Effect of Metallic Seed Layers on the Crystallization of NiTi Thin Films

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Abstract

NiTi films are widely used as sensors, actuators, and switches in microelectromechanical systems (MEMS) because of their shape memory effect (SME). As-deposited NiTi films are amorphous and do not show SME. The high-temperature annealing required to crystallize NiTi films (to induce SME) leads to undesirable thermal stresses in MEMS. This project seeks to reduce the crystallization temperature (T_X) of amorphous NiTi films by incorporating carefully selected metallic seed layers. Different seed layers with low/high lattice mismatch will be explored to determine their effects on T_X. This approach, if successful, can help systematically control the T_X of NiTi films, leading to faster, energy-efficient MEMS fabrication and fewer post-fabrication failures.

Methods

Sample Preparation

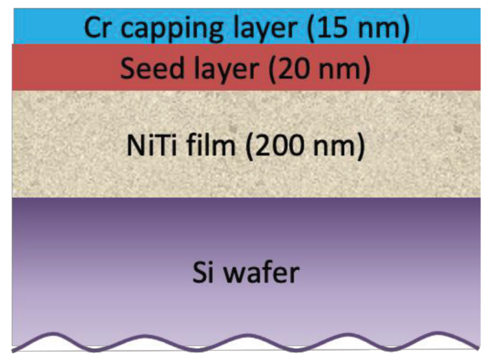
- Thin films deposited using AJA Orion 5 magnetron sputtering system.
- Step 1: Deposit ~250 nm thick NiTi film (equiatomic) on Si wafers by co-sputtering from Ni and Ti targets.
- Step 2: Deposit Cr, W, Ta and Fe seed layers (20 nm) on NiTi film without breaking vacuum. Seed layers have same crystal structure as NiTi to promote crystal nucleation.
- Step 3: Cap the seed layer with an ~15 nm thick Cr layer to avoid oxidation of seed layer/NiTi film during annealing.

Crystallization Temperature Measurement:

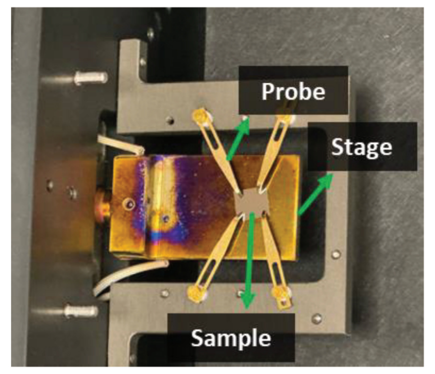
- Measure electrical resistivity of NiTi films with/without seed layers as a function of temperature (RT to 500°C).
- Resistivity measured using a 4-point probe in a Ecopia Hall effect measurement system.
- Crystallization is indicated by a steep drop in resistivity.

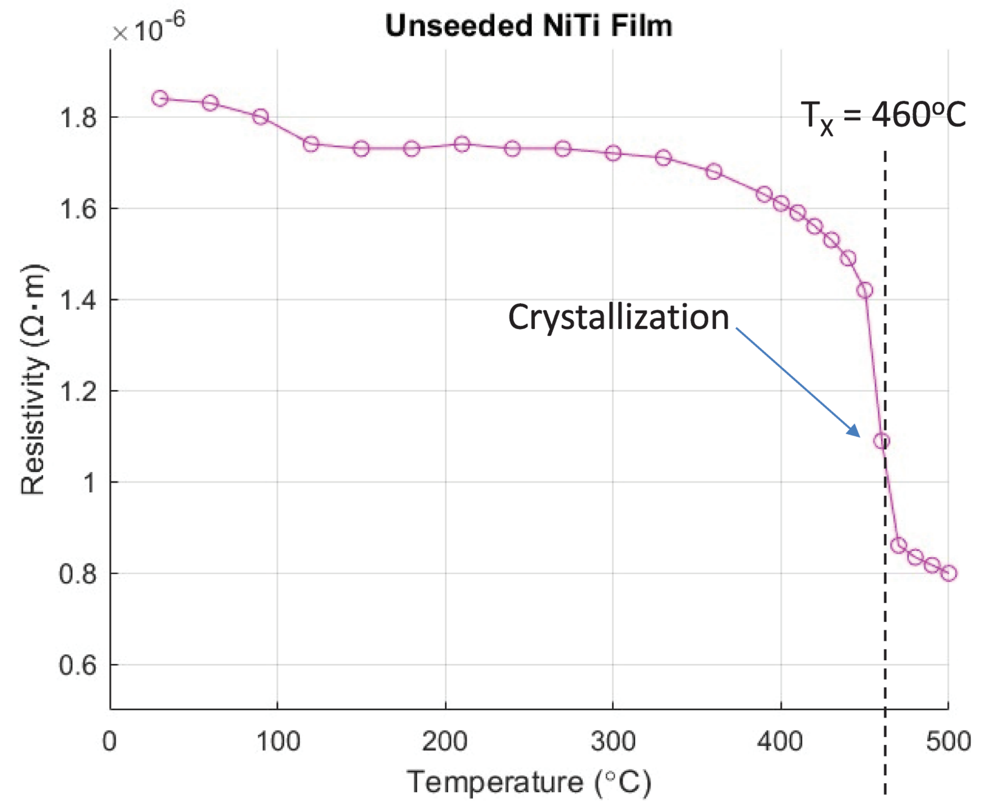
Experimental Setup and Results

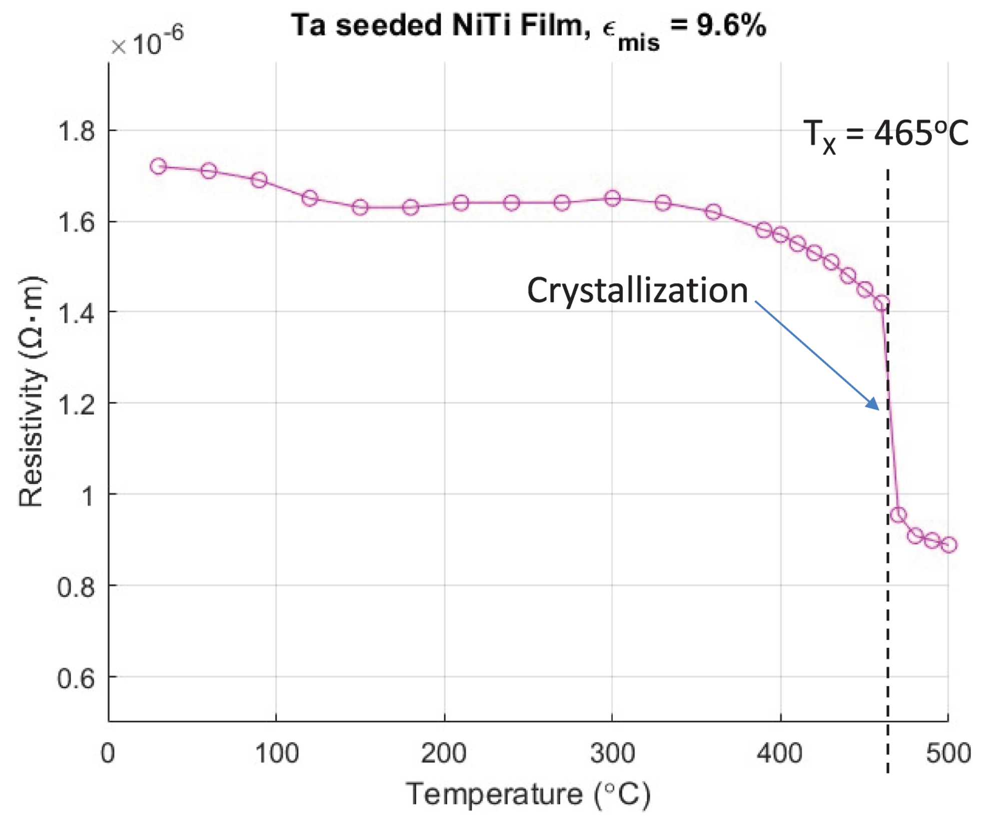
Sample cross-section

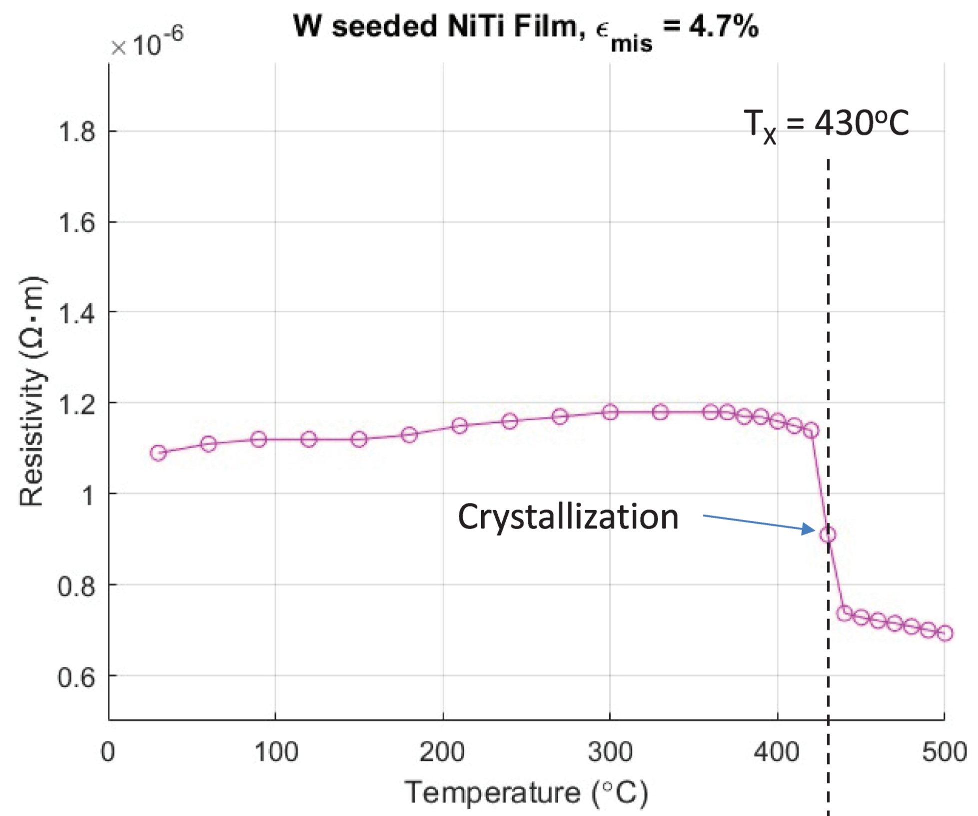


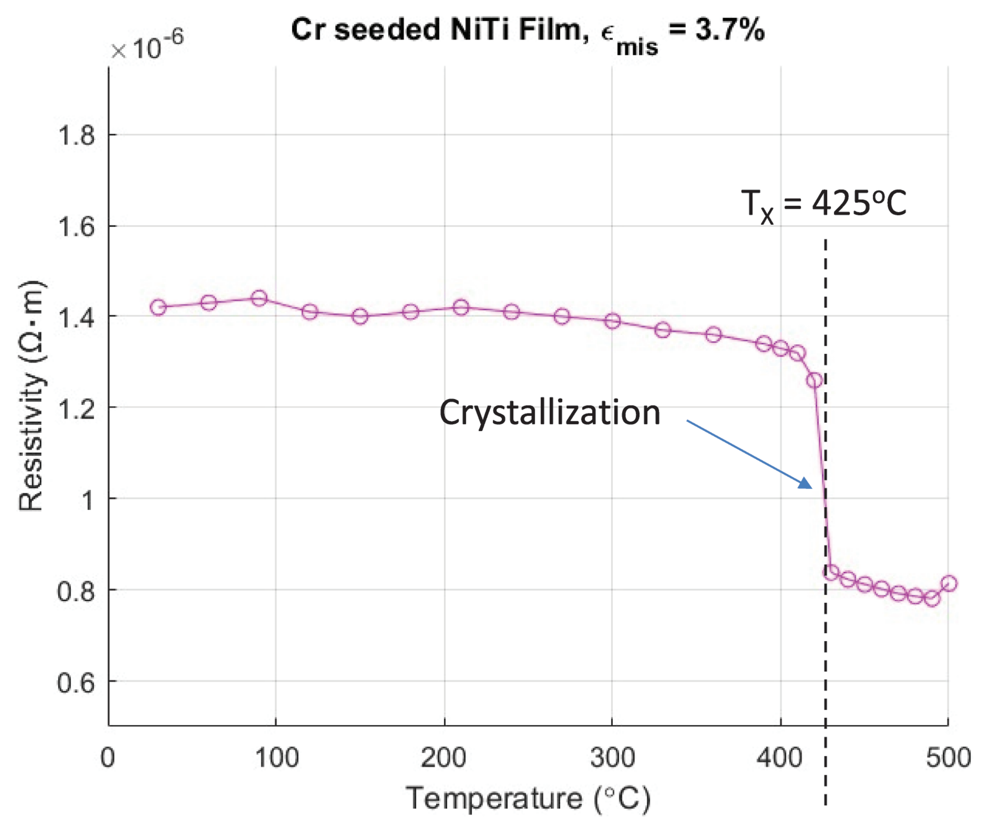
Electrical resistivity testing setup

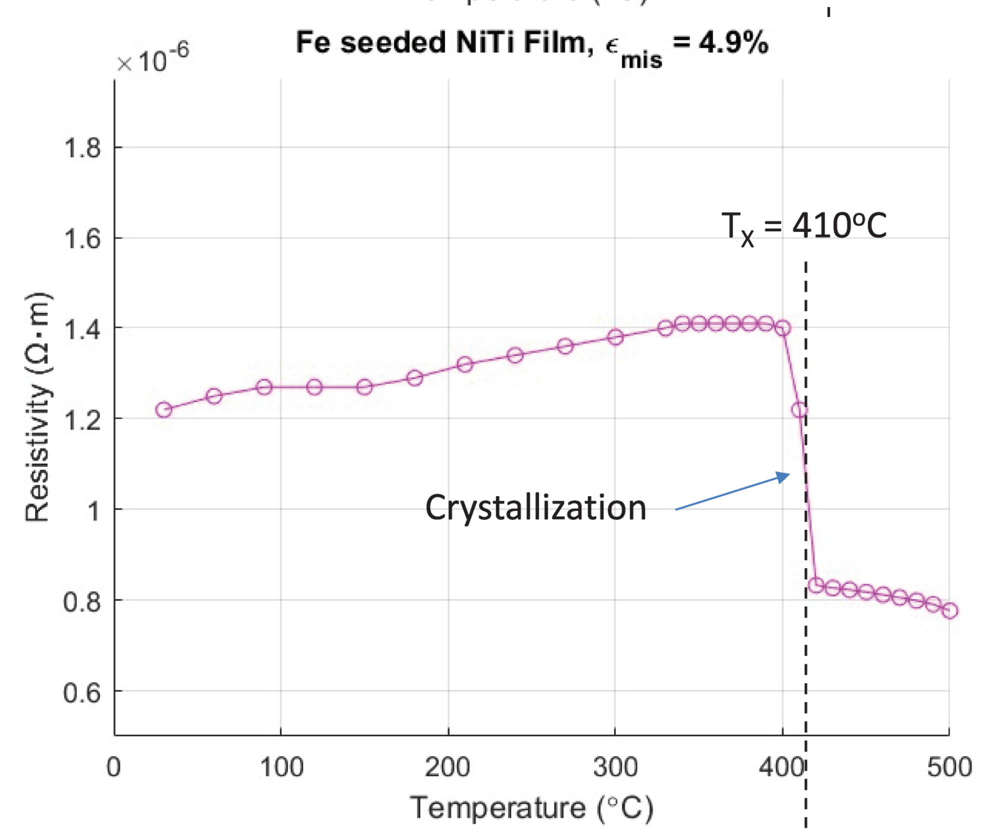












Conclusions

- Seed layers significantly reduce the crystallization temperature (T_X) of amorphous NiTi films.
- Reduction in T_X can be as high as 50°C for the case of Fe seed layers.
- Seed layers must be crystalline to reduce T_X of NiTi films. Ta seed layer does not cause any reduction in T_X because it is amorphous.
- For Fe seed layer, the reduction in T_X is even larger compared to Cr, which has a lower lattice mismatch strain with NiTi.
- Fe could be diffusing into NiTi (as revealed by a steady increase in resistivity before crystallization), which possibly depresses T_X more than expected.
- Crystallization proceeds rapidly once it starts, which suggests that nucleation is the rate limiting step in the crystallization process.

Future Work

- Study compositional effects of the seed layers in addition to lattice mismatch on the crystallization kinetics of amorphous NiTi films.
- Examine the phase transformation behavior of NiTi films crystallized using seed layers.
- Explore if seed layers can be used to tune the phase transformation temperatures of NiTi films for different applications.