Hot-Wire Anemometer Probe with SU-8 Support Structure

CNF Project Number: 2532-17

Principal Investigator(s): Gregory P. Bewley

User(s): Edmund T. Liu

Affiliation(s): The Sibley School of Mechanical and Aerospace Engineering, Cornell University

Primary Source(s) of Research Funding: The Sibley School of Mechanical and Aerospace Engineering, Cornell University

Contact(s): gpb1@cornell.edu, etl46@cornell.edu

Primary CNF Tools Used: Heidelberg mask writer - DWL2000, SÜSS MA-6, Oxford PECVD, CVC SC4500 odd-hour evaporator, SU-8 hot plates

Abstract:

Nanoscale hot-wire anemometer probe fabrication processes have focused largely on the micromachining of silicon substrates to form support structures, an etch-heavy procedure. We detail the development of a hot-wire probe constructed through additive means with SU-8. An additive approach to manufacturing holds a number of advantages over silicon etching, including the ability to precisely define the probe structure with photolithography and control the final thickness of the supports.

Summary of Research:

Significant benefits in the sensing capabilities of hot-wire anemometer probes, including improved temporal and spatial resolutions, may be achieved by shrinking physical wire dimensions. Semiconductor manufacturing tools are well-suited to this task, allowing for the fabrication of wires measuring only tens of microns in length, microns in width, and hundreds of nanometers thick, previously unachievable or impractical with conventional means. Existing hot-wire probes created through such means rely on silicon etching to produce the probe support structures, utilizing deep reaction-ion etching (RIE) and RIE-lag effects to produce a 3D aerodynamic structure.

Etched silicon structures are the result of subtractive processes, where the substrate is meticulously sculpted and forms an integral component of the final sensor. Associated processes are proven and have resulted in successful probe fabrication at high yield and throughput. However, it is found that the final probe outline after etching seldom resembles the original mask design, and the process requires multiple design iterations to achieve a desired shape. Moreover, due to the thin silicon supports near the wire and the lack of an etch stop, the process is sensitive to over-etching that may undercut and thus jeopardize the sensor.

To address these issues, additive processes are used instead. Rather than using the substrate as a support material, structures are built upon a silicon wafer and subsequently lifted off. By using SU-8, a negative photoresist with a wide range of possible thicknesses, the final probe shape may be precisely defined by light, avoiding an iterative design process. SU-8 also allows for control over the final thickness of the supports by using formulations with different viscosities and modifying spin parameters.

SU-8 probes are manufactured by first depositing a 500 nm silicon dioxide film on a single-side polished silicon wafer using plasma-enhanced chemical vapor deposition (PECVD). This film acts as a sacrificial layer on which the probes lie. 100 nm of platinum with a 10 nm titanium adhesion layer is then evaporated and lifted off with a LOR bi-layer. Two SU-8 layers of varying thickness are processed. First, a layer of SU-8 2035 is spun to about 16 μm and soft-baked according to datasheet guidelines. Only the arms and solder pads of the evaporated metal trace, excluding the wire, are exposed. Next, a second layer of SU-8 2035 is spun on the exposed first layer and soft-baked, reaching a thickness of about 100 μm. This layer serves to hold both arms of the probe in fixed positions. After exposure of the second layer, a post-exposure bake (PEB) is performed at 55°C overnight. The low PEB temperature is used to minimize residual stress in the final SU-8 structure [1].

Finally, the probes are lifted from the wafer by immersion in concentrated 49% HF, which etches the PECVD oxide underneath each probe. Following lift-off, the probes are rinsed in water and dried in air.

A probe lifted from the substrate is displayed in Figure 1. The relatively thin probe arms and the thicker support structure are visible, as is the platinum wire. A prominent feature of the probe is the peeling of the metal film. Due to residual stresses during processing, the SU-8 will tend to

MECHANICAL DEVICES

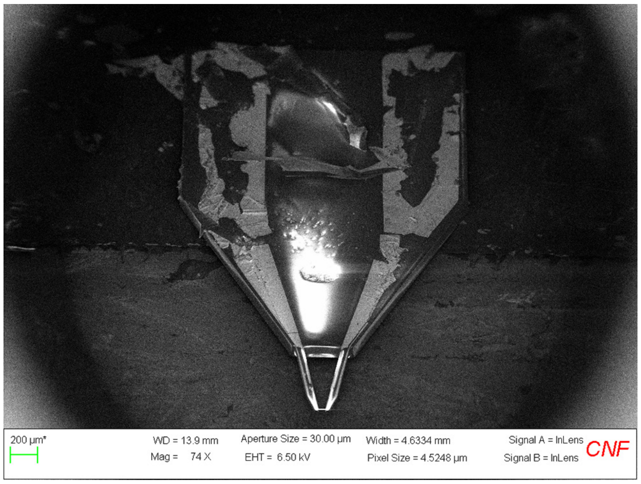

Figure 1: An SU-8 probe lifted from the substrate shows significant metal tearing, an effect of deflection of the SU-8 probe arms.

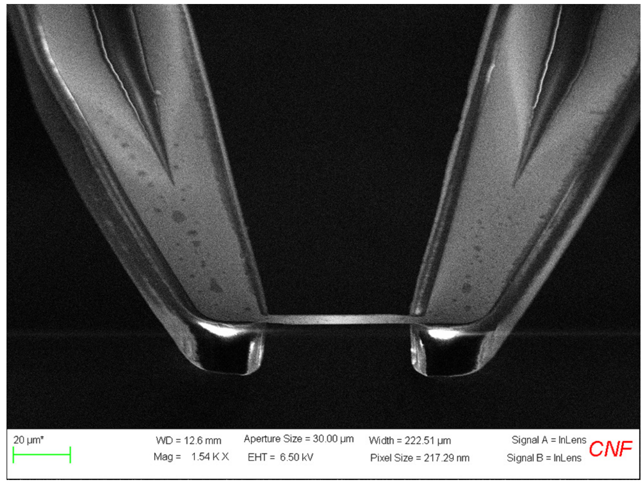

Figure 2: Magnified image of an SU-8 probe. The arm outline is precisely defined by photolithography and the thickness set by SU-8 processing parameters. Metal film peeling is visible along the center of the arms.

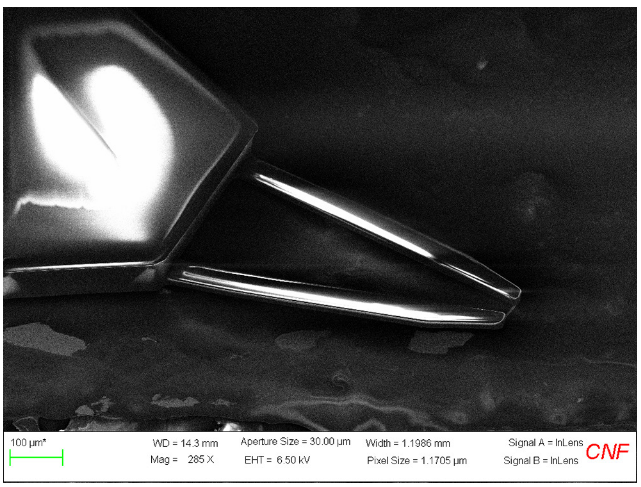

Figure 3: Backside of probe showing varying thickness of SU-8 layers.

deflect, pulling the metal film from the substrate and leading to tearing. This tearing is also visible along the probe arms in Figure 2. However, we see that the SU-8 arms are well-defined, with a controlled thickness. Figure 3 shows the underside of the probe, where the varying thickness of the SU-8 layers is clear.

Future work will focus on modifying the metal film stack and SU-8 processing to minimize stress and tearing.

References:

[1] Li B., Liu M. and Chen Q., "Low-stress ultra-thick SU-8 UV photolithography process for MEMS," J. Micro/Nanolith. MEMS MOEMS, vol. 4, no. 4, 043008, Oct. 2015, https://doi.org/10.1117/1.2117108.