HIGH-ASPECT-RATIO INDUCTIVELY COUPLED PLASMA ETCHING OF BULK TITANIUM FOR MEMS APPLICATIONS

E. R. Parker[1], M. F. Aimi[2], B. J. Thibeault[3], M. P. Rao[1], and N. C. MacDonald[1,2]
[1]Mechanical and Environmental Engineering Department
[2]Materials Department
[3]Electrical and Computer Engineering Department
University of California, Santa Barbara
Santa Barbara, California 93106, USA

Traditionally, bulk micromachined MEMS devices have relied heavily on single crystal silicon. However, new material systems are now being considered as potential candidates to expand this silicon-based technology. For example, recent developments have allowed for the realization of bulk titanium MEMS for devices that require higher fracture toughness or resistance to harsh environments (1). Titanium is widely reported to be biocompatible (2) and may serve as a potential substrate for *in vivo* MEMS applications. In order for the bulk micromachining of titanium to be competitive with silicon, high etch rates, aspect ratio uniformity, and high mask selectivity are essential. This paper reports on the development of a new high-aspect-ratio titanium micromachining method, the Titanium Inductively coupled plasma Deep Etching (TIDE) process, which satisfies these requirements.

An Inductively Coupled Plasma (ICP) based etching system was used to study bulk titanium etch rate and selectivity to a sputtered TiO_2 mask in a Cl_2/Ar chemistry. ICP source power, sample RF power, pressure, and gas flow rates were varied individually and plotted to determine first order trends for each variation. Based on the results of this etch characterization, parameters were optimized to etch high-aspect-ratio microstructures into thick titanium substrates. Bulk titanium etch rates in excess of 2 µm/min with high mask selectivity were realized. These rates are comparable to the standard Bosch process used for the high-aspect-ratio etching of silicon (3). However, unlike the Bosch process, the TIDE process is non-cyclic and results in exceptionally smooth sidewalls. Fig. 1 shows a typical MEMS comb drive structure etched into a 500 µm thick titanium substrate using the TIDE process. Fig. 2 shows a 1-µm wide beam structure, which demonstrates the highly anisotropic nature of the TIDE process. Narrow sub-micrometer features have also been successfully etched, as shown in Fig. 3. The TIDE process is currently being used for a number of MEMS applications. With these etching capabilities, titanium is a promising new material system for bulk micromachining.

ACKNOWLEDGMENTS

This research was funded by the Materials Technology Office at the Defense Advanced Research Projects Agency.

REFERENCES

1. M. F. Aimi, M. P. Rao, N. C. MacDonald, A. S. Zuruzi, and D. P. Bothman, Nat. Mater., **3**, 103 (2004).
2. D. M. Brunette, P. Tengvall, M. Textor, and P. Thomsen, Titanium in Medicine: Material Science, Surface Science, Engineering, Biological Responses and Medical Applications, Springer, Berlin (2001)
3. F. Laermer and A. Schilp, Robert Bosch GmbH, US Patent 5,501,893 (1996).

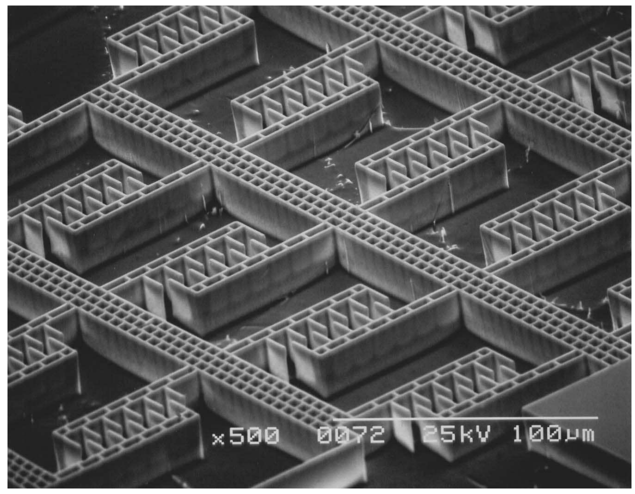

Fig. 1. Scanning electron micrograph of a titanium-based MEMS comb drive structure. The pattern was generated using contact lithography and transferred to a sputtered TiO_2 mask via a CHF_3 oxide etch. The sample was then deep etched using the TIDE process.

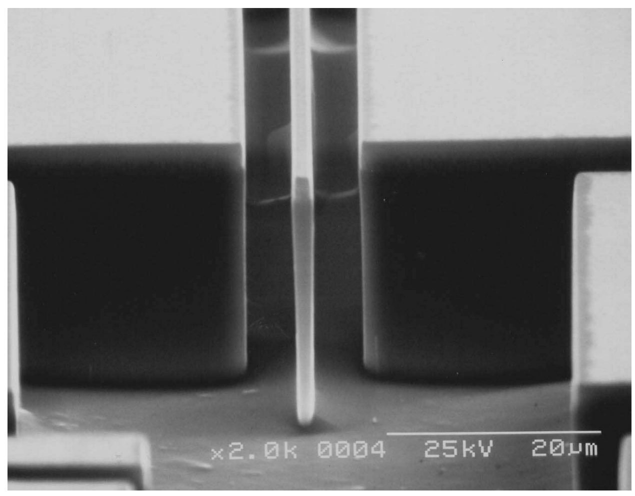

Fig. 2. Scanning electron micrograph of a 1 µm wide beam structure. Microstructures have smooth sidewalls because the TIDE process does not require cyclic passivation to maintain anisotropy. This sample was etched for 10 minutes resulting in an etch depth greater than 20 µm.

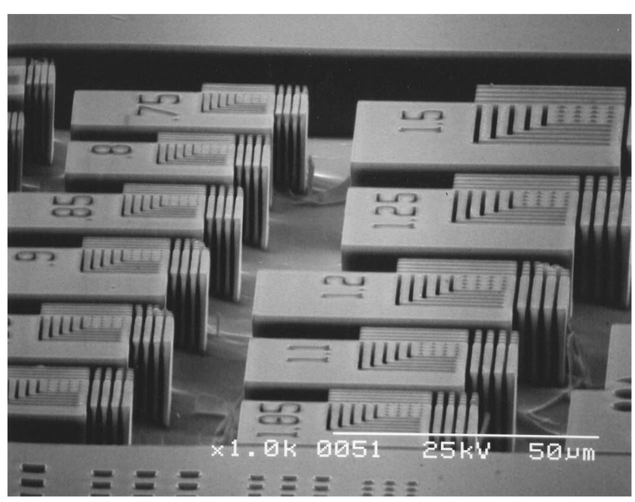

Fig. 3. Scanning electron micrograph illustrating sub-micrometer minimum feature size capability. Numbers indicate feature size in micrometers. 750 nm narrow lines were reproducibly patterned and etched.