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About the understanding of loading and unloading curves in nanoindentation

Abstract

In the following study a surprisingly simple hypotheses for self similar indenters about the nature of indentation loading and unloading curves will be put under investigation.

Introduction

Hypothesis for self similar indenters (Berkovich, Vickers):
1. According to Pharr's concept of the effectively shaped indenter we assume that for a monolithic material a single elastic indenter could be found which fits the unloading curve of any indentation experiment by the means of a completely elastic theory. This should hold as long as no severe inelastic effects like pop in or big fractures occur during the unloading process. Then the elastic surface stress distribution of the effective indenter in the moment of beginning unloading can be used for the determination of critical parameters like the yield strength of the material.
2. A perfectly self similar indenter should always produce the same surface pressure distribution shape (only the contact radius a is changing) during the whole loading process. Thus, we further assume that the loading curve can be fitted by applying the stress distribution of the effective indenter in the moment of beginning unloading and an effective Young's modulus being smaller than the real one due to the fact that inelastic effects are occurring during the loading.

Test by examples

At first we determine the usual (contact area, Young's modulus) by applying the O&P-method to the unloading curve of a Berkovich measurement (fig. 1).
Then we fit an effective indenter to the unloading curve and determine the surface stress distribution of this indenter in the moment of beginning unloading (at maximum load of 100mN) by applying the extended Hertzian approach (Figures 2 and 3).
This surface stress distribution is now used to fit an effective Young's modulus for the loading curve. Thereby we take into account that the contact radius increases with increasing depth in dependence on the surface stress shape. The resulting fit is shown in fig. 4. The fit is quite good except for the beginning of the loading curve. Similar good results have been obtained for a great variety of indentation data.

Questions:

If nothing extraordinary has happened, shouldn't this second fit be always possible?
If it is not possible the loading cannot have been self similar or the results of the previous steps are flawed (due to pile up for instance)?
Is there something one could use here?

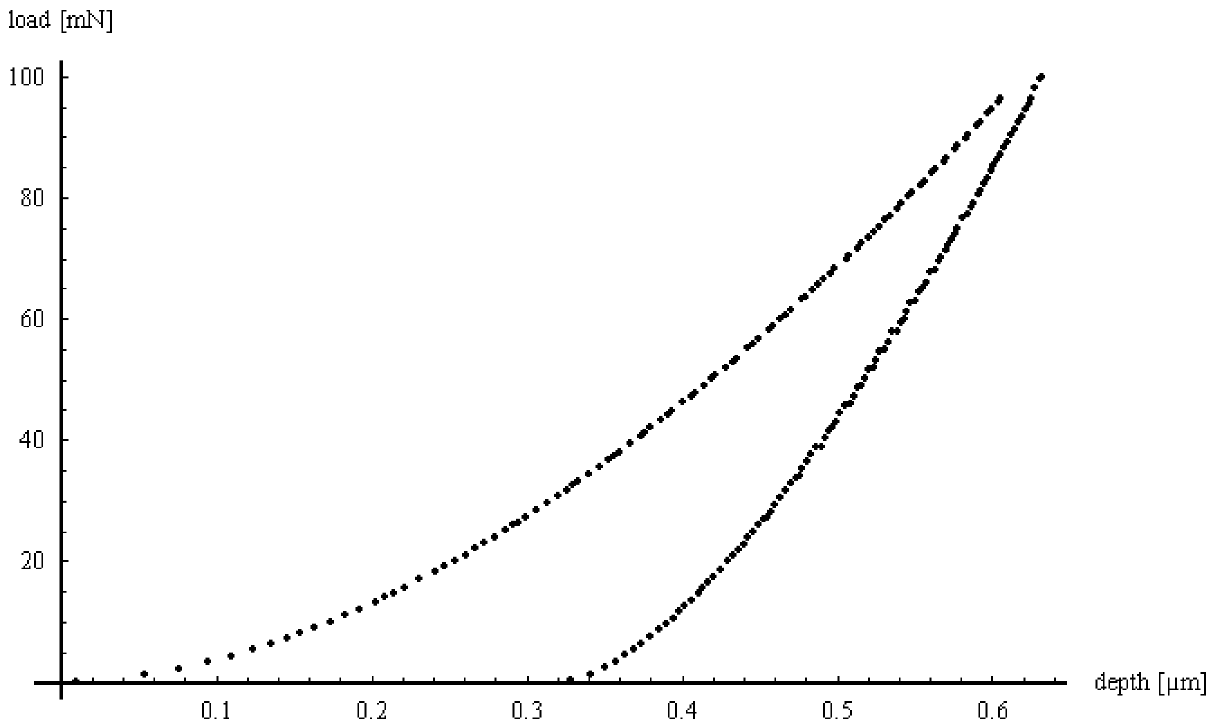

Fig. 1 Berkovich indentation with contact radius at maximum load of a=1.447µm and Young's modulus E=244.69GPa determined with the classical O&P-method

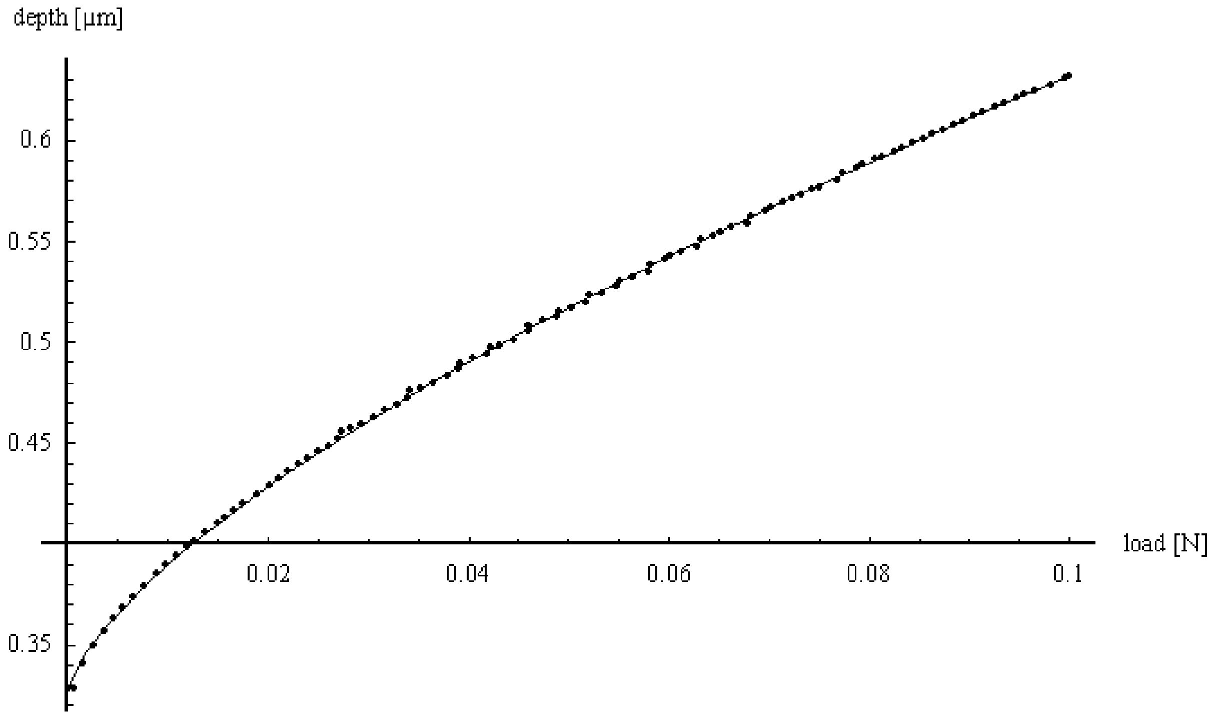

Fig. 2 Effective indenter fit to the Berkovich indentation of fig. 1 determined with the extended Hertzian approach of the author

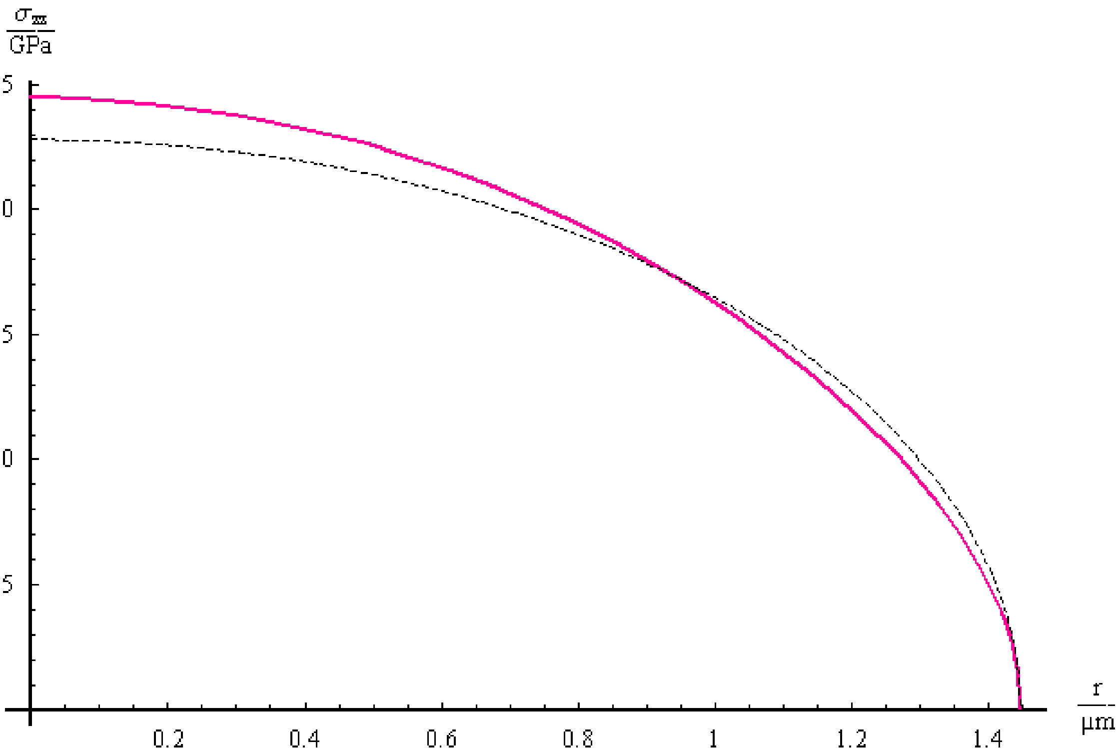

Fig. 3 Resulting surface stress distribution (red curve) to the Berkovich indentation of fig.1 in the moment of beginning unloading determined with the extended Hertzian approach (the dashed line gives the Hertzian pressure distribution for comparison)

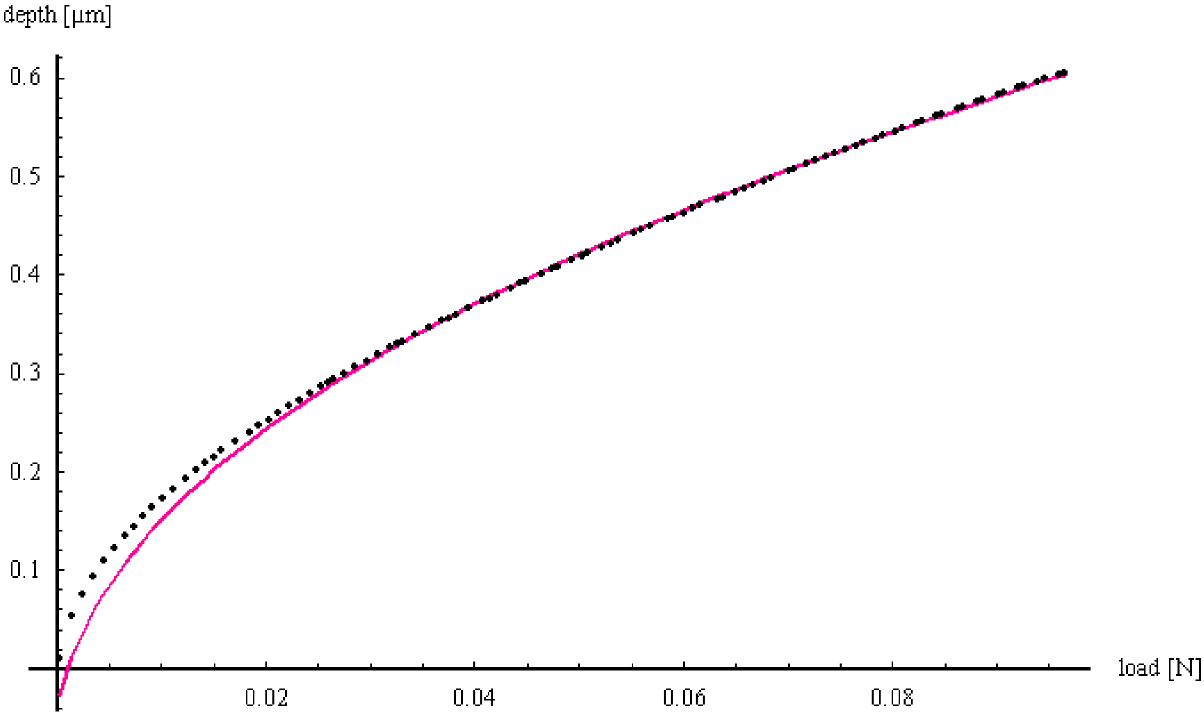

Fig. 4 Effective half-space fit (red line) to the Berkovich indentation loading curve of fig. 1 (black dots) determined with the extended Hertzian approach by using the surface stress distribution of fig. 3. The fitted effective Young's modulus is 76.5GPa