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# Ni line pattern coarsening on zirconia substrates: Impact of initial dimensions

Yong Hao [a,b], Yunyi Ling [a,b], Tae-Sik Oh [c,*]

[a] Institute of Engineering Thermophysics, Chinese Academy of Sciences, Beijing 100190, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Department of Chemical Engineering, Auburn University, Auburn, AL 36849, USA

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ABSTRACT

Long-term thermal stability of nickel line patterns was investigated. 5 μm-wide patterns and 20 μm-wide patterns were deposited with four different thicknesses, and their morphological change was compared after heat treatment. Displaced volume was calculated by post-annealing image analysis. Opposite coarsening trends were found for the two tested widths. 20 μm-wide patterns show deviation from predictions of previous models, but they still behave as expected: thinner pattern shows higher mobility. This is reversed for 5 μm-wide patterns. Surface tension at the metal-gas interface, the usual driving force behind coarsening, can still explain the unexpected displaced volume dependence on thickness.


## 1. Introduction

Metal coarsening is a universal problem for devices operating at elevated temperatures when a metallic microstructure's morphological stability underpins successful device operation. The need to understand this phenomenon is well recognized leading to many studies on metal thin films deposited on flat, thermally stable oxide surfaces. In some cases, the metal thin film coarsening process was strategically designed and controlled to achieve certain shape at certain locations [1,2]. Gold, platinum, and silver are typical choices for the coarsening study [3–14]. Brandon and Bradshaw [11] have applied thermal grooving model from Mullins [15] to correlate the diameter change of the spontaneously formed holes to surface diffusion coefficient. Apart from neat solid film, well-defined metal lines with controlled width and thickness are often fabricated when the metal-oxide contact line becomes important [16–18]. Jiran and Thompson studied coarsening kinetics with gold line patterns from time change of laser beam transmission intensity [12]. Due to the initial geometry difference, their void growth showed different dependence exponent $n_{JT}$, −3, on the metal initial thickness h from Brandon and Bradshaw's work [11] ($n_{BB} = -3/5$). Including these seminal works, most of the thin film/line pattern coarsening studies focus on short-term evolution of the metal structures [2,4,6,9,19,20]. In the present work, we instead focus on practically important long-term morphology change of nickel line patterns fabricated on (1 0 0) oriented single crystal yttria stabilized zirconia (YSZ).

## 2. Experimental

Nickel line patterns are fabricated on YSZ substrate with (1 0 0) orientation by thermal evaporation. Using a photolithography mask, 20 μm-wide metal lines were deposited with 20 μm-wide spacing. Another mask was used to fabricate 5 μm-wide metal lines with 5 μm-wide spacing. Prior to metal deposition, Shipley 1813 (Microchem) photoresist was spin-coated first. The spin-coating process was repeated multiple times as needed for thicker deposition. After coating, selected portions of the photoresist film were exposed to UV light (4.5–5.0 mW/cm$^2$) between 45 s and 3 min. Thicker film required longer exposure time. The film was then developed in MF-319 (Microchem) to manifest the pattern. After nickel deposition, substrates need to be soaked in acetone for a set period, which can be less than 1 min for thin (e.g. 200 nm) patterns or more than 1 h for thick (e.g. 600 nm) ones to ensure satisfactory quality of metal lines upon liftoff. Due to the practical limitations in fabrication processes, it was hard to make nickel lines thicker than 600 nm. In 20 vol% hydrogen in balance nitrogen, the nickel line patterns were heated for 24 h at 800 °C and 900 °C with ramp rate at 3 °C/min. After heat treatment, scanning electron

* Corresponding author.
*E-mail address:* taesik.oh@auburn.edu (T.-S. Oh).

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microscopy images with 10,000× magnification were taken and analyzed to estimate metal-covered and uncovered areas. Nickel line pattern fabrication and heat treatment conditions are summarized in Table 1.

**Table 1**
Nickel line pattern fabrication and heat treatment conditions.

| Parameter | Value |
|---|---|
| Nickel pattern width | 20 μm, 5 μm |
| Nickel pattern thickness | 200 nm, 300 nm, 400 nm, 540* nm, 600 nm |
| Substrate | YSZ (1 0 0) |
| Heating temperature | 800 °C, 900 °C |
| Gas for heat treatment | 20 vol% hydrogen in nitrogen |
| Dwell time at set temperature | 24 h |

* For 5 μm-wide nickel lines, we couldn't make 600 nm thick patterns reproducibly; therefore, we used 540 nm thick pattern as the thickest one for 5 μm-wide lines.

## 3. Results and discussion

Fig. 1 shows a simplified model for the pattern shape evolution. After metal line pattern fabrication as shown in panel (a), metal line thickness will, under heating, increase to reduce the metal surface area. The schematic is drawn not to scale: the width of the as-fabricated metal line is at most 100 times of its thickness. The major constraint on the morphology change is the metal mass conservation as described in panels (b) and (c). The displaced volume of the metal per unit length per side is illustrated as the hatched region.

After heat treatment, as illustrated in Fig. 2, we confirmed the expected shrinkage of the metal line patterns. Less area is covered by metal, and oxide surface that was once beneath the metal line pattern becomes exposed. Apart from the metal line width, we varied the as-fabricated thickness of the metal deposition to map out

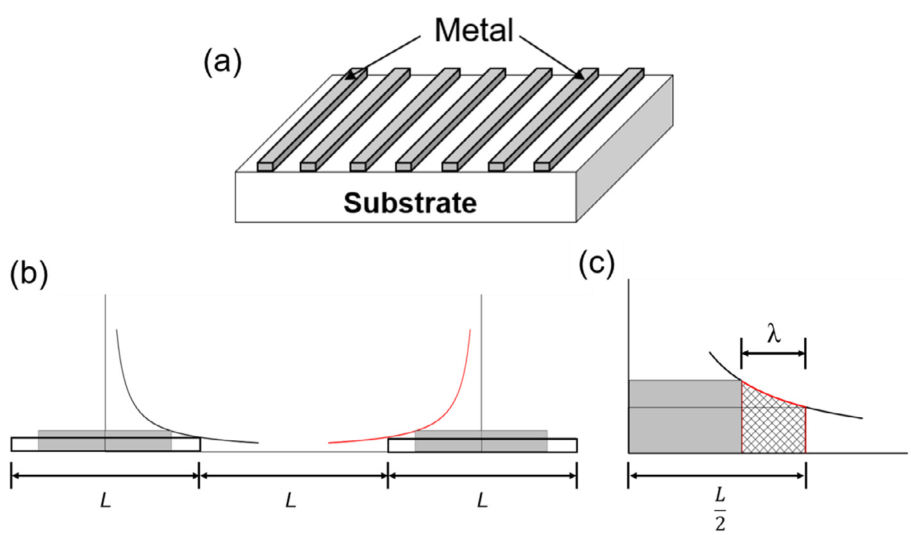


**Fig. 1.** Simplified model for the metal pattern shape evolution. In this model, cross-sectional area is conserved due to mass conservation. (a) As-fabricated metal line pattern schematic 3-dimensional view. (b) White rectangles illustrate as-fabricated metal patterns with width *L* and spacing *L*, and gray rectangles show coarsened metal patterns. Two metal strips are shown. (c) The hatched region shows displaced volume per unit length of metal strip on one side. This is a zoomed-in view of the left metal strip in (b). λ is the retraction length calculated from area change.

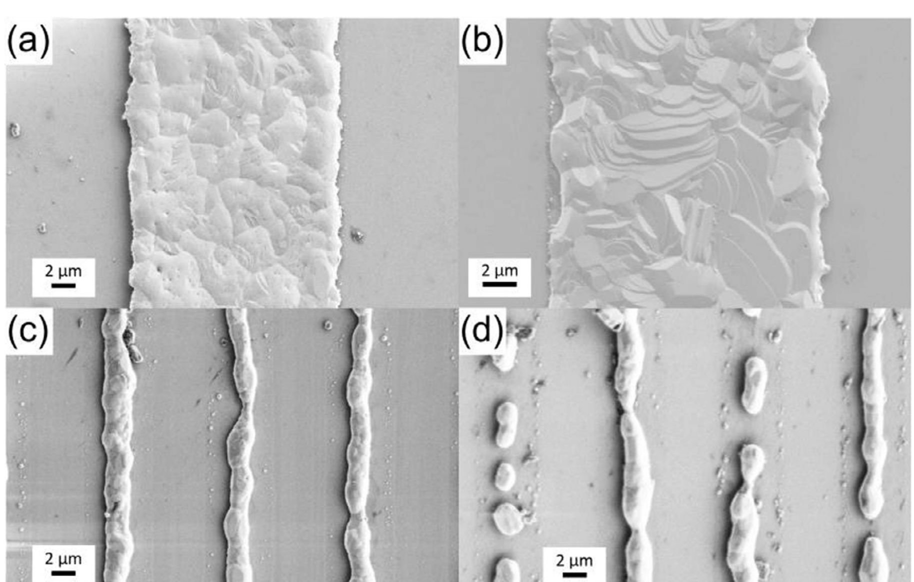


**Fig. 2.** Ni patterns after thermal treatment for 24 h in 20% $H_2$ at various temperatures. (a) 800 °C, 600 nm; (b) 900 °C, 600 nm; 20 μm-wide nickel line with 20 μm spacing for (a) and (b). (c) 800 °C, 540 nm; (d) 900 °C, 540 nm; 5 μm-wide nickel line with 5 μm spacing for (c) and (d).