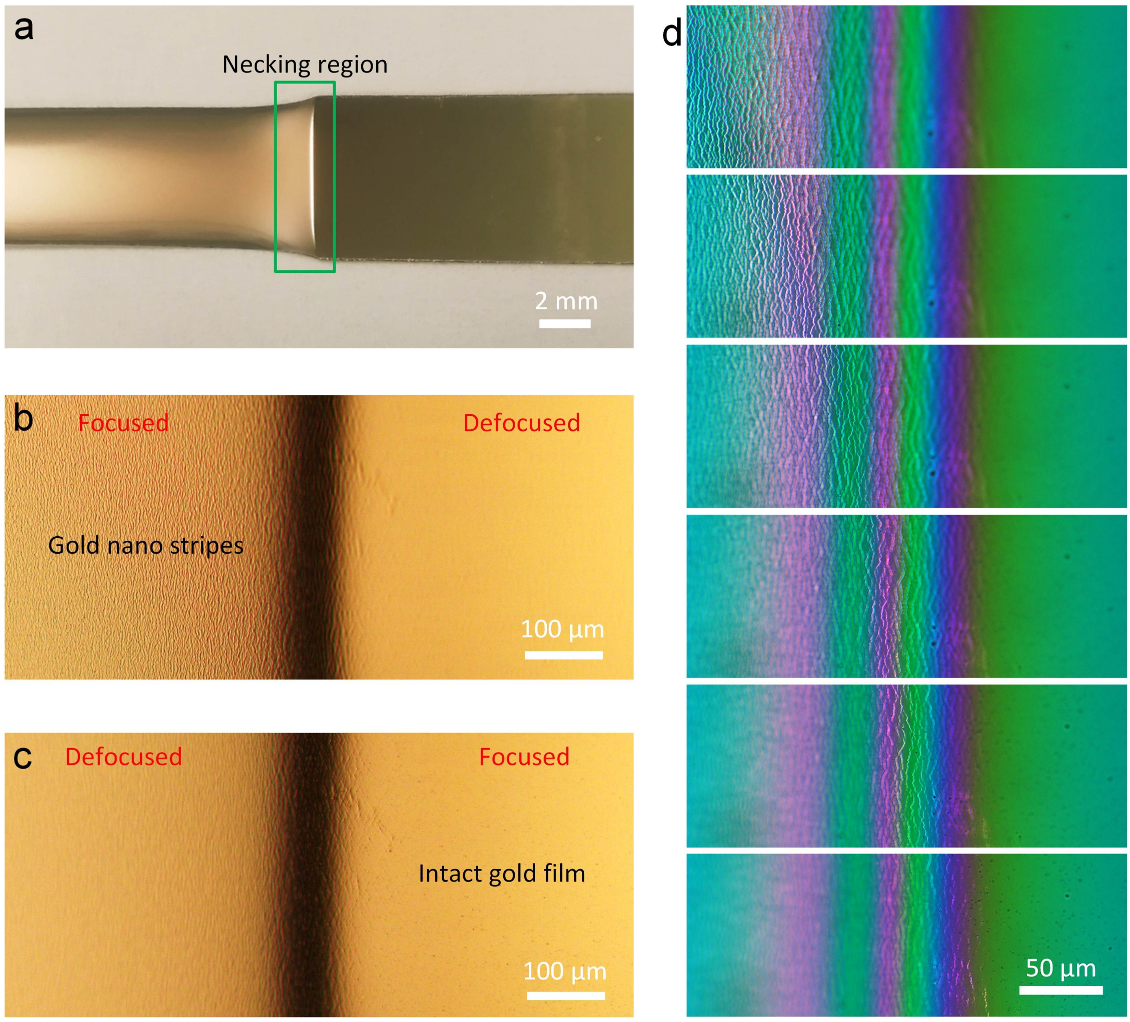

Fig. S2 Fragmentation of the gold nano-film in the necking region during 1D stretching. (a) Photograph of a gold/PC film during the 1D stretching. (b) Micrograph of the necking region with the microscope focused on the gold nano-stripes produced by 1D stretching. (c) Micrograph of the necking region with the microscope focused on the intact gold nano-film before 1D stretching. (d) Optical micrograph of necking region under cross polarized illumination with the microscope focused on different surface levels. Thickness of gold film, 50 nm.

Shear lag model and fragmentation process analysis

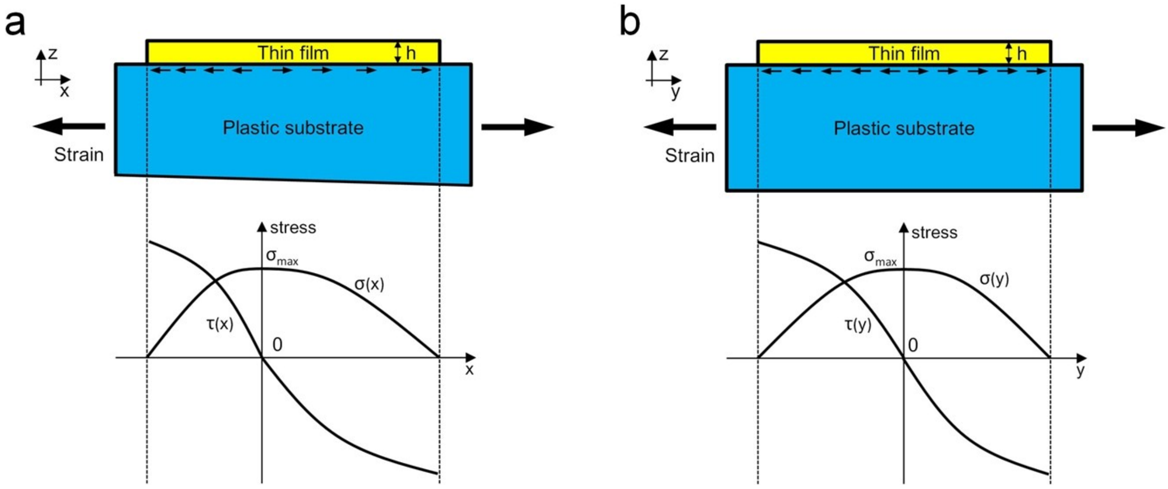

Fig. S3 Shear lag model for thin films on plastic substrates. (a) 1D stretching where the plastic substrate goes through non-homogeneous elongation. (b) 2D stretching where the plastic substrate goes through homogeneous elongation.

For 1D stretching, the fragmentation occurs in the necking region, where non-homogeneous elongation takes place (Fig. S2b-c). We adopt a modified shear lag model with a tapered plastic substrate to describe the fragmentation process of the thin film (Fig. S3a). The tensile stress in the thin film can be expressed as, [S1]

$$\sigma(x) = \frac{1}{h}\int_0^x \tau(x)dx \tag{1}$$

where $\tau(x)$ and h represent the shear stress at the interface and the thickness of the gold film, respectively. As the thin end of the tapered substrate goes through lager deformation than the thick end, thus the tensile stress in the substrate (represented by the rainbow color in Fig. S2d) and the shear stress at the interface are larger, leading to a tensile stress concentration in the gold film at the thin end. As the neck initiates, the gold film first ruptures at the thinnest part of the substrate. Then the rupture extends towards the thick end as the necking propagates along the whole substrate.

For 2D stretching, the fragmentation process of a gold thin film coated on a plastic substrate which undergoes homogeneous elongation can be well descripted by the standard shear lag model (Fig. S3b). Obviously, the maximum tensile strength occurs in the middle point of the coating segment. Thus, when we stretch the substrate, the thin film cracks into two sub-fragments when the stress in the middle point exceeds the fracture strength σ^*. A large scale of fragments is produced as the stretching goes on until the stress transferred from the substrate is insufficient to break existing fragments, thus further breaks of the fragments slow down and the width of fragments L reaches saturation gradually. For thin films subjected to large strain, a semi empirical equation $L = (2h\sigma^*) / \sigma_0$ is more preferable to calculate the fracture strength, where σ_0 denotes the applied stress on the substrate.[S2]

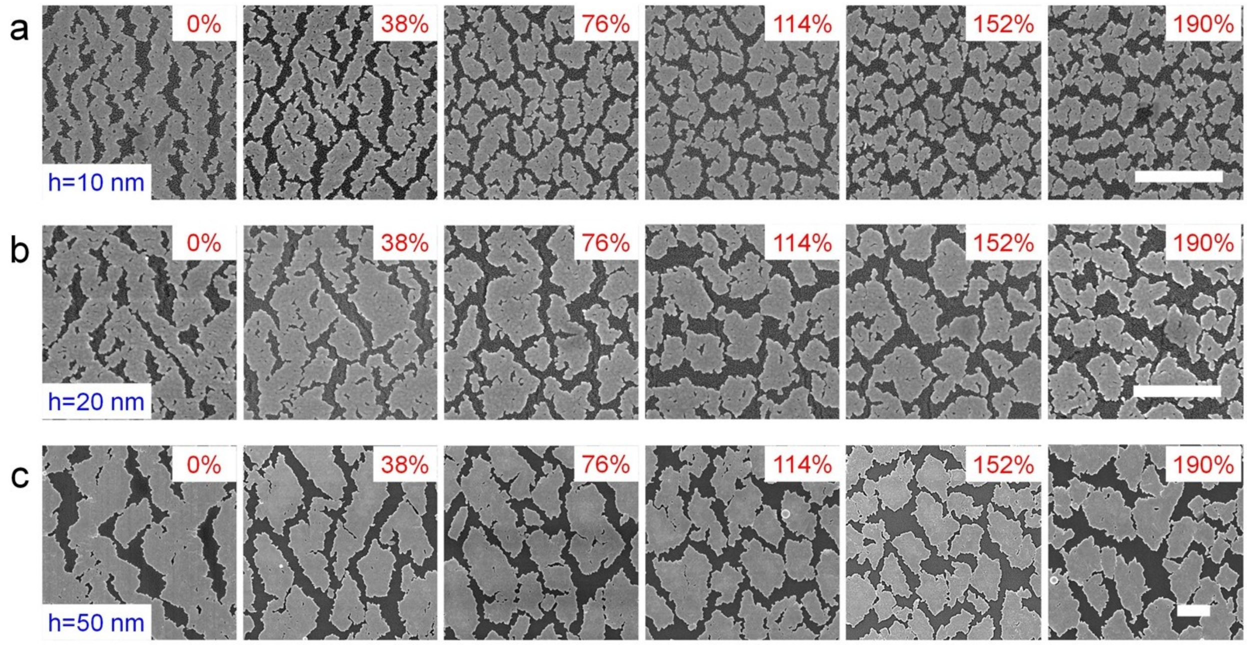

Fig. S4 SEM images of the gold patterns under different elongation at 2D stretching stage. (a) Au film thickness, 10 nm. (b) Au film thickness, 20 nm. (c) Au film thickness, 50 nm. Scale bars, 1 μm.

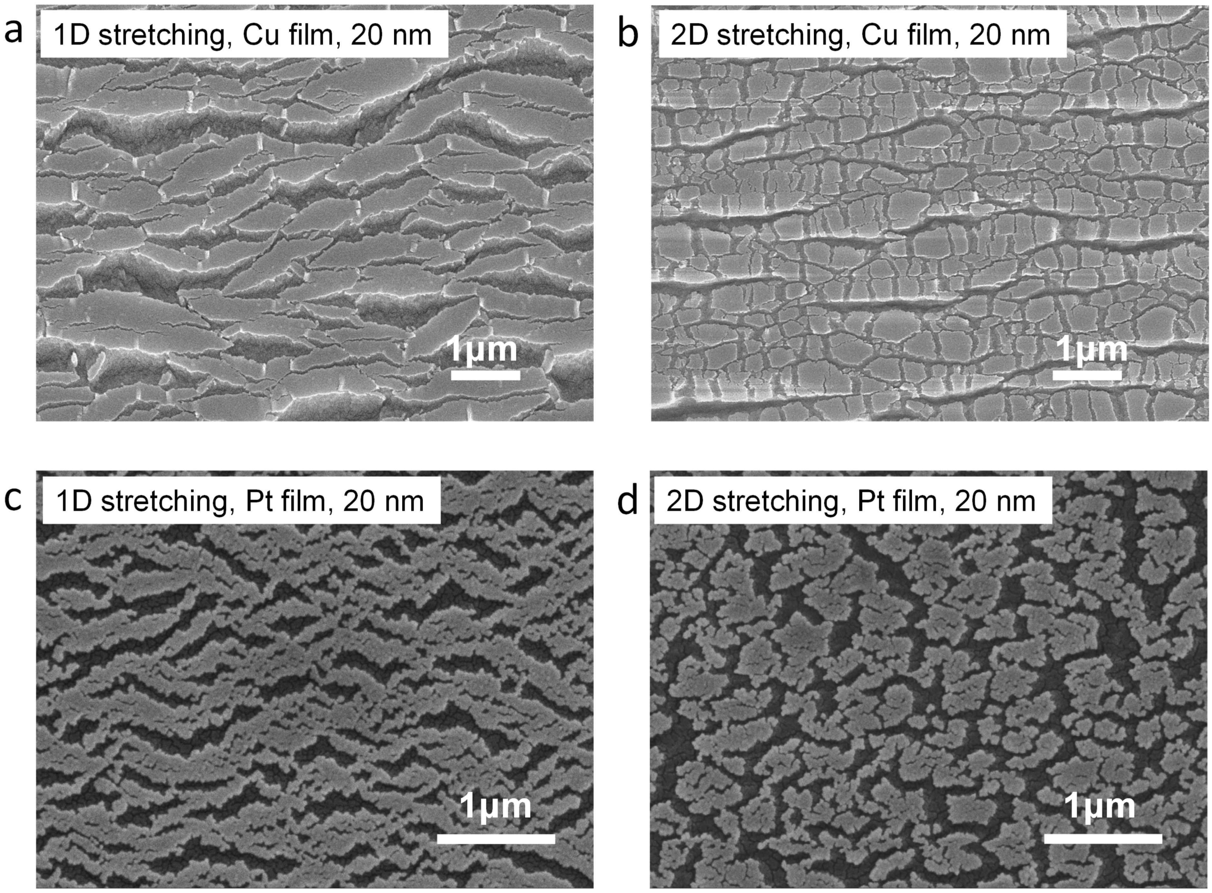

Fig. S5 SEM images of nano-patterns fabricated from copper and platinum nano-films. (a) Copper nano-stripes after 1D stretching. (b) Copper nano-patterns after 2D stretching. (c) Platinum nano-stripes after 1D stretching. (d) Platinum nano-patterns after 2D stretching. Film thicknesses, 20 nm; substrate, 125 μm-thick PC film; elongation for 2D stretching, 152%.

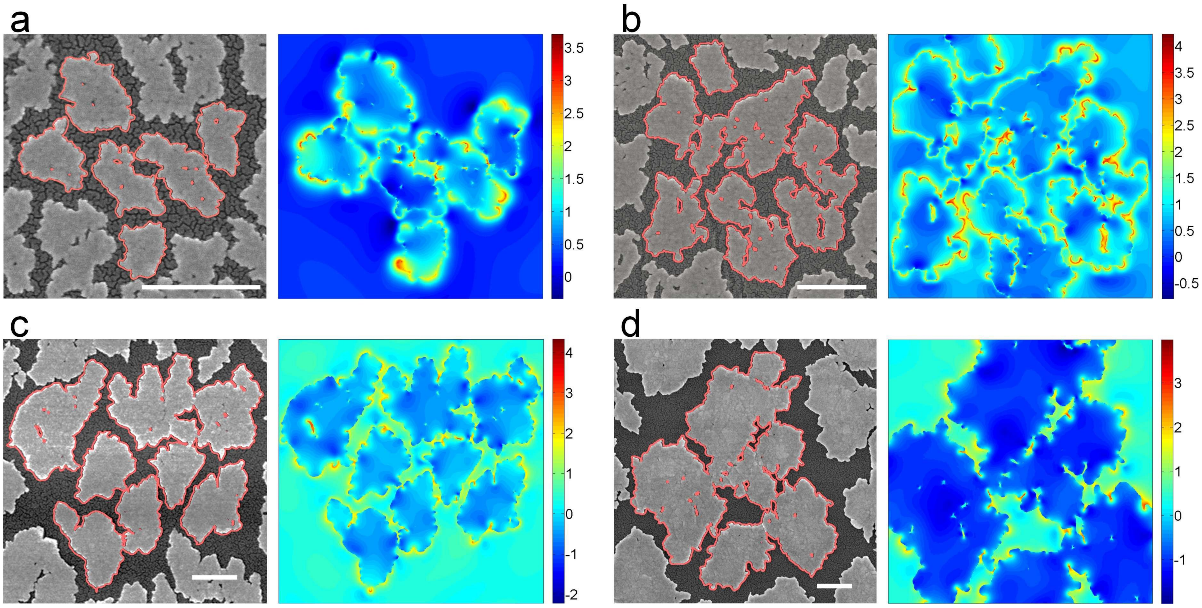

Fig. S6 SEM images of gold nano-patterns and simulated electromagnetic near field distributions showing strong E-field enhancement. Thicknesses of gold nano-films: (a) 10 nm, (b) 20 nm, (c) 30 nm, (d) 50 nm. Scale bars, 500 nm.

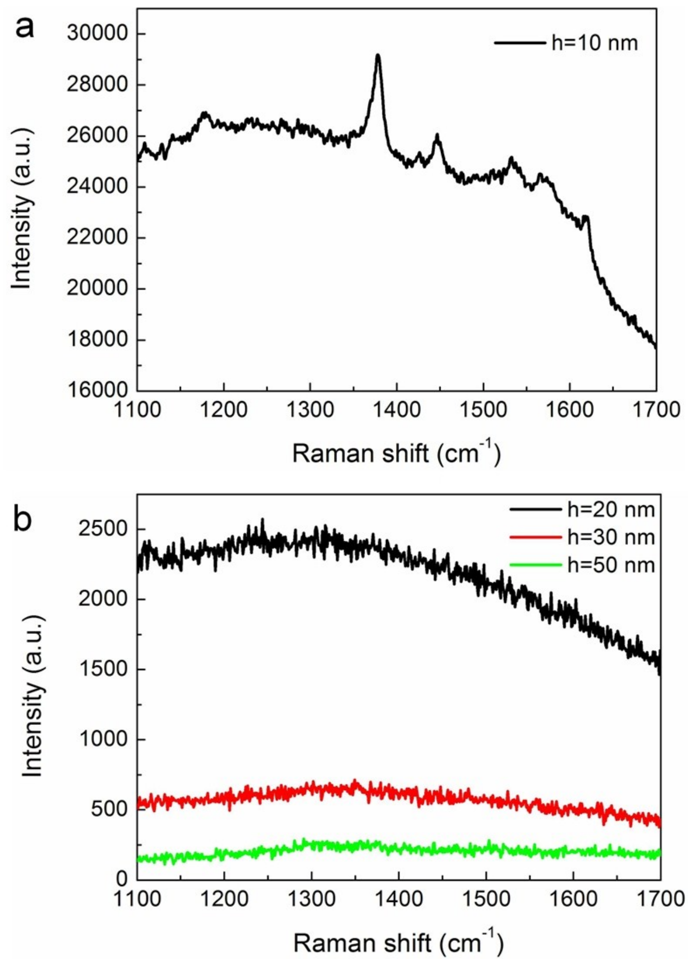

Fig. S7 SERS spectra of NT on intact gold films. (a) Thickness of gold film, 10 nm. (b) Thickness of gold films, 20nm, 30 nm and 50 nm. Concentration of NT solution, 50 μM.

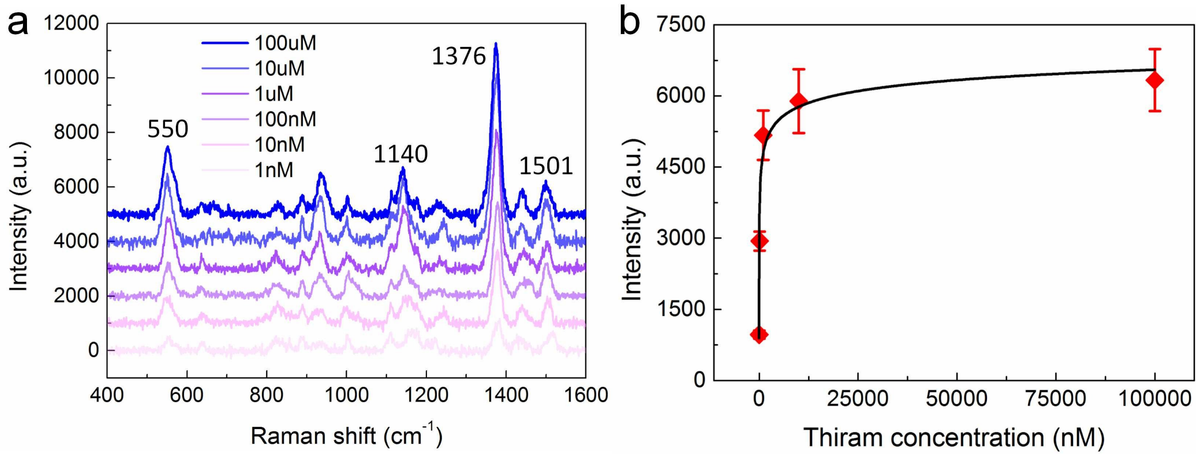

Fig. S8 SERS sensing of thiram on gold nano-patterned planar PC substrates. (a) SERS spectra of thiram at concentrations ranging from 1 pM to 100 nM (thickness of gold film, 20 nm). (b) Peak intensity at 1376 cm^{-1} as a function of thiram concentration.

References:

[S1] Yanaka M, Tsukahara Y, Nasako N, Takeda N. Cracking Phenomena of Brittle Films in Nanostructure Composites Analysed by a Modified Shear Lag Model with Residual Strain. *J Mater Sci* 1998; **33**: 2111–2119.

[S2] Volynskii AL, Bazhenov S, Lebedeva O V., Ozerin AN, Bakeev NF. Multiple cracking of rigid platinum film covering polymer substrate. *J Appl Polym Sci* 1999; **72**: 1267–1275.