7.3 THERMOMECHANICS OF RESILIENT MICRO-ENGINEERED PLASMA FACING MATERIALS—David Rivera, Richard Wirz, Nasr M. Ghoniem (University of California, Los Angeles)

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The need for reliable high temperature materials to facilitate the development of technologies such as fusion energy, space electric propulsion, and traditional nuclear power has led to the creation of a new materials concept making use of “microarchitected” surfaces to prevent damage due to the accumulation of detrimental plastic strains. Such surfaces are intended to be applied to engineering components in need of thermal protection in the form of a coating and are comprised of refractory metals such as tungsten and rhenium. The focus of this study is a tungsten – rhenium coating system made up of Re micro-pillars (approximately 20-25 microns in height with a diameter of 4-6 microns) coated with a light layer of W about 0.5 – 1 micron thick, an image of such a surface is shown in Figure 1. These surfaces are capable of withstanding heat fluxes in excess of 20 MW/m^2 through a distinct strain tolerant geometry capable of freely expanding or contracting to accommodate thermal strains as seen in Figure 2.

The effect of an incoming heat flux on micro-engineered surfaces was contrasted with those of conventional planar surfaces through the use of a high heat flux testing facility constructed at UCLA. Both planar and micro-engineered materials were subjected to a battery of pulsed operation high heat flux tests. Pulse duration was 6 s at 16 MW/m^2 intensity for several hundred pulses under cooled conditions. The heat flux is generated by a commercial plasma gun of arc-jet configuration. Samples are mounted using a special holder which provides cooling to the specimens while they are exposed to the plasma. This configuration prevents excessive heat buildup and premature melting or failure of the sample. During pulsing, compressive thermal stresses are generated at the sample center as a result of the constrained nature of the set-up, an illustration of the plasma beam striking the sample surface can been seen in Figure 3. This combination of high stress and high temperature leads to plastic flow as the yield stress of tungsten rapidly decreases with increasing temperature. Characterization of the exposed samples was conducted through tools such as X-ray diffraction and scanning electron microscopy.

As a result of testing, planar materials were shown to have experienced a recrystallization of their microstructure as was evidenced by the appearance of new X-ray diffraction (XRD) peaks not present in the initial unexposed profile as seen in Figure 4. Such microstructural reorganization of the material has been proven to lead to embrittlement and should be avoided [1]. In addition, analysis of the effects of heat flux on XRD peak breadth (a qualitative measure of the plastic distortion) determines that planar surfaces suffer from large plastic strains which invariably lead to fracture of the material as a result of residual stress build-up. In contrast, micro-engineered surfaces are able resist plastic distortion relative to planar surfaces as is evident from a comparison of the XRD peak broadening data as seen in Figure 5. This figure shows the decreased trend in plastic distortion as a function of accumulated energy density (no.pulses x pulse duration x pulse intensity) for micro-engineered surfaces when compared to planar material. When more quantitative XRD measures of stress are employed such as the sin^2psi method, micro-engineered material again demonstrates a marked reduction in levels of residual stress marking it as an ideal candidate for thermal protection systems. The increase in resilience when exposed to high heat flux stems from a combination of ideal material geometry (free expansion of pillars) and suitable choice of starting materials (W-Re). The W-Re alloy system has proven to be among the best choices available for elevated temperature applications [2] possessing improved ductility and flow strength over pure tungsten. The micro-engineered approach harnesses both these characteristics to pave the way towards new materials capable of safer more reliable operation of future technologies.

References

[1] Babak, A. V. "Effect of recrystallization on the fracture toughness of tungsten." *Powder Metallurgy and Metal Ceramics* 22.4 (1983): 316-318.

[2] Raffo, Peter L. "Yielding and fracture in tungsten and tungsten-rhenium alloys." *Journal of the Less Common Metals* 17.2 (1969): 133-149.

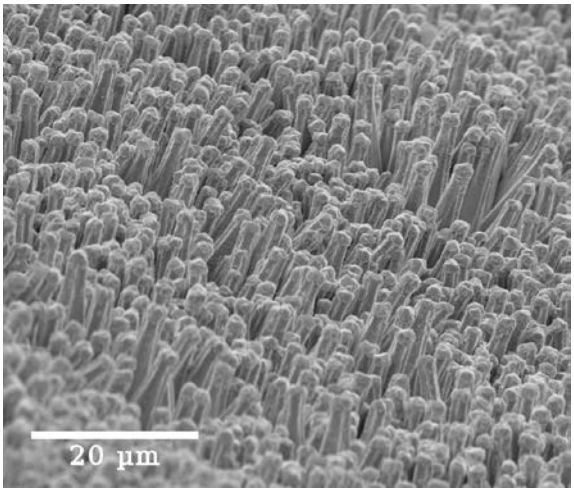

Figure 1. Micro-engineered surface consisting of W coated Re pillars.

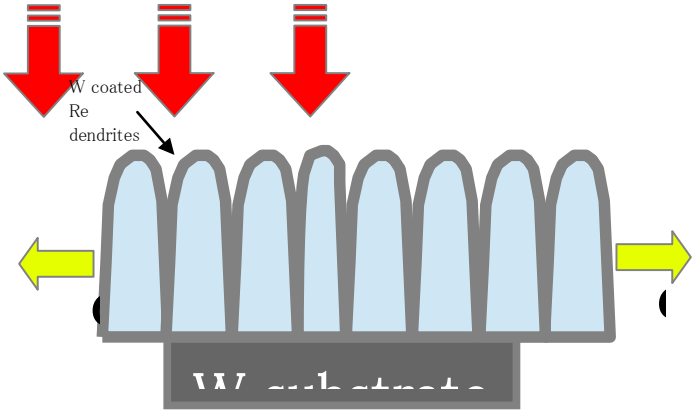

Figure 2. As a heat flux impinges on the surface pillars are able to freely expand or contract thus accommodating thermal strain and relieving stress.

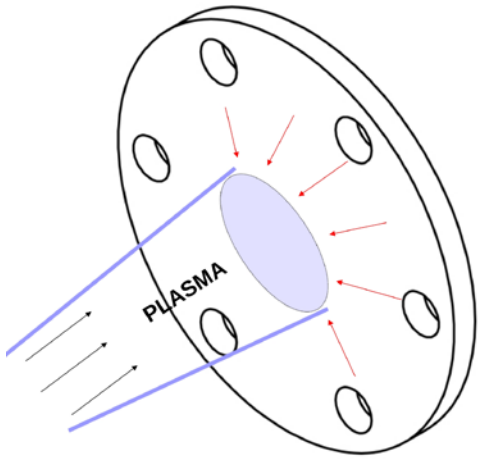

Figure 3. Illustration of a sample being struck by the plasma column during an experimental run, the small diameter of the beam relative to the sample size generates compressive stress as the hot central region of the sample is confined by the cooler unexposed material culminating in the generation of large compressive stresses at sample center.

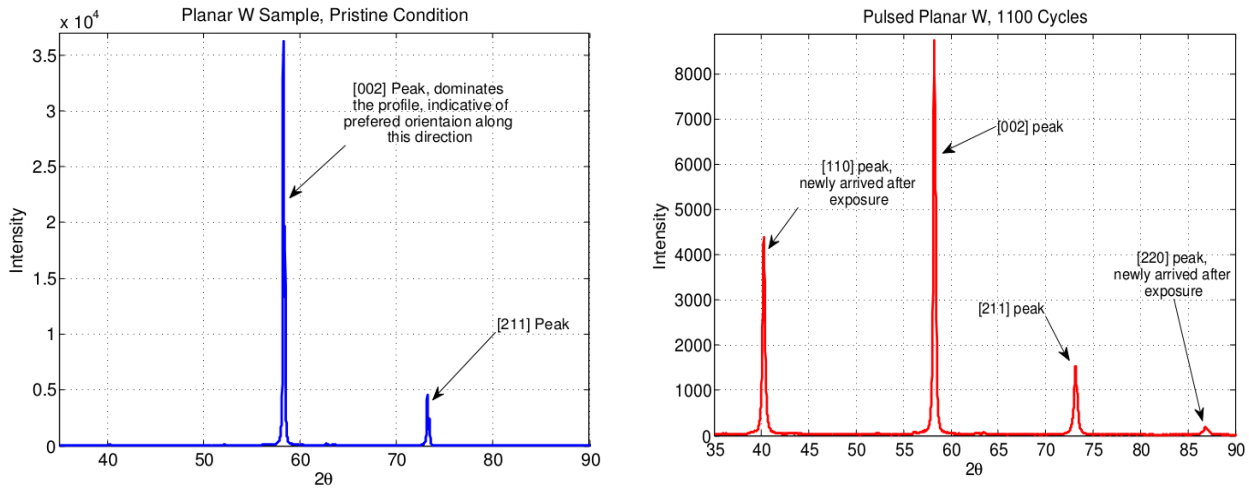

Figure 4. XRD patterns for unexposed (left) and exposed (right) planar W, emergence of new diffraction peaks in the exposed case is a result of the recrystallization of the microstructure, this type of microstructural change has been shown to lead to embrittlement of the material.

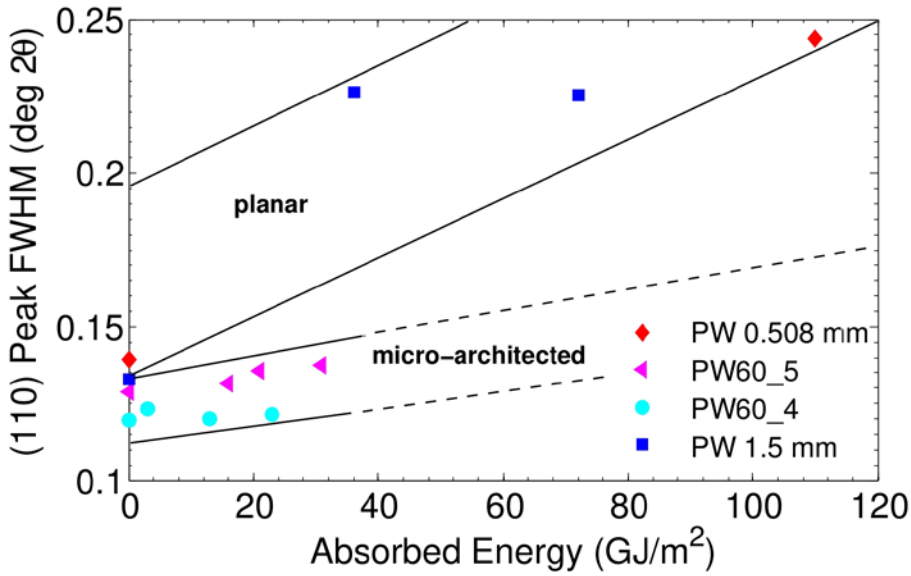

Figure 5. Peak breadth vs absorbed energy comparison between micro-engineered and planar surfaces, peak breadth can be interpreted as a qualitative measure of the level of plastic strain a material has endured, from the chart it is evident that micro-engineered surfaces exhibit less plastic deformation than their planar counterparts.