



基于金属材料的跨尺度原位力学研究

上海交通大学 特种材料所

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原位力学试验平台



上海交通大学材料科学与工程学院

特种材料研究所

王浩伟教授 长江学者

- 陶铝材料
- 铝基复合材料合成、成形
- 塑性变形
- 增材制造
- 中子检测技术

原位力学试验平台



陈哲

强塑性、同步辐射、变形和再结晶、增材制造、残余应力

TESCAN MAIA3

- 布鲁克EBSD、EDS



TESCAN LYRA3 FIB-SEM

- 牛津EBSD、EDS



金属材料的跨尺度力学性能研究



力学性能测试:

- 拉伸
- 压缩
- 疲劳
- 弯曲
- 高低温

...

宏观尺度 (厘/毫米级)

- 多晶、粗晶
- 传统金属结构材料

微观尺度 (微/纳米级)

- 单晶
- 超细晶、纳米晶
- 薄膜材料
- 微机电系统 (MEMS)

...

非原位观察

- 光镜、SEM、TEM、XRD...

原位观察

- 扫描电镜
- HR-EBSD、DIC
- FIB-TEM
- AFM
- 同步辐射

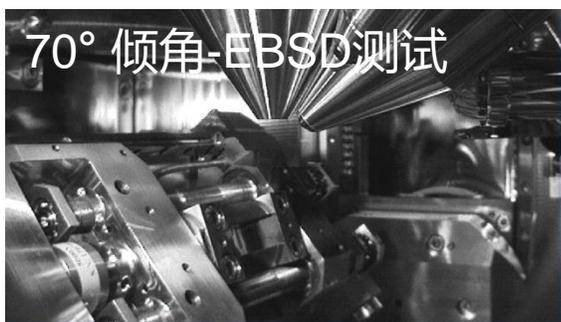
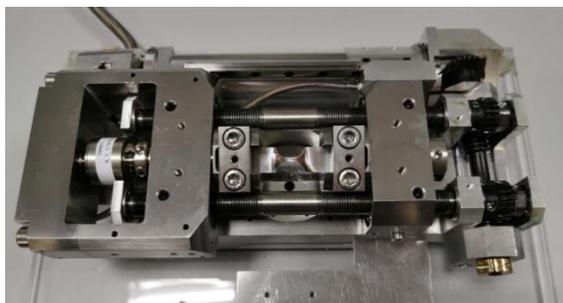
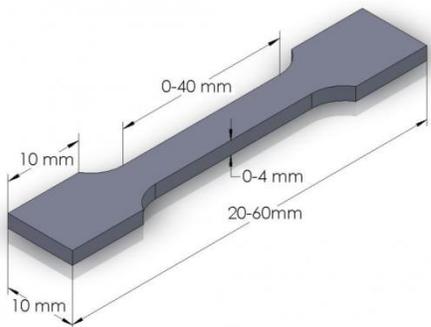
...

- 宏观应力应变曲线
- 局部应力应变场
- 局部微观结构演变
- 位错密度演变
- 位错滑移

一、原位室温/高温力学测试模块



● Kammrath&Weiss 拉伸-压缩力学测试系统



可开展实验:

- 室温拉伸/压缩
- 500N、5KN
- 高温拉伸/压缩
- RT-1000°C
- 裂纹扩展
- SEM图像
- 疲劳

可配套表征:

- EBSD
- 高分辨率EBSD
- DIC
- AFM
- 同步辐射
- ...

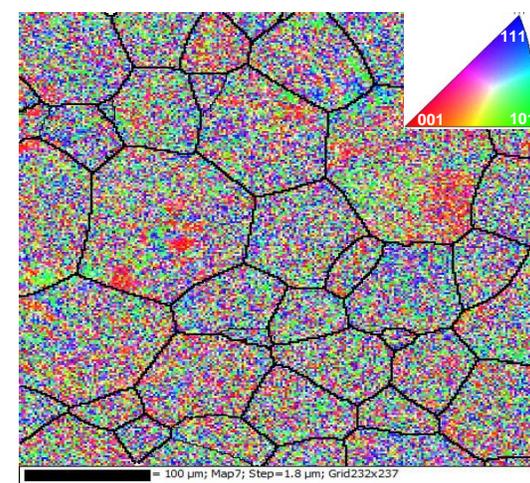
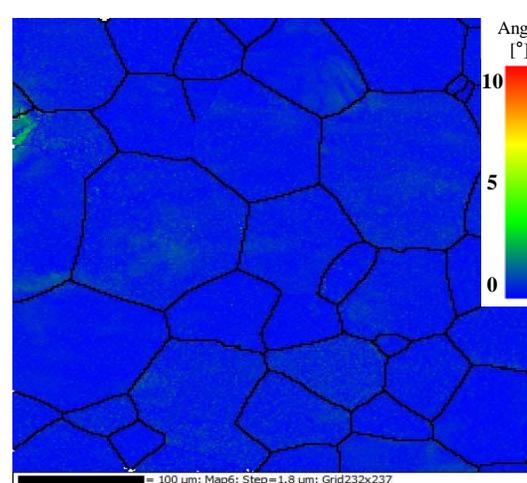
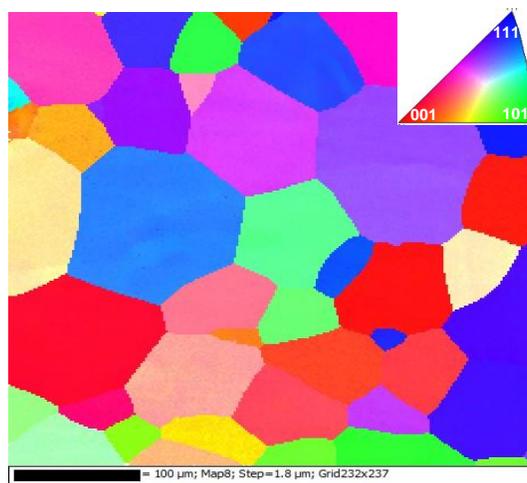
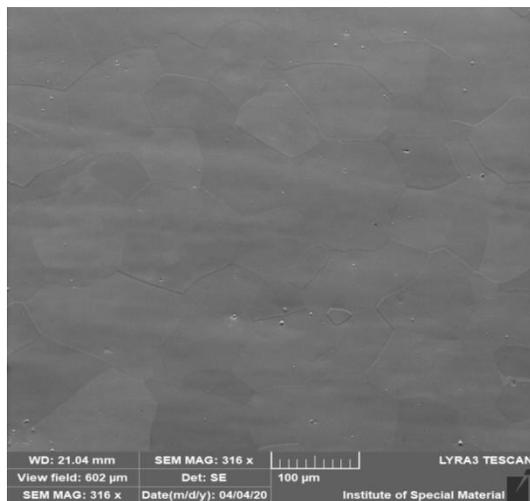
获得信息:

- 力学实验曲线
- 滑移线追踪
- 晶粒取向追踪
- 小角晶界演化
- 应力应变场
- 位错密度演化
- ...

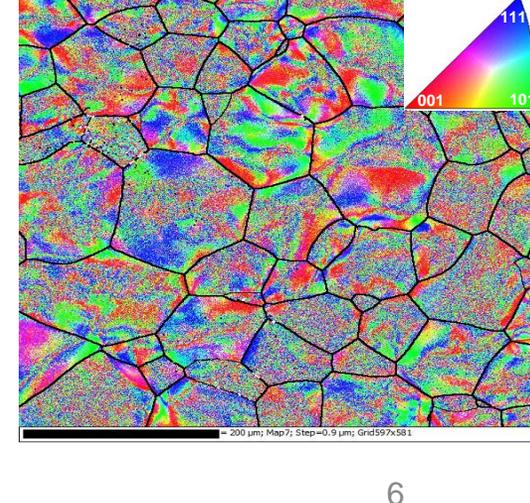
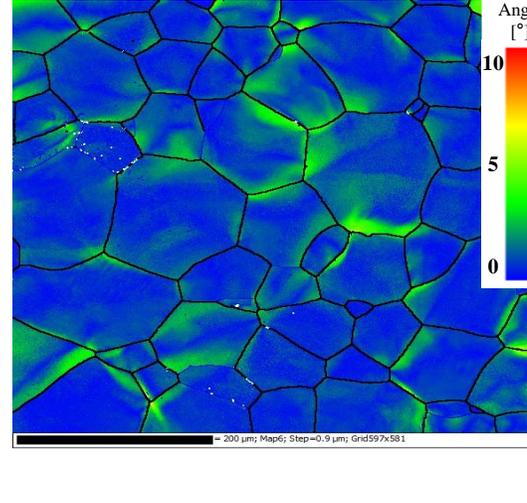
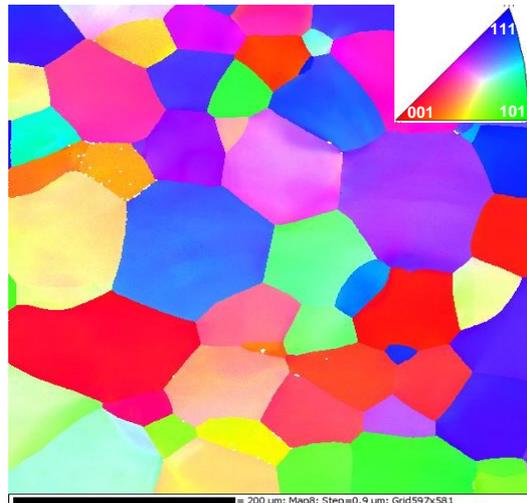
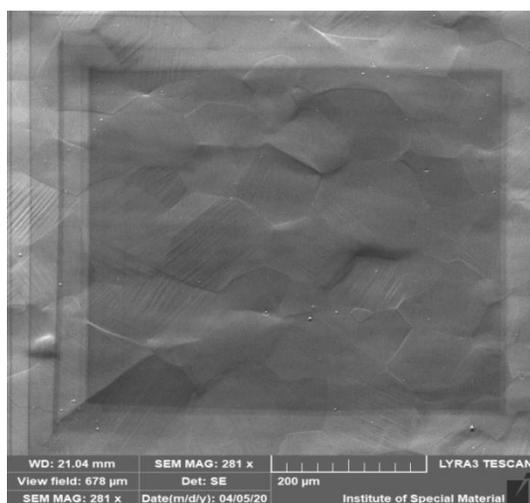
原位拉伸-EBSD表征



拉伸前

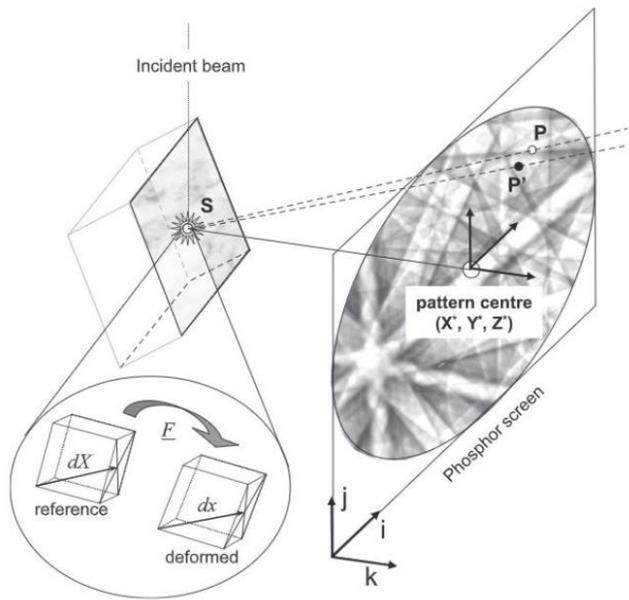


拉伸至4%



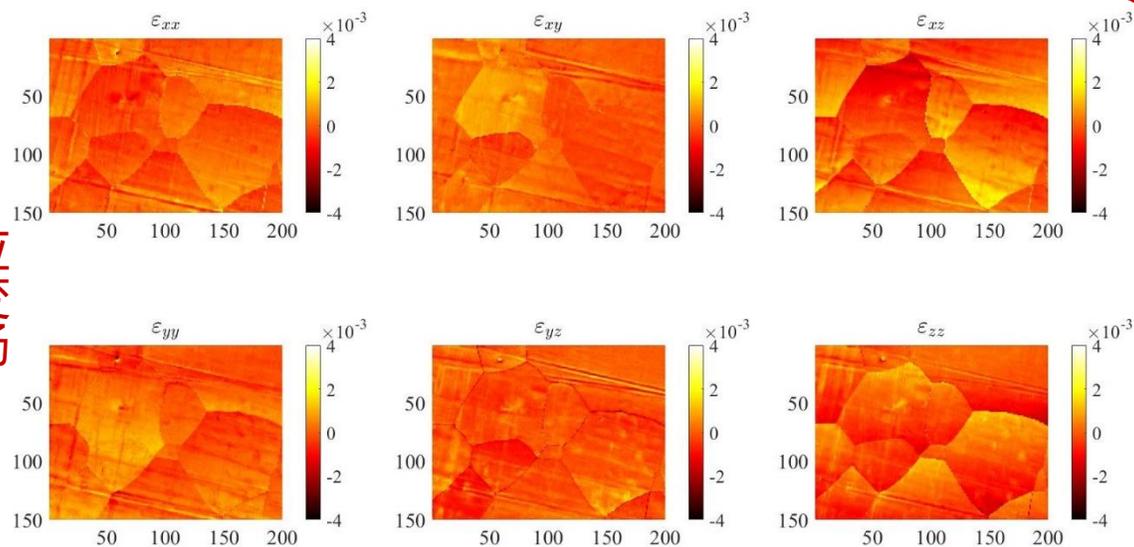
高分辨率EBSD表征

高分辨率EBSD技术将常规EBSD的角度分辨率由 $0.3-0.5^\circ$ 提升至 $10^{-5}-10^{-4}$ rad, 可以表征微纳米尺度下的应力场、应变场和几何必需位错 (GNDs) 分布等。

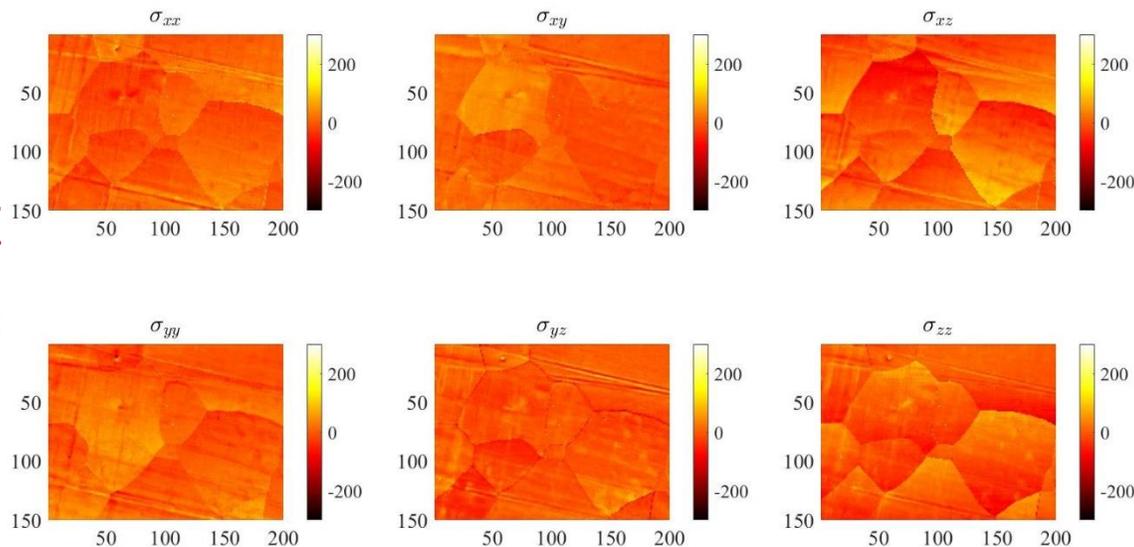


施奇伟
高分辨EBSD、DIC、ECCI

应变场



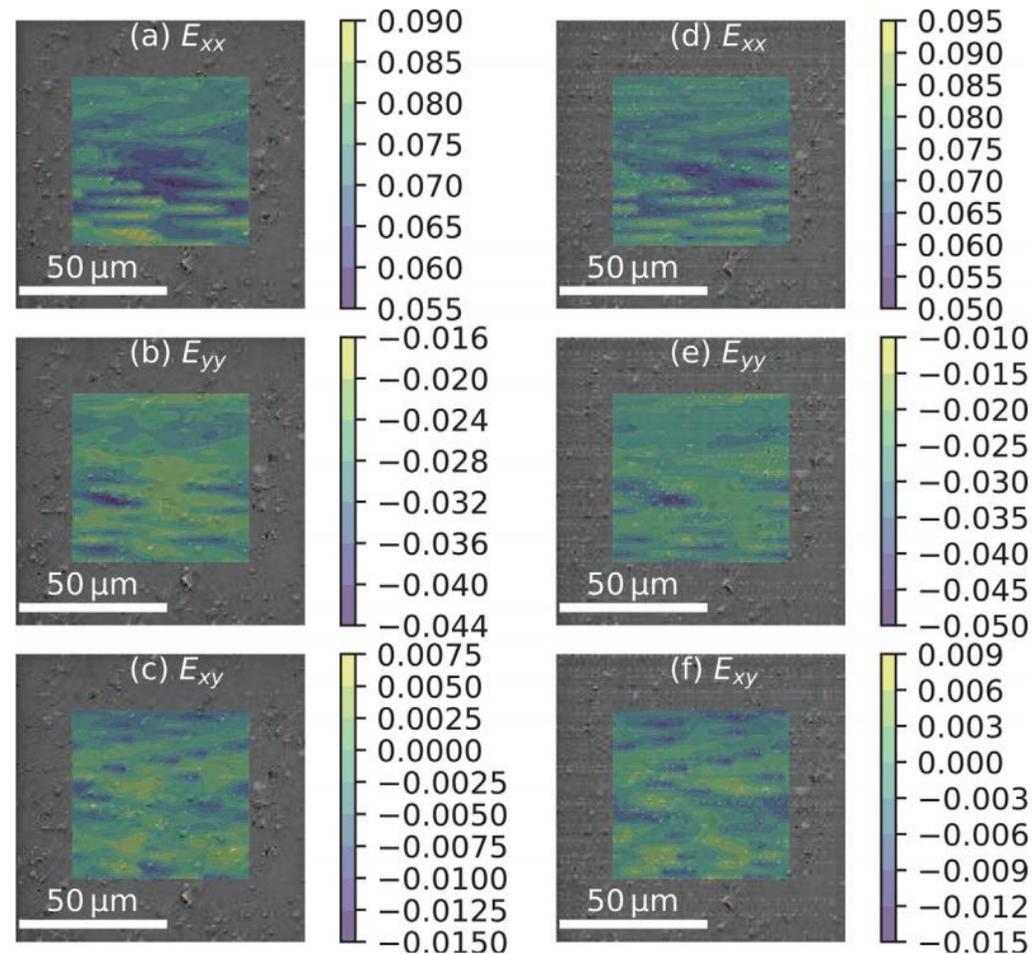
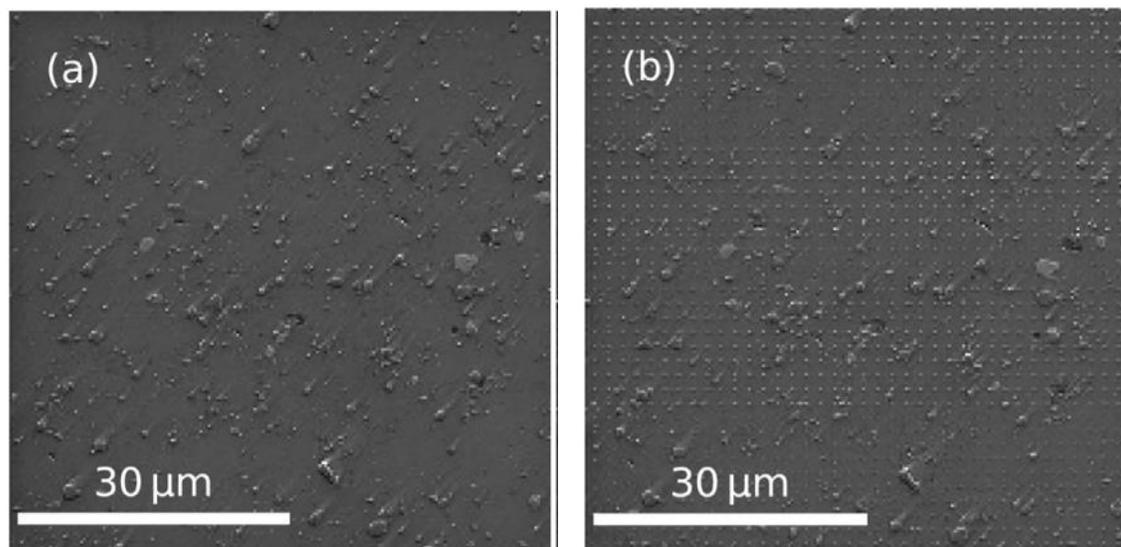
应力场



原位拉伸-DIC-应变场



In-situ TiB_2 reinforced AlZnMgCu composites

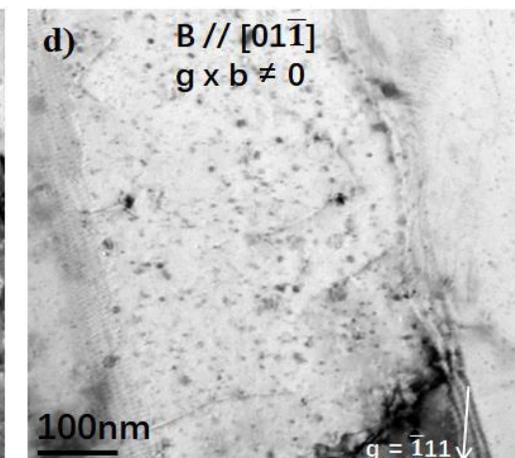
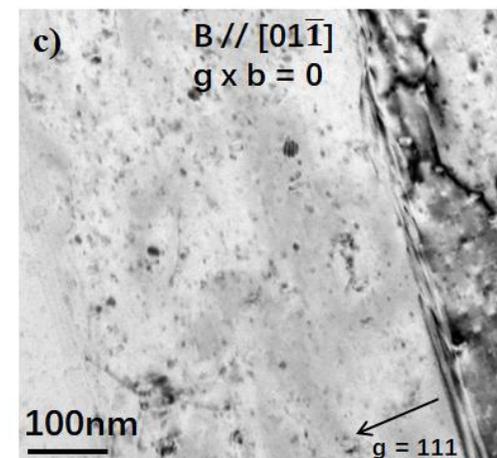
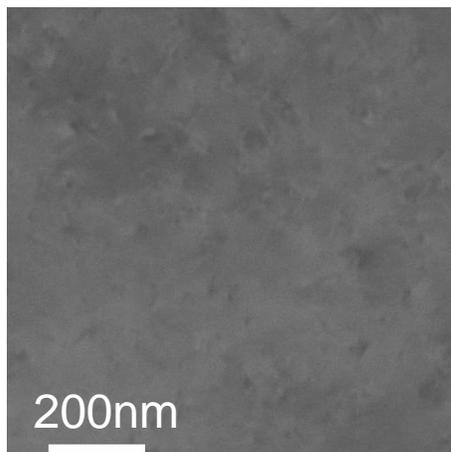
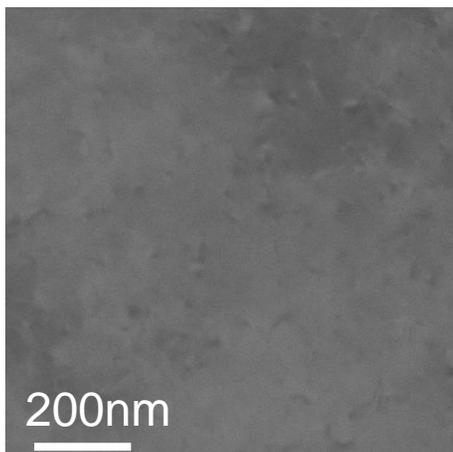
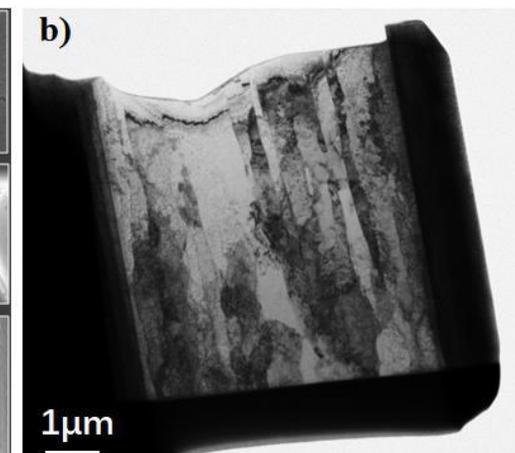
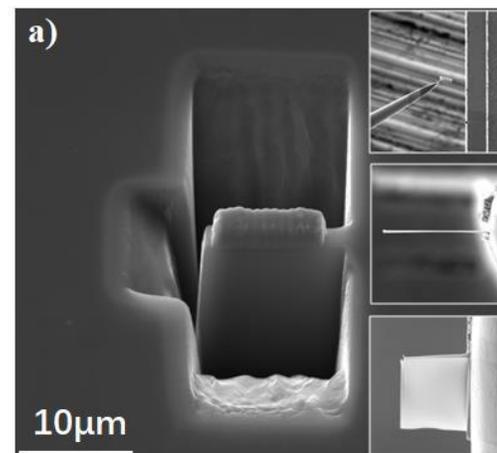
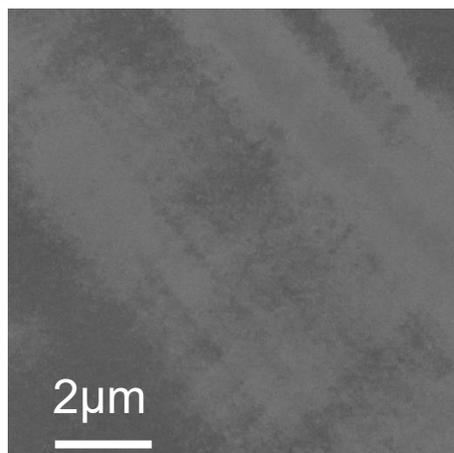
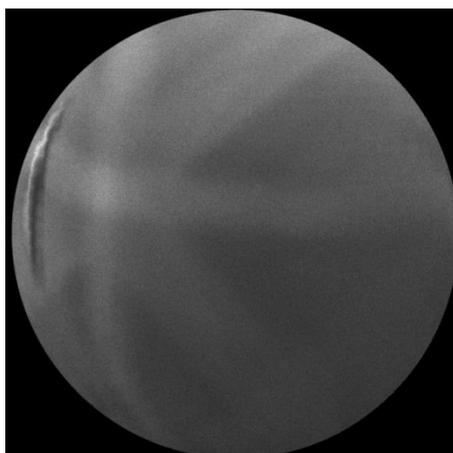


张丰果
DIC、有限元模拟、劳厄衍射

ECCI-FIB TEM



ECCI: Channeling Mode + BSE



二、微纳米尺度力学测试模块

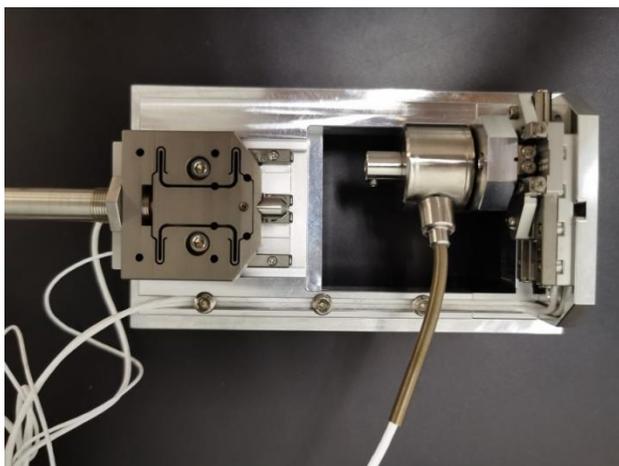
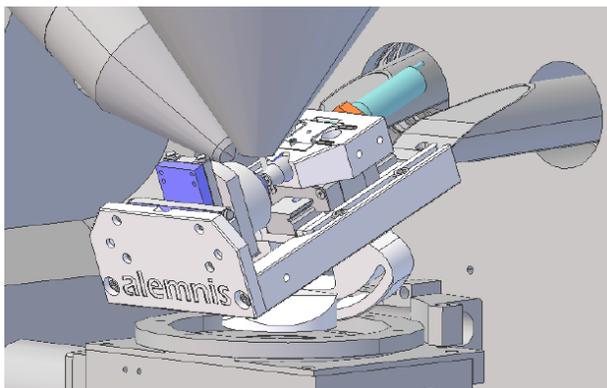


• Alemnis 原位纳米力学测试系统



Materials Science and Technology

瑞士联邦材料科学与技术实验室-合作

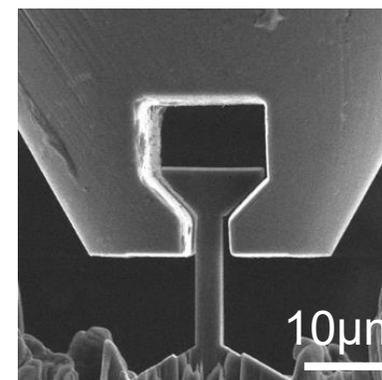
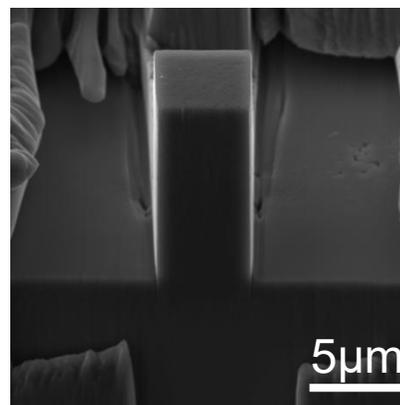
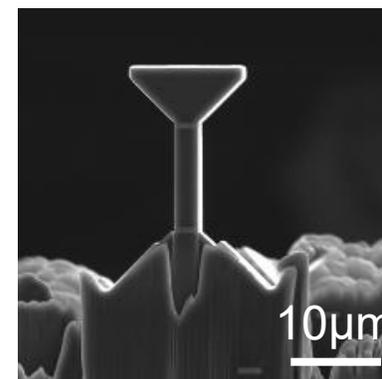


可开展实验:

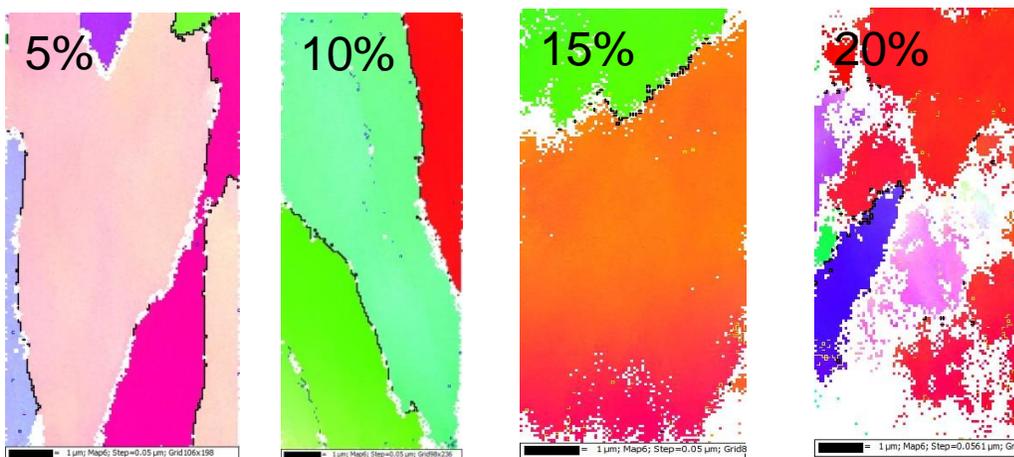
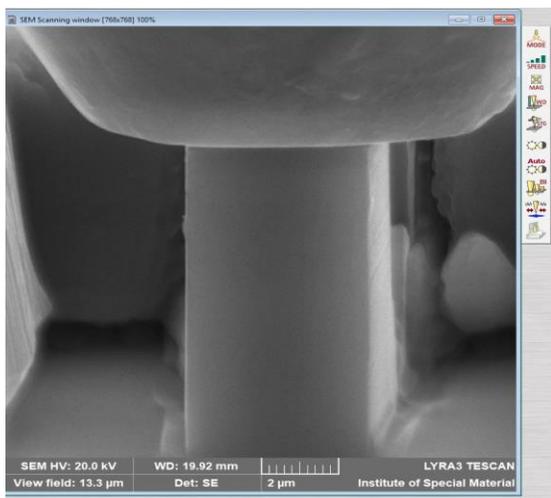
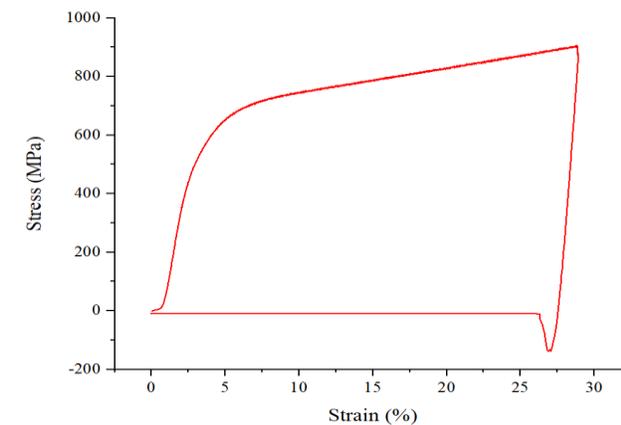
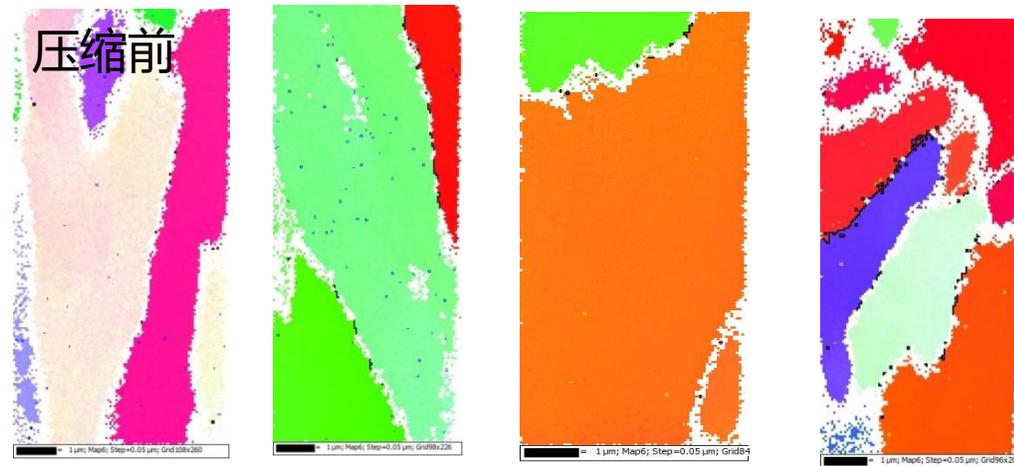
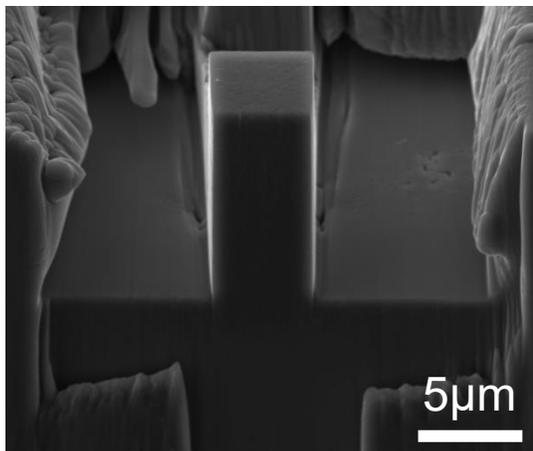
- 纳米压痕
- 微柱压缩
- 原位拉伸
- 弯曲/剪切
- 疲劳
- 高低温
(-150 to 800°C)
- 高应变速率
(10^{-5} to 10^4 s⁻¹)

可配套表征:

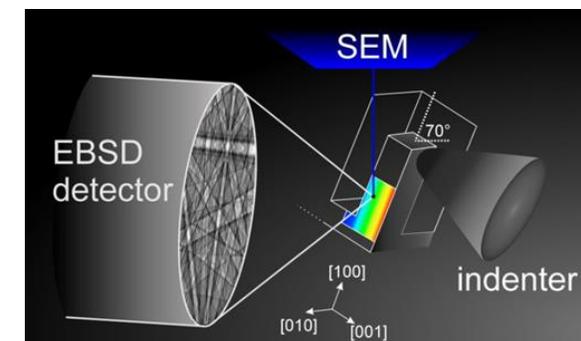
- EBSD
- 高分辨率EBSD
- DIC
- 劳厄衍射



微柱压缩实验

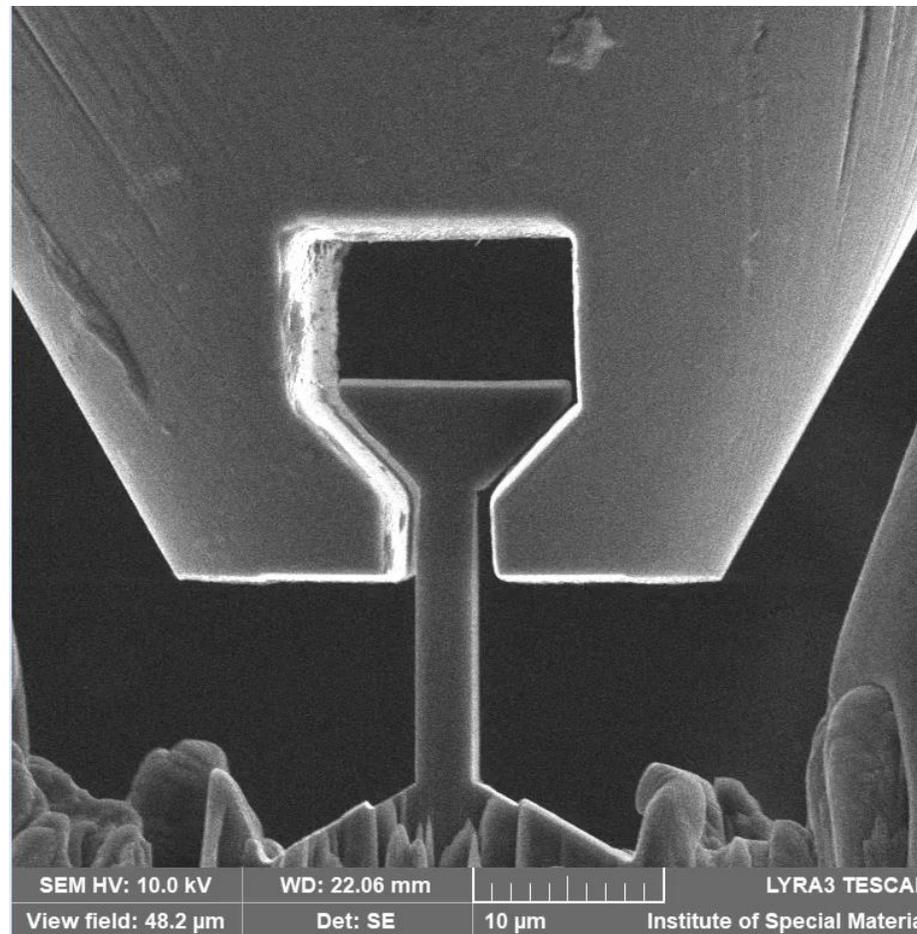
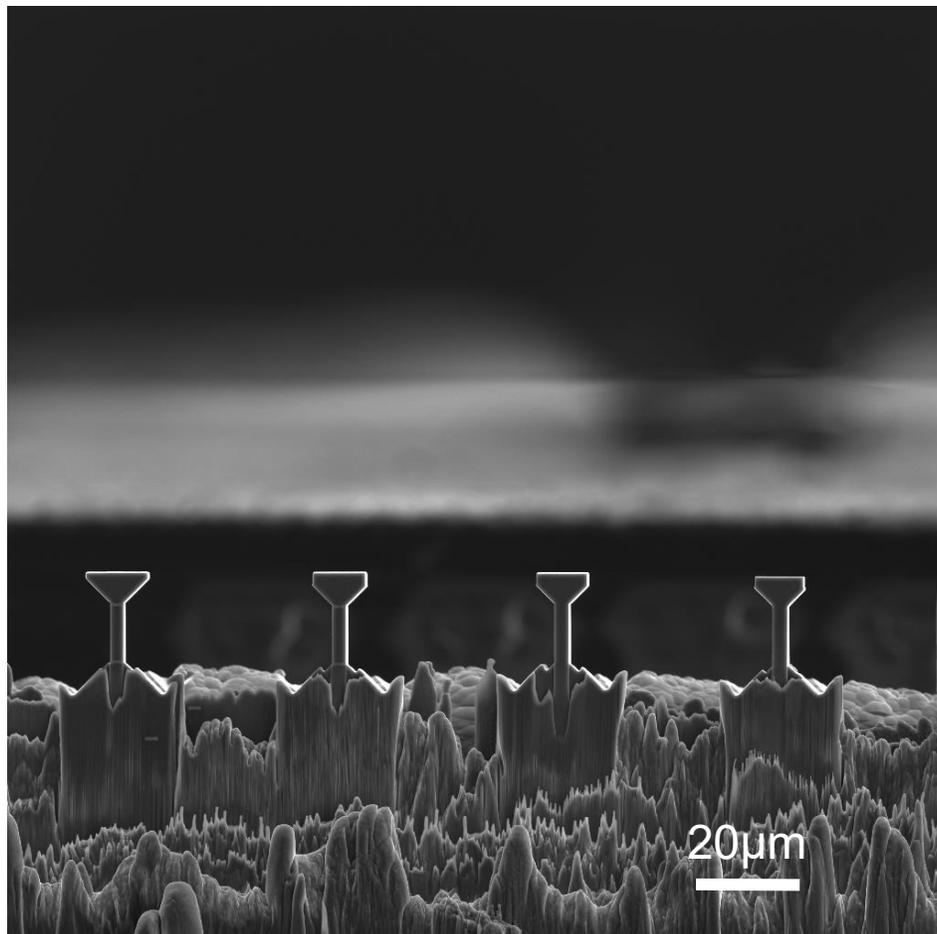


原位HR-EBSD^[1]

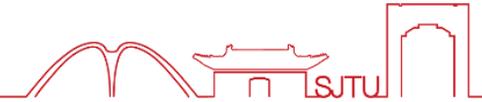


1. Ast J, et. al. Materials & Design 2017;117:265-6

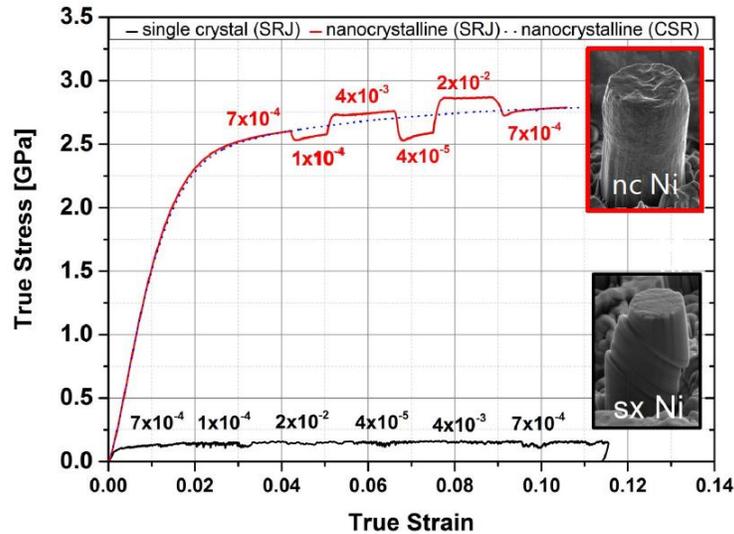
原位拉伸实验 (微米尺度)



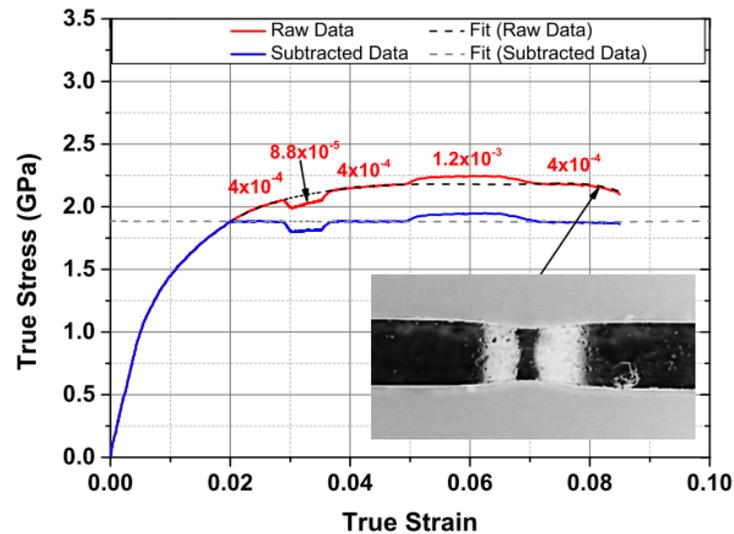
Strain rate jump test



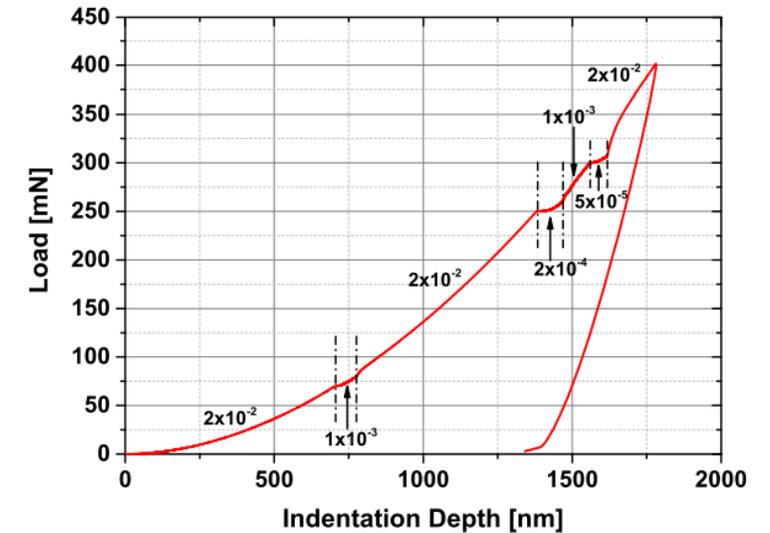
Microcompression



Miniature Tension

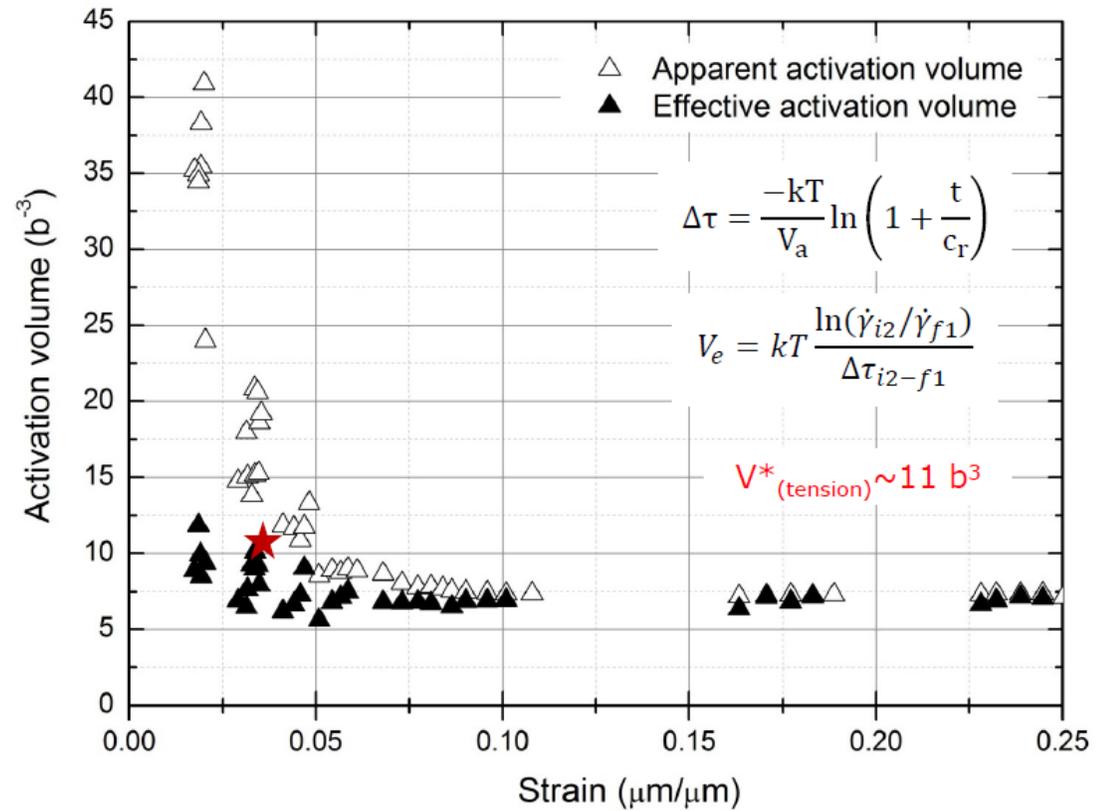
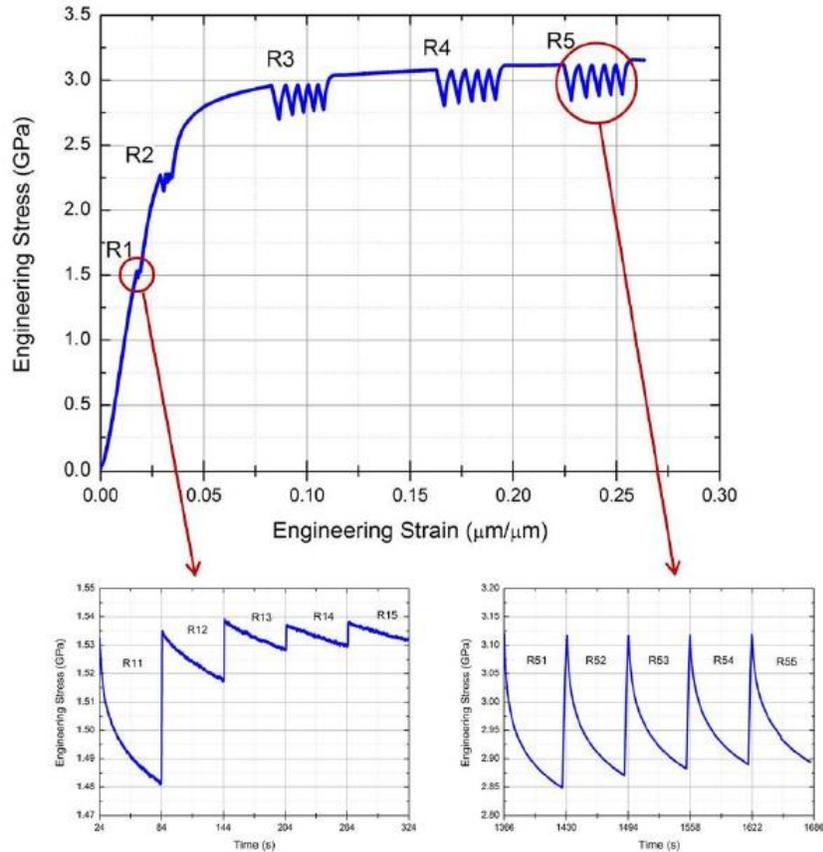
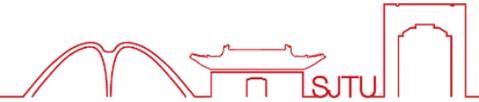


Nanoindentation

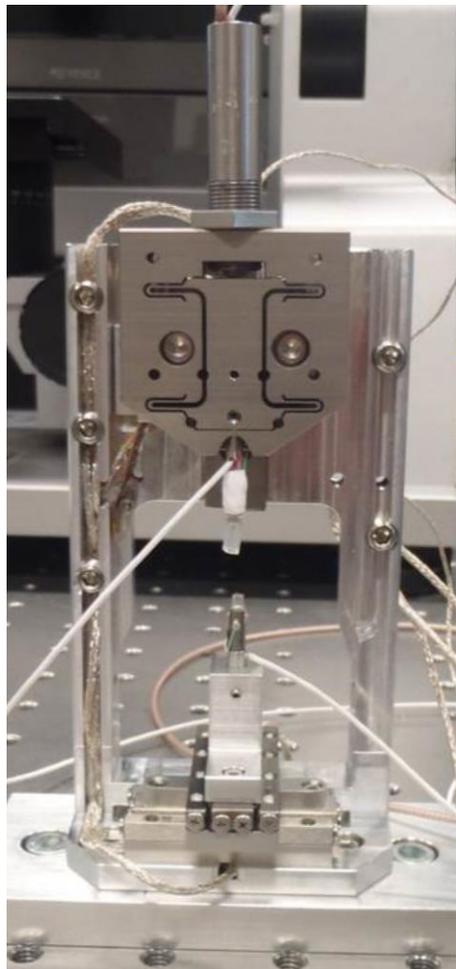


应变速率敏感系数:
$$m = \left[\frac{d(\ln \sigma)}{d(\ln \dot{\epsilon})} \right]_T$$

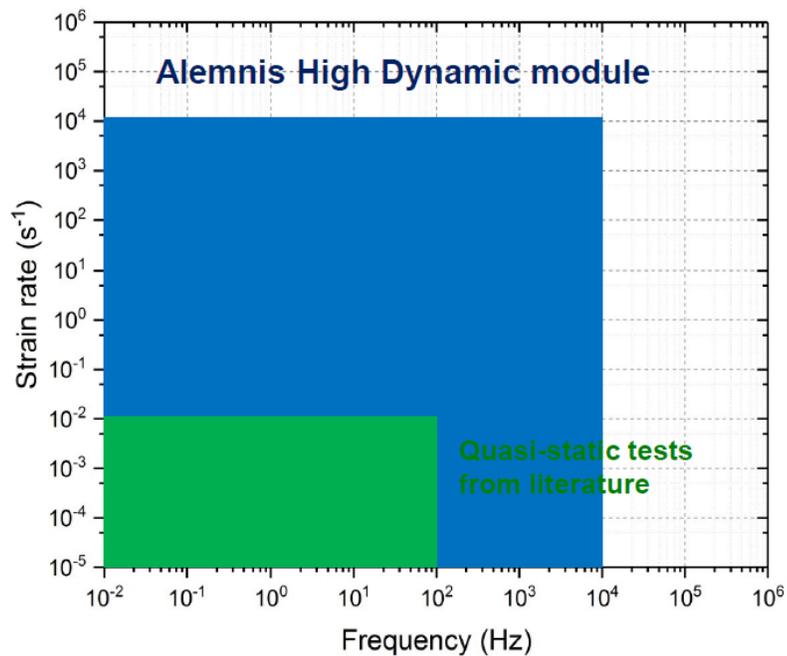
应力松弛实验



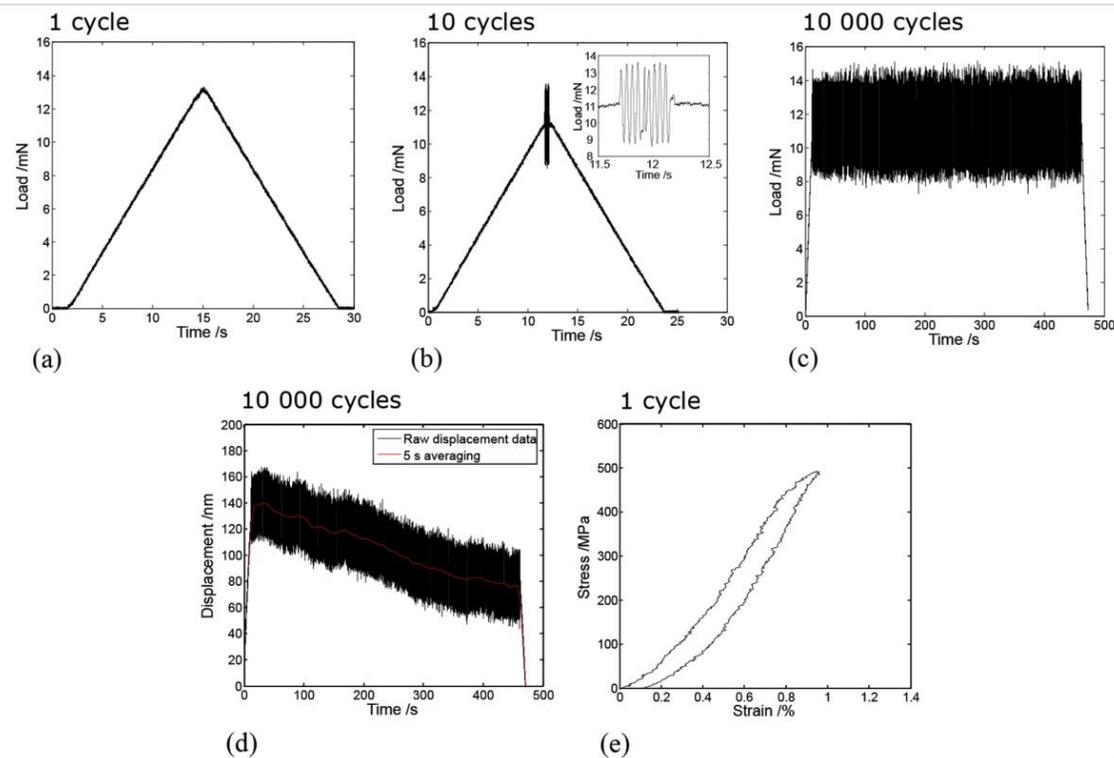
高应变速率模块



最大载荷: 1N
最大位移: 5 μ m
最快频率: 10kHz



疲劳实验



谢谢各位!



上海交通大学

SHANGHAI JIAO TONG UNIVERSITY