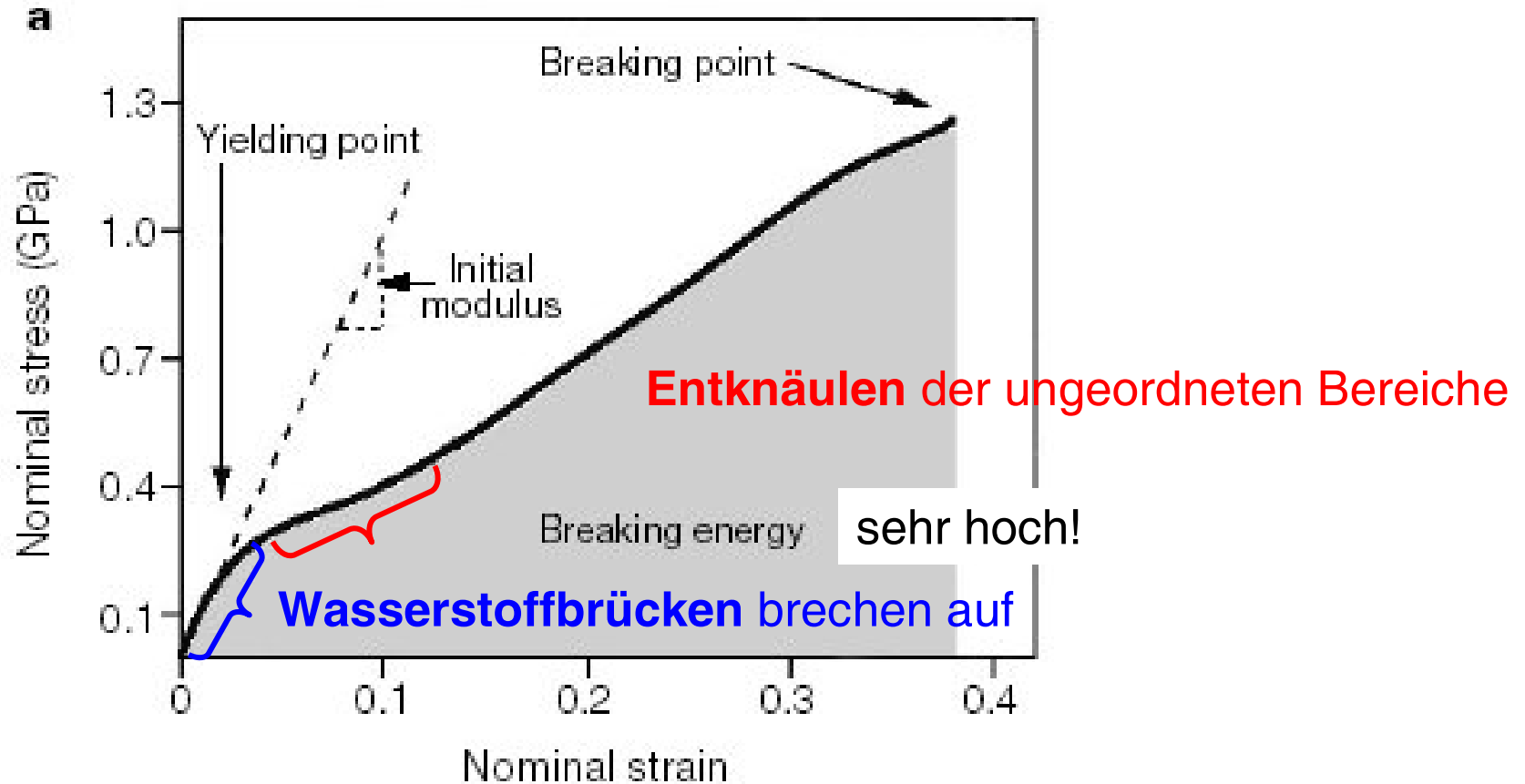
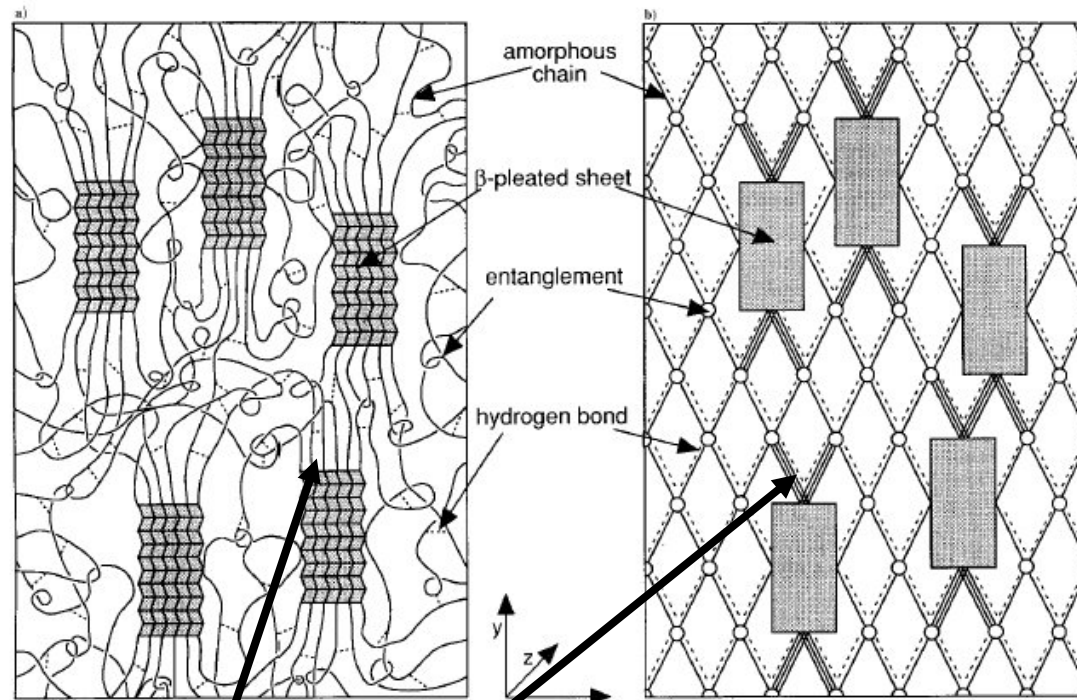


## Mikroskopische Erklärung

des Spannungs-Dehnungs-Diagramms von Spinnenseide



## Neuestes Morphologie-Modell für Spinnenseide

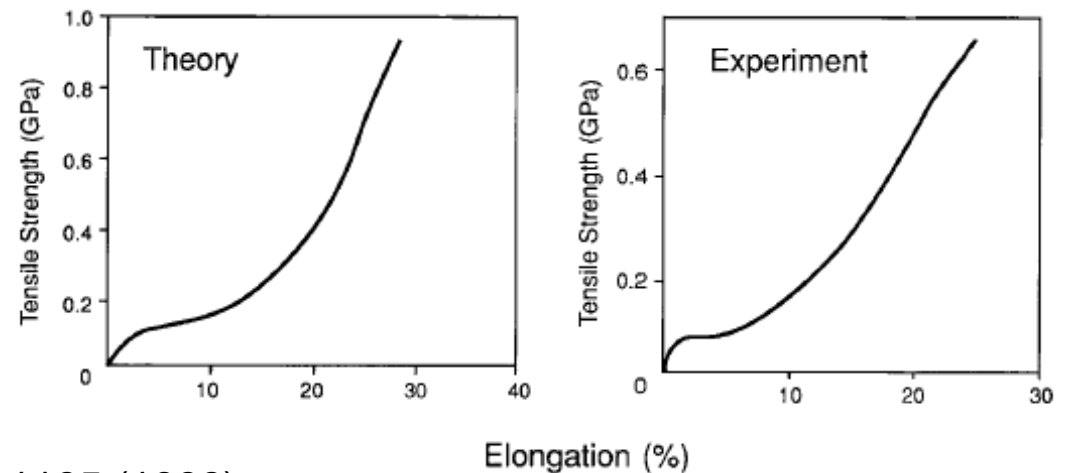


Schicht:  
„orientiert amorph“

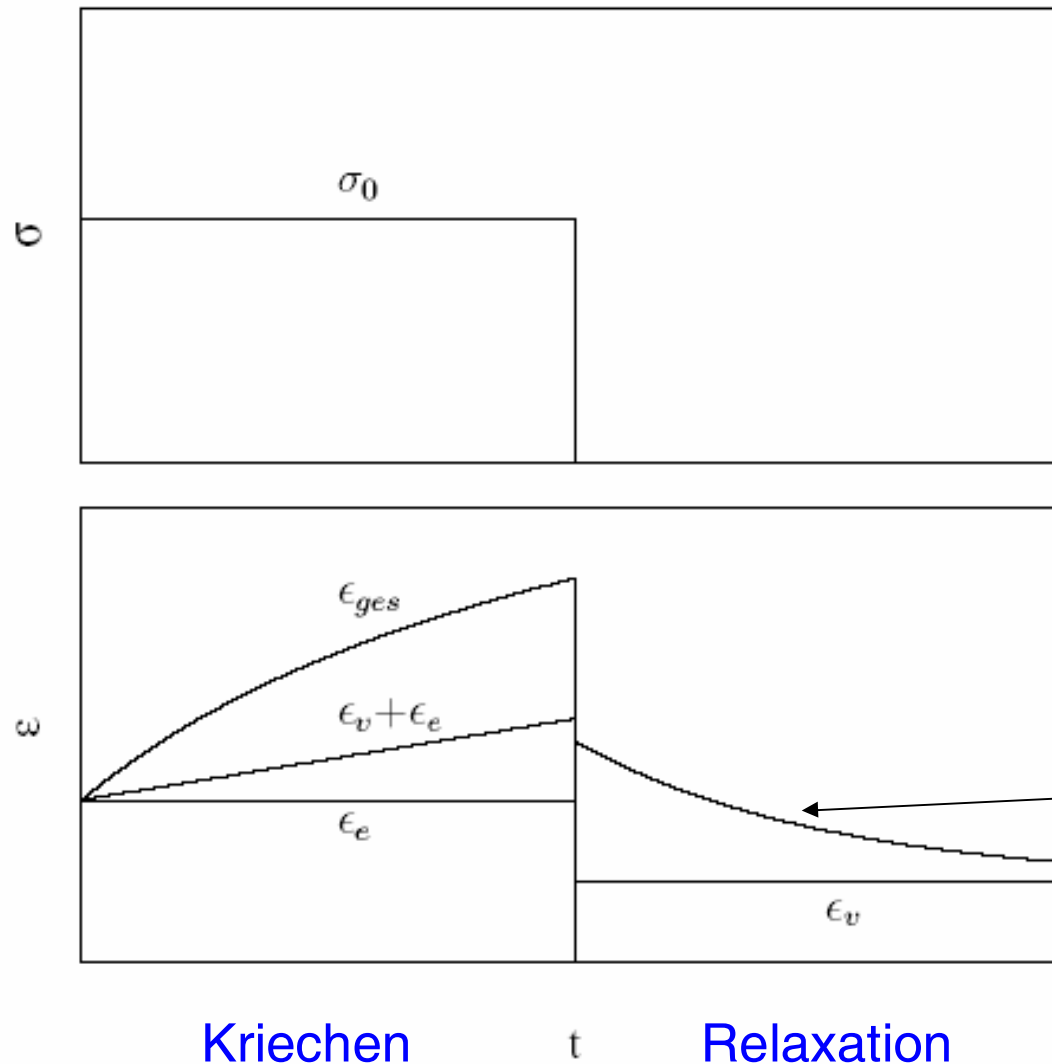
### Elastizitätsmoduli:

- Kristalle 160 GPa
- H-Brücken 4 GPa
- Schicht 24 GPa

### Spannungs- Dehnungs-Diagramme



## Zeitabhängigkeit der Dehnung: **Viskoelastizität**



$\epsilon_e$ : **elastisch**

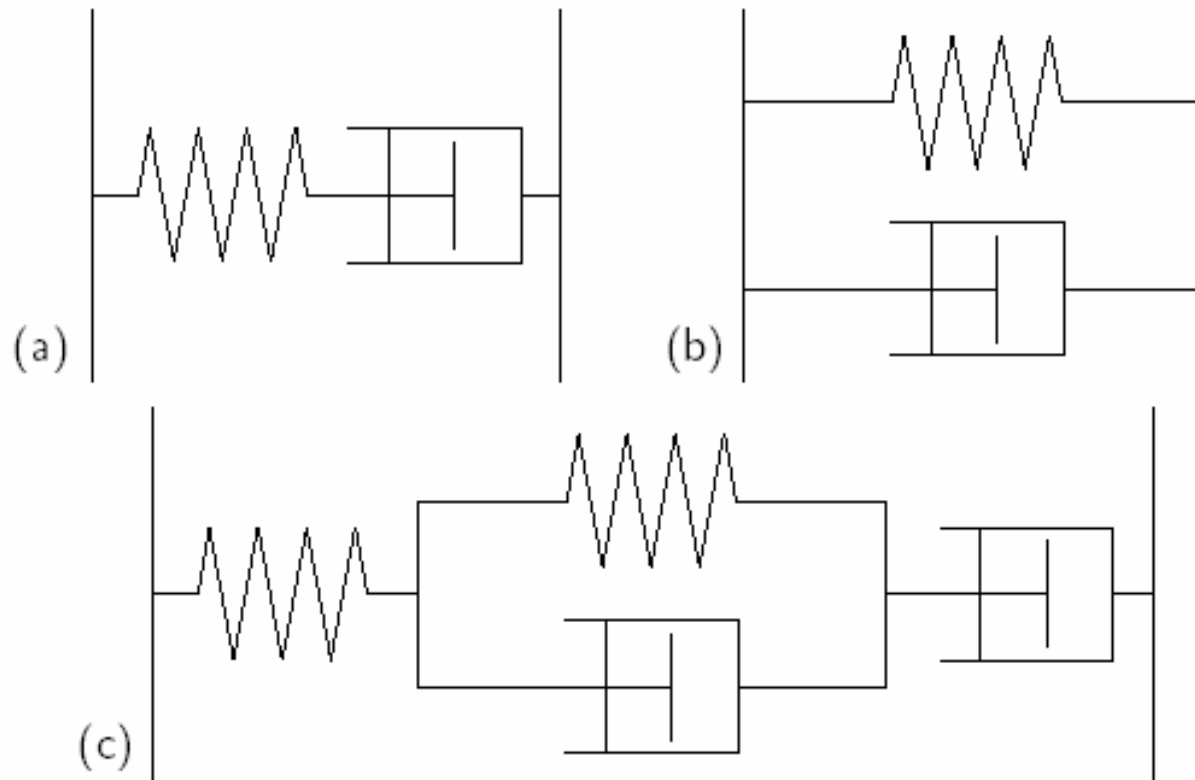
$$\epsilon_e(t) = \frac{\sigma}{E_e}$$

$\epsilon_v$ : **plastisch** (viskos)

$$\epsilon_v(t) = \frac{\sigma}{\eta} t$$

$\epsilon_r$ : **viskoelastisch** (relaxierend)

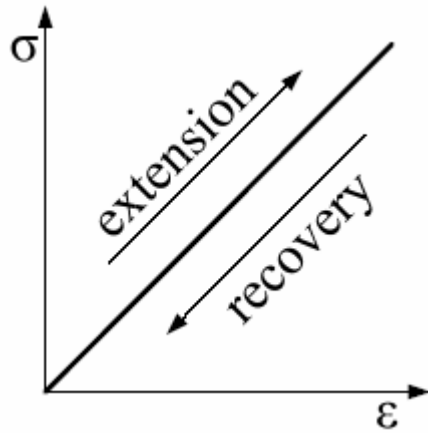
$$\epsilon_r(t) = \frac{\sigma}{E_r} (1 - e^{-t/\tau})$$

**Modelle:** Kombination von Federn (Hooke) und Dämpfern

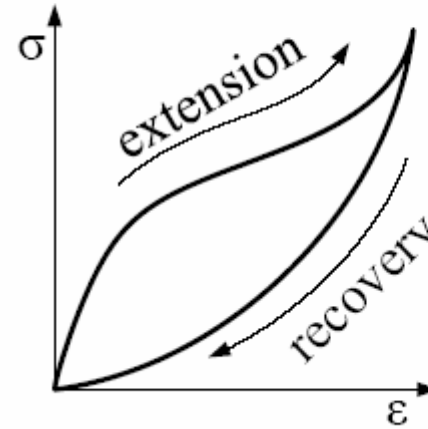
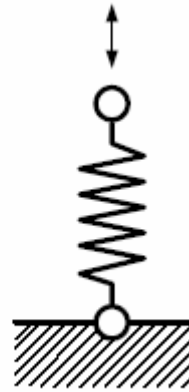
a) **Maxwell-Modell:** elastisch-plastisch

b) **Voigt-Kelvin-Modell:** viskoelastisch

c) **Burger-Modell:** allgemeiner Fall

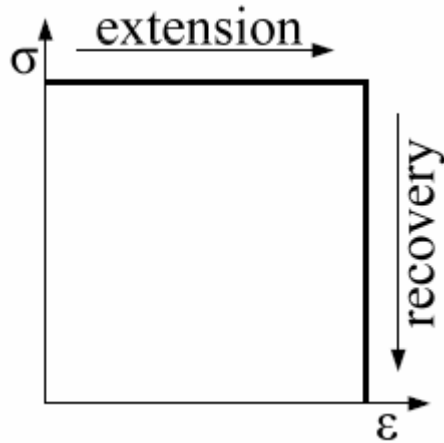
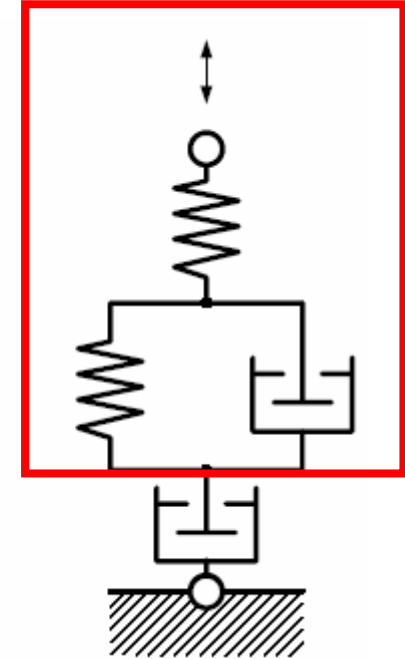


ideal elastisch

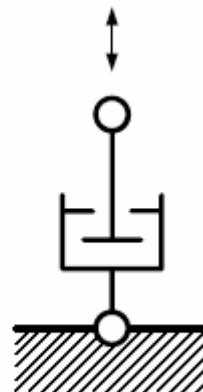


ideal linear viskoelastisch

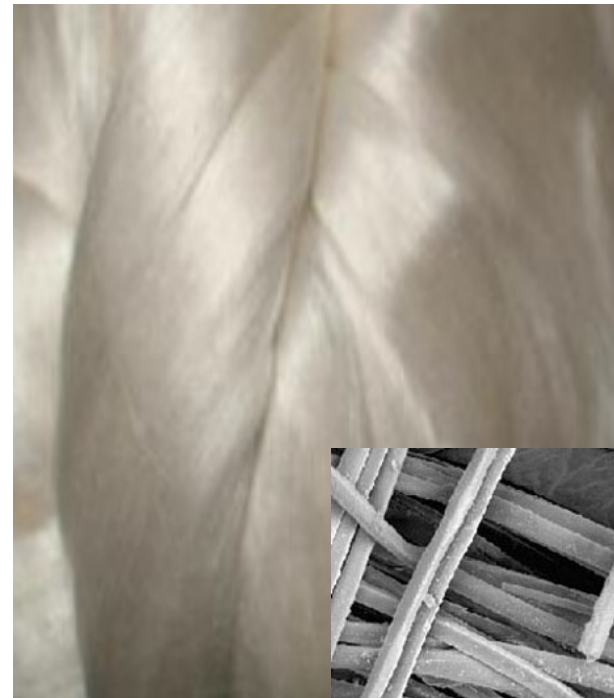
Seide



Flüssigkeit: komplette plastische Verformung



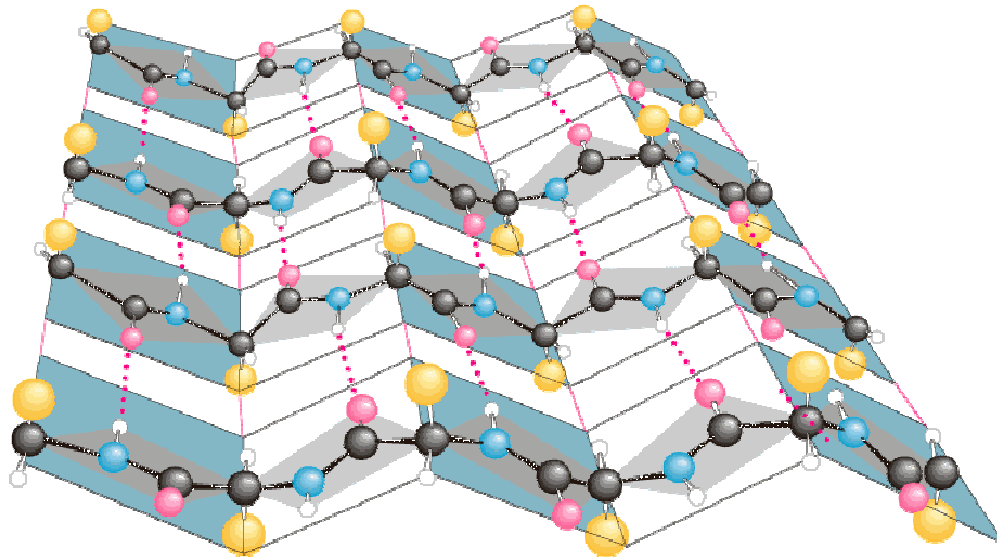
## 2.4 Seide der Seidenraupe (Maulbeerspinner *Bombyx mori*)



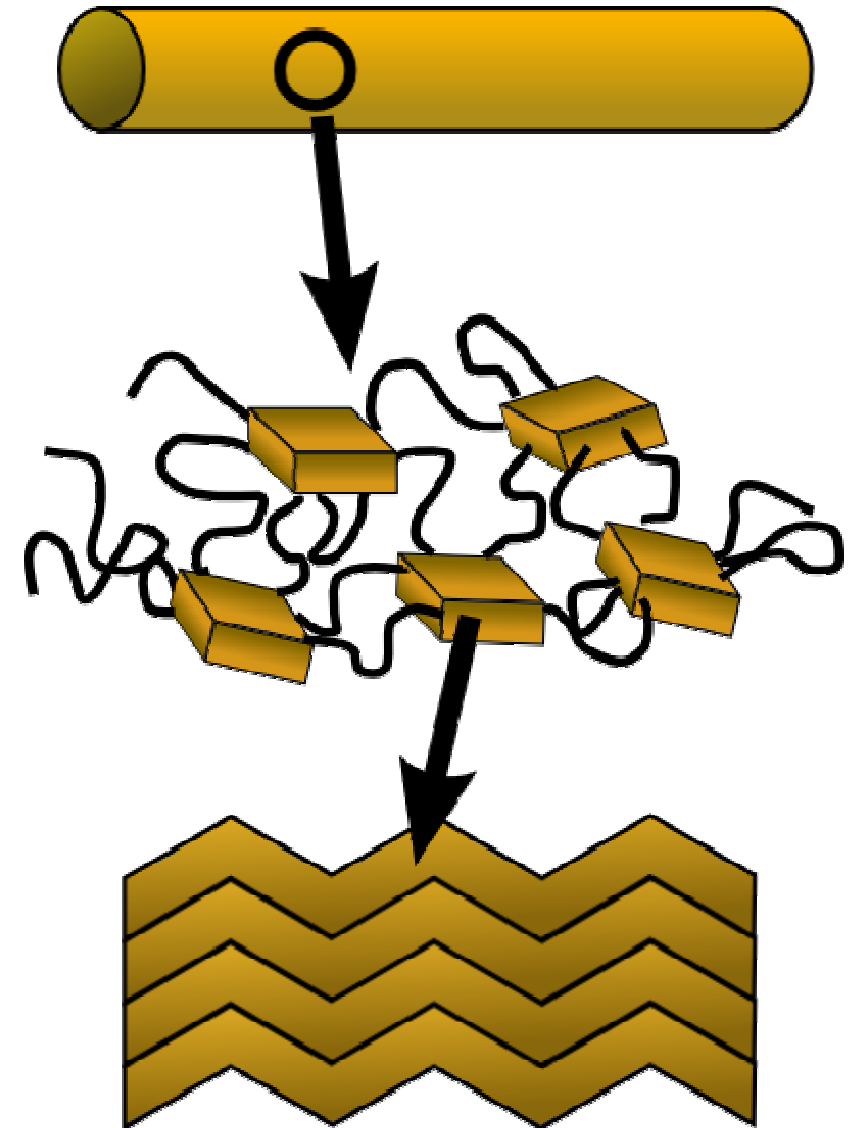
- hohe Festigkeit, gute Dehnbarkeit (etwas geringer als bei Spinnenseide)
- Isolierung gegen Wärme und Kälte

### Proteinfaser (Fibroin):

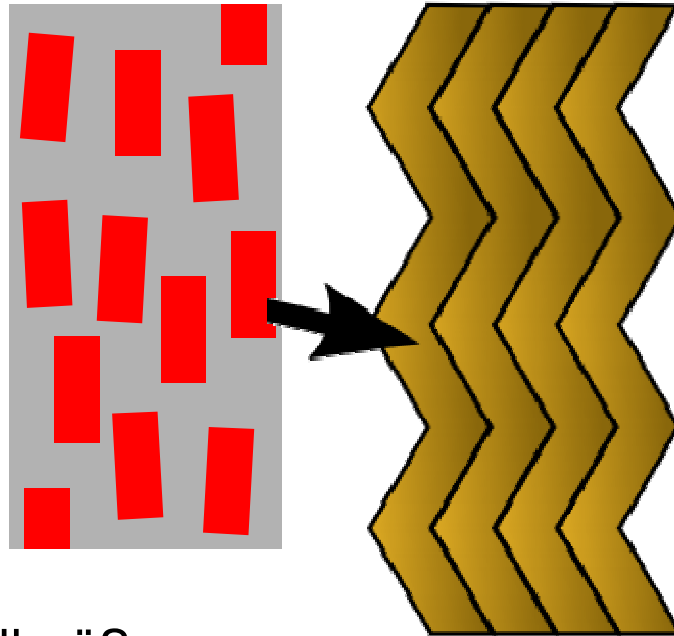
- bekannte Sequenz (Poly-Alanin-Glycin)
- chemische Ähnlichkeit zu Spinnenseide (etwas andere Sequenz)



Kristalle:  $\beta$ -Faltblattstruktur



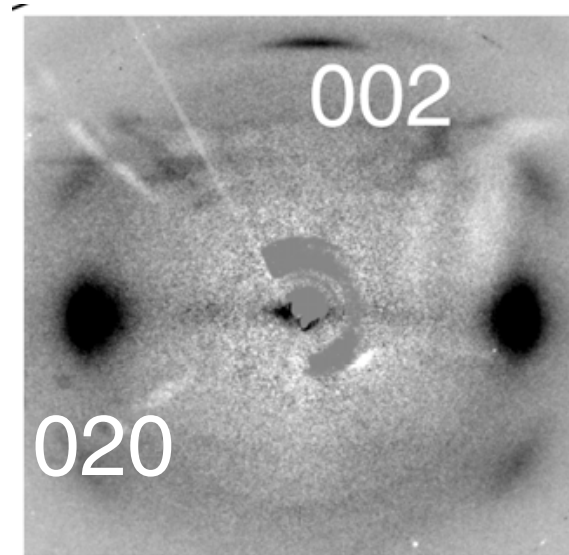
wieder **semikristalline** Morphologie



Kristallgröße:

5 nm × 2 nm × 7 nm

β-Faltblatt-  
Kristall

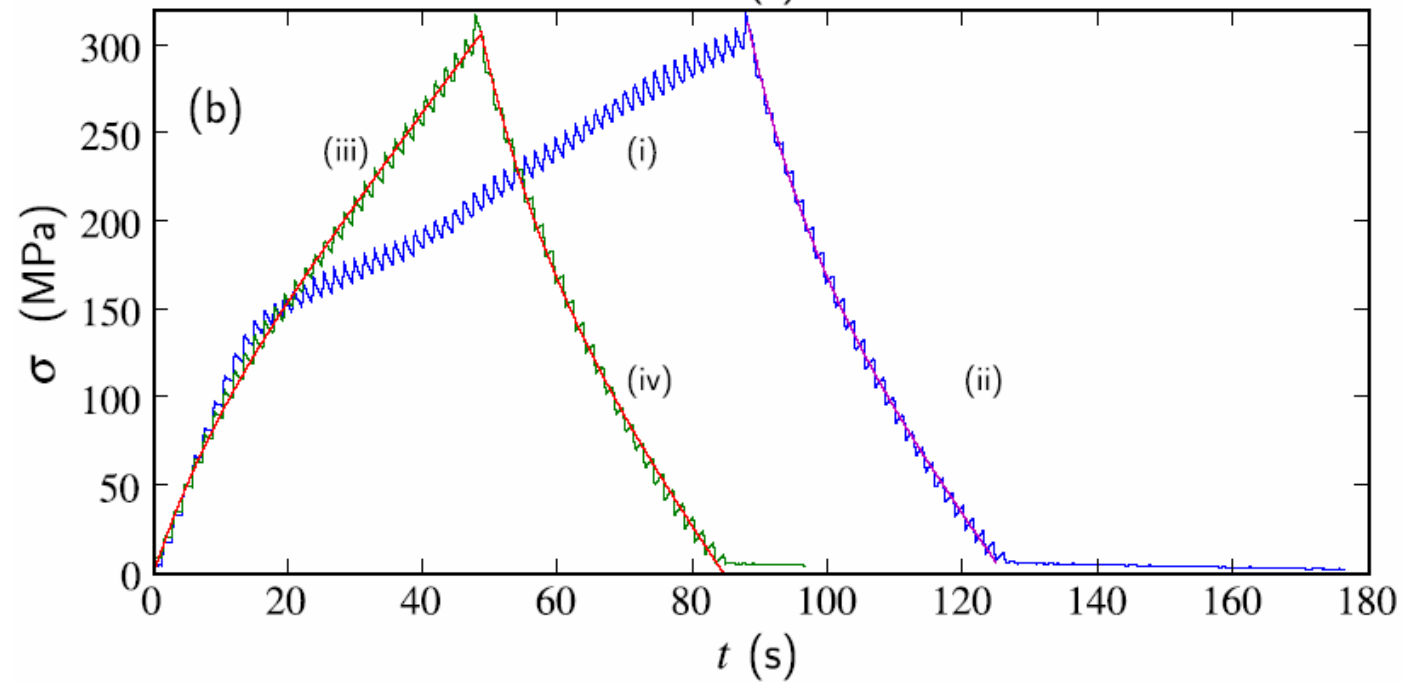
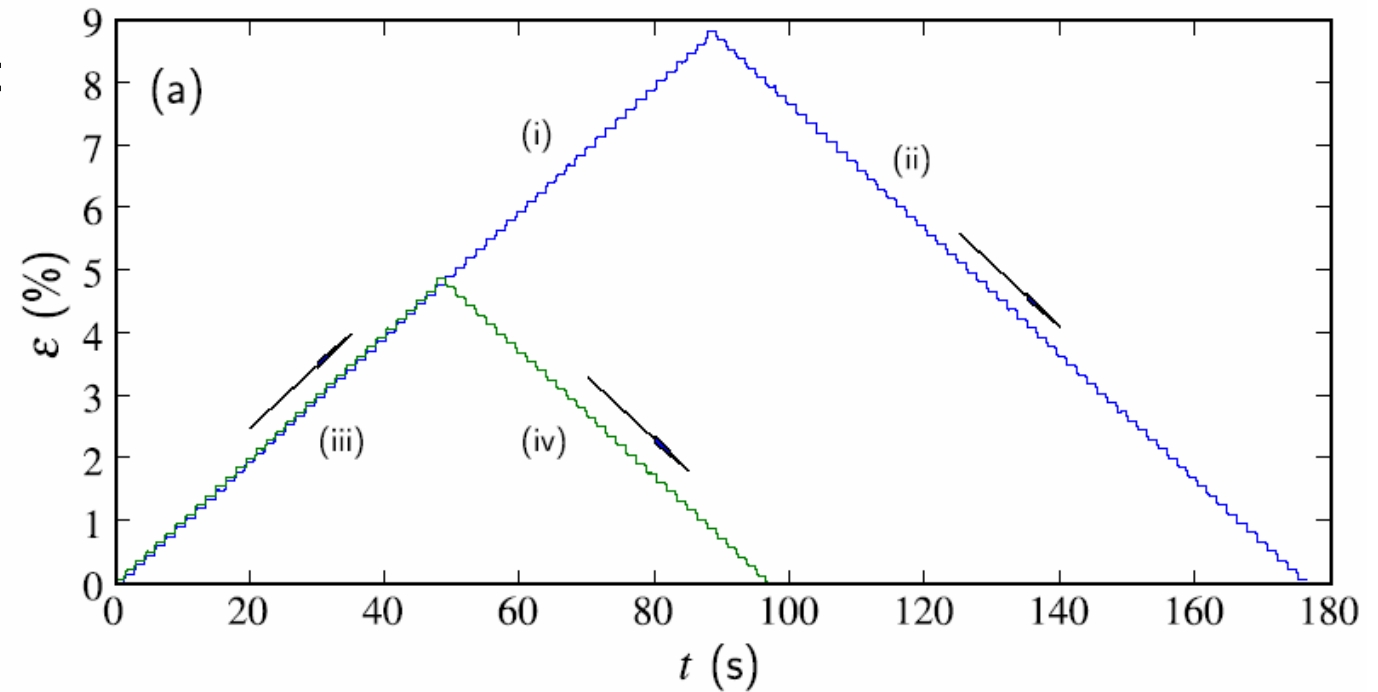


Röntgendiffraktogramm

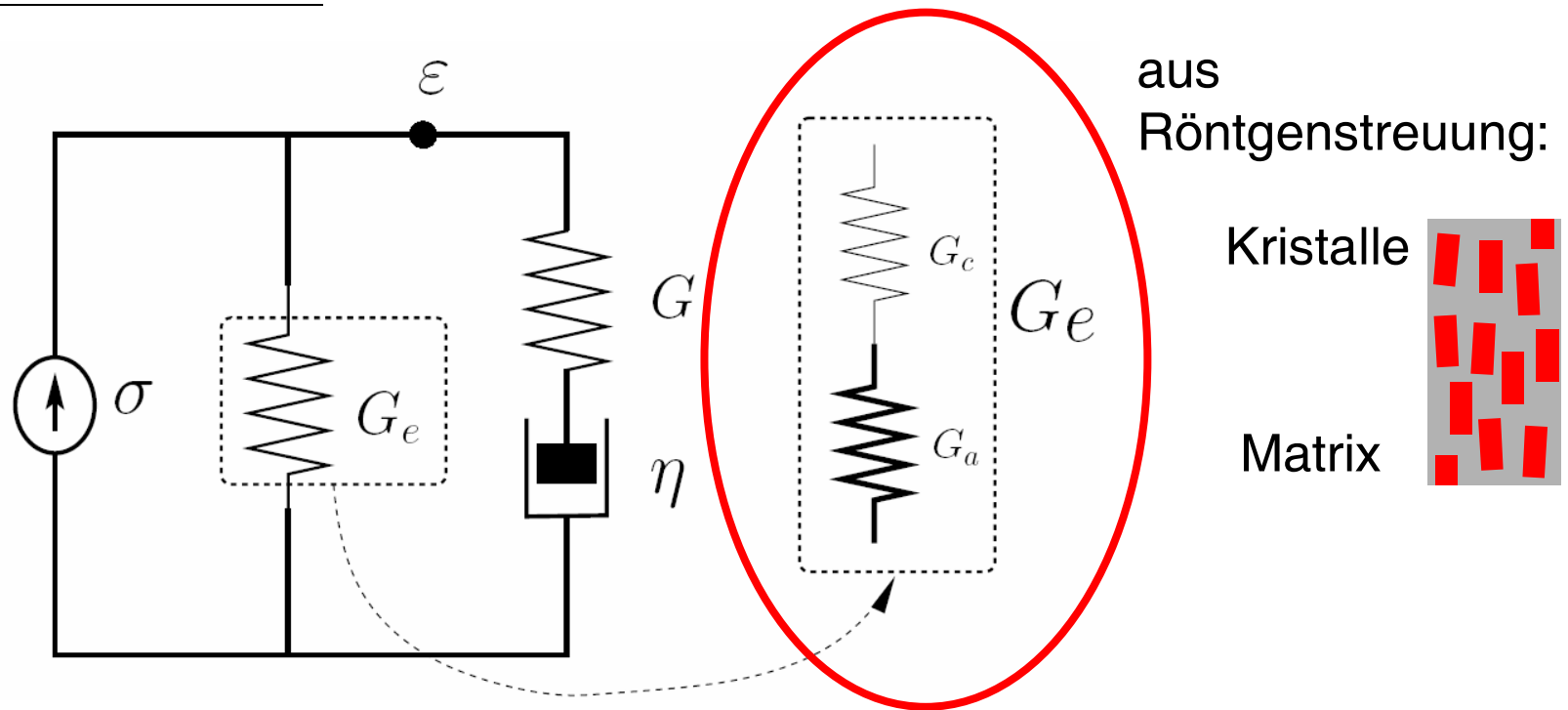
mechanische Eigenschaften?



**Streckexperiment**  
an einzelner  
Seidenfaser:  
kleine Stufen,  
**zyklisch**



mechanisches Modell:

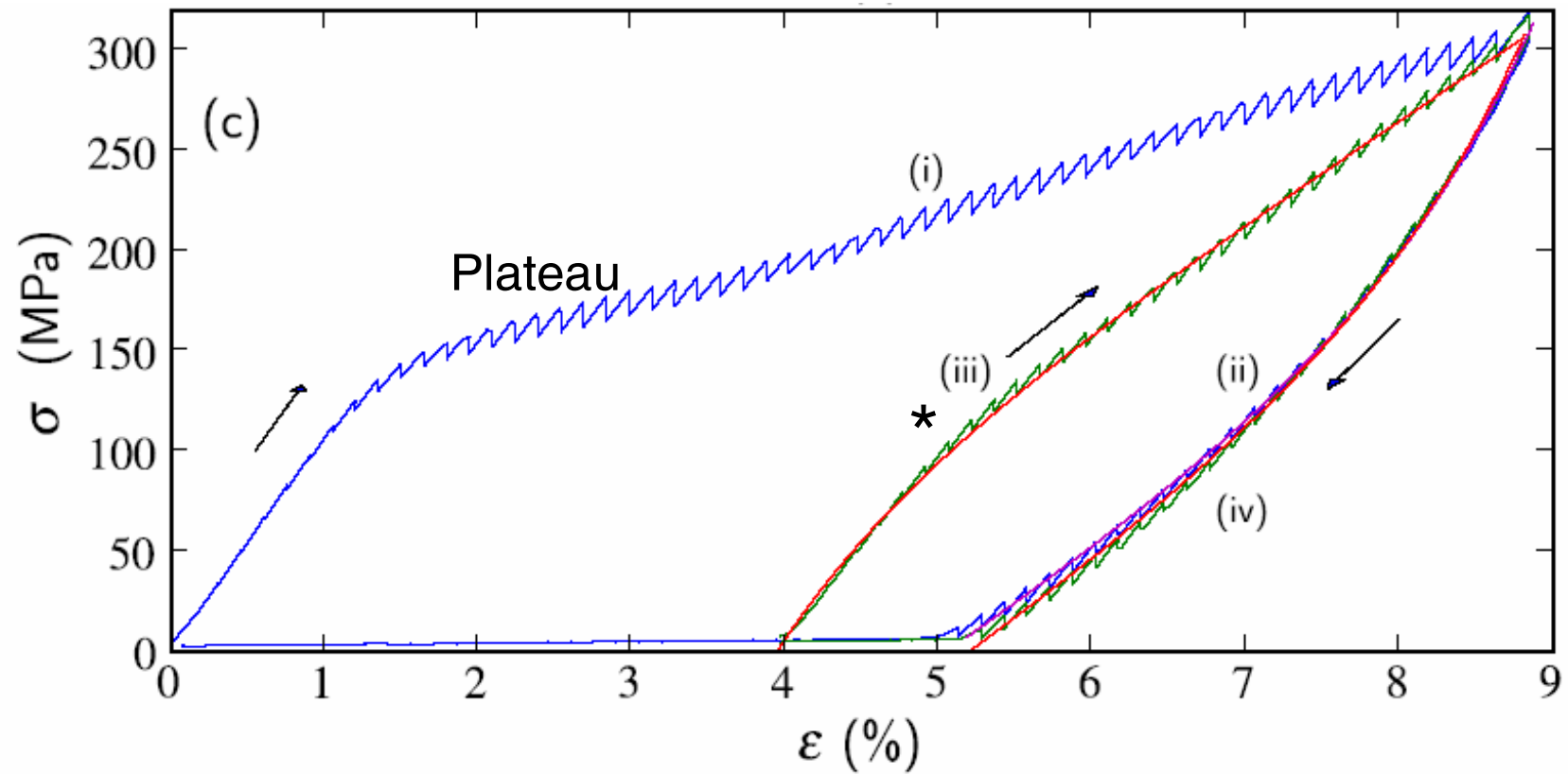


$$\sigma(t)/\dot{\varepsilon}_0 \equiv \tilde{\eta}(t) = G_e t + G\tau \left(1 - e^{-\frac{t}{\tau}}\right)$$

asymptotisch für kleine Zeiten:

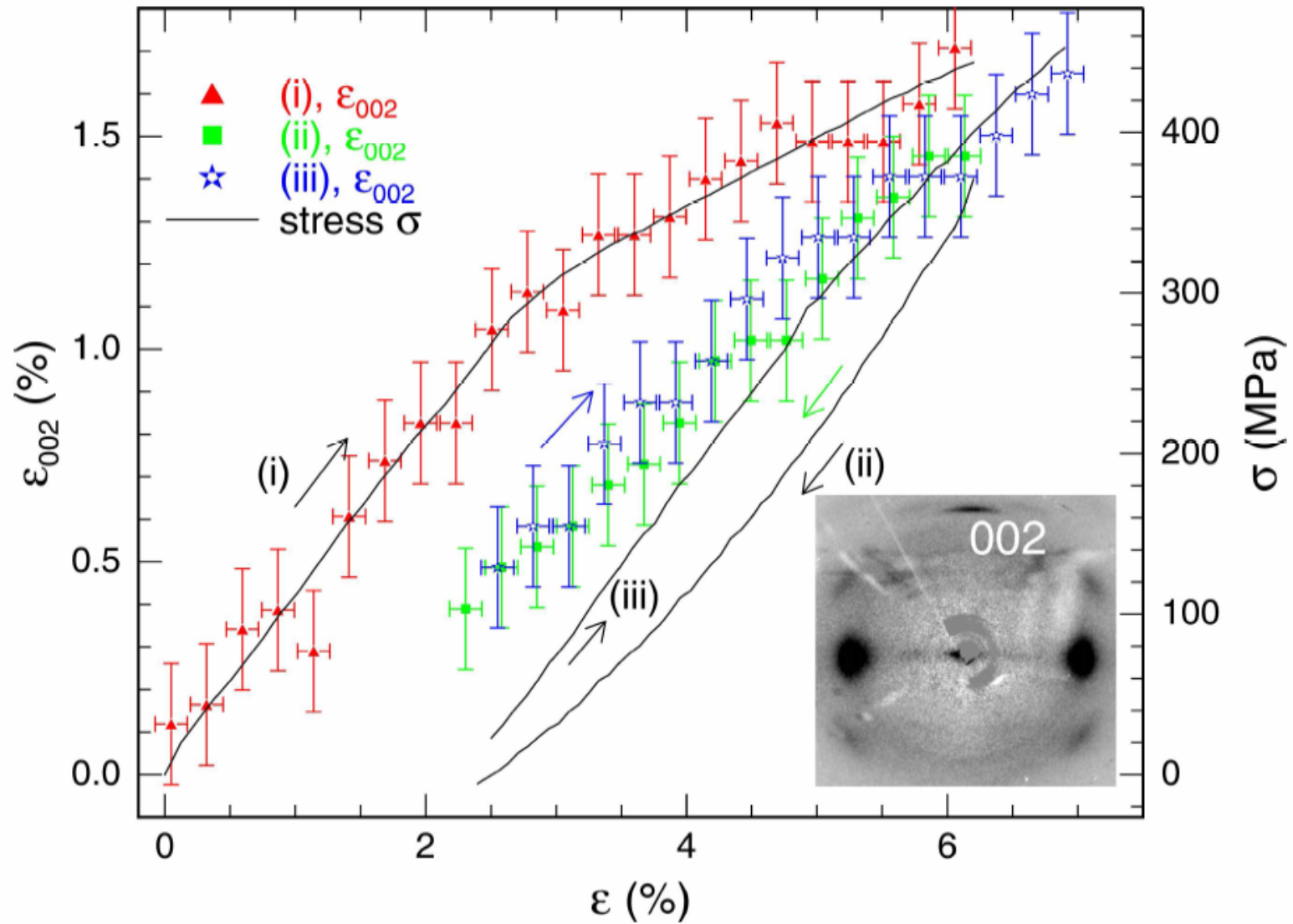
$$G_g = G_e + G$$

„Antwortzeit“  $\tau = \eta/G$



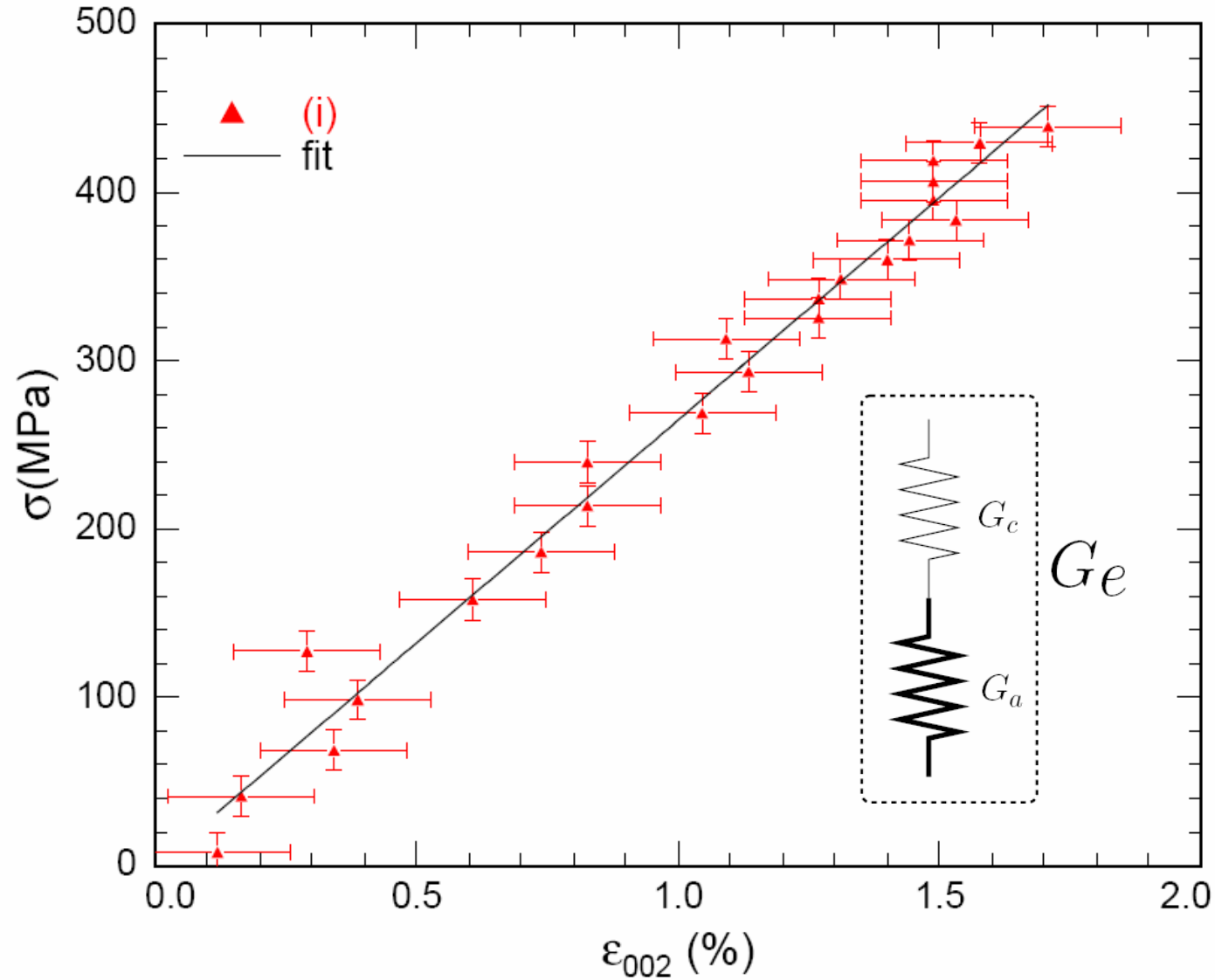
- Streckgrenze im 2. Zyklus (\*) durch Viskoelastizität erklärbar
- Plateau: zusätzlicher Mechanismus (H-Brücken?)

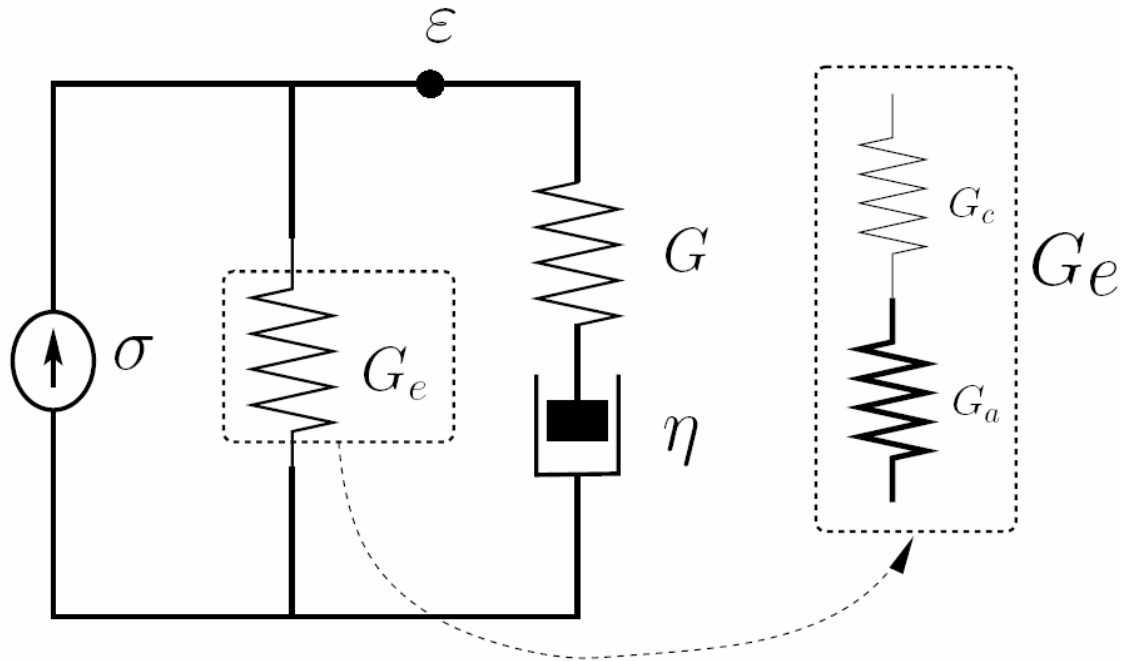
Röntgenstreuung: Kristalldehnung aus 002-Reflex  
Annahme rein elastischer Kristalle



Proportionalitat von Spannung und Kristalldehnung:  
Reihenschaltung (Reuss-Modell)

$$\frac{1}{G_e} = \frac{1}{G_c} + \frac{1}{G_a}$$





**Zahlenwerte:**

$$\left. \begin{array}{l} G = 6.6 \text{ GPa} \\ G_e = 5.1 \text{ GPa} \end{array} \right\} G_g = 11.7 \text{ GPa}$$

$$G_c = 26.5 \text{ GPa}$$

$$G_a = 6.3 \text{ GPa}$$