High Aspect-Ratio Neural Probes using Conventional Blade Dicing

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Abstract. Exploring deep neural circuits has triggered the development of long penetrating neural probes. Moreover, driven by brain displacement, the long neural probes require also a high aspect-ratio shafts design. In this paper, a simple and reproducible method of manufacturing long-shafts neural probes using blade dicing technology is presented. Results shows shafts up to 8 mm long and 200 μm wide, features competitive to the current state-of-art, being its outline simply accomplished by a single blade dicing program. Therefore, conventional blade dicing presents itself as a viable option to manufacture long neural probes.

1. Introduction

Neuroprostheses have been probing a variety of neural circuits so the scientific community can improve its knowledge about several brain diseases and disorders. Recording and stimulation of brain networks have already reached widespread clinical application. Indeed, deep brain stimulation (DBS) has proved to show beneficial effects in a variety of neurological conditions, such as depression, obsessive compulsive disorder (OCD), chronic pain, Parkinson's disease, epilepsy, essential tremor, dystonia, Tourette syndrome, blindness, deafness and spinal cord injuries [1, 2]. More recently, optogenetics has shown potential in selectively controlling dysfunctional circuits throughout optical neuromodulation, and therefore also has been proposed to assist several diseases and neuropsychiatric disorders [3].

Exploring cortical neural circuits have been a common practice in neuroscience studies. Nevertheless, the need to increase scientific insights of deeper neurons populations has triggered the development of longer penetrating devices, capable of overcoming length limitation of devices aiming for superficial brain regions. For example, the hippocampus that is frequently used as a research model for exploring both normal and pathological conditions of the nervous system, including the processes involved in memory and learning and neurodegenerative diseases [4], requires devices with shafts longer than 4 mm. Depending on the target area, probes length could require up to 10 mm long shafts in a mice-based experiment.

Accordingly, long probes designs have been reported, but mostly their approach rely on wet etching technology to form the outlines of the devices. Deep reactive ion etching (DRIE) [5–7], wet [8, 9], dry [10] and plasma etching [11, 12] technologies or a combination of these [13] has been a popular approach to define probes design. Others techniques were explored such as direct write laser (DWL) [14], microwire electrical discharge machining [15] and self-assembled

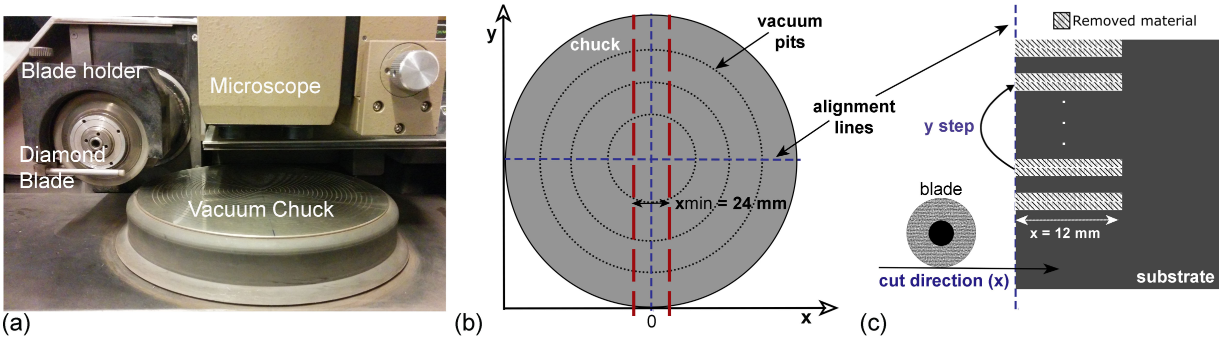

Figure 1. (a) Blade dicing setup photography. (b) Schematic of dicing cut process in the chuck, and (c) Top view detailed plan of the dicing process for producing long planar probes.

based methods [16] to achieve long designs. Nevertheless, they are complex and expensive manufacturing processes.

This paper demonstrates a fabrication approach of long and high aspect-ratio silicon probe design using standard blade dicing technology. Blade dicing has been the most widely used process in the separation of silicon wafers into individual devices both in semiconductor and micro-electro-mechanical systems (MEMS) technologies [17]. By employing this fabrication process, our approach presents some main advantages: (1) simplicity, since shaft outline is accomplish with a single technique and manufacturing runs within few blade cuts; (2) is highly scalable to wafer processes, requiring simply the repetition of cut patterns; and, (3) fabrication relies on a purely mechanical process, avoiding chemical changes in the probe bulk material. The fabrication of up to 8 mm long and 200 μm wide probe was successfully accomplished.

2. Fabrication Process

2.1. Blade Dicing

All cuts were carried out by a high precision Disco DAD 2H/6T dicing saw. Mechanical dicing process uses a dicing equipment to fully or partially cut through wafers. Fig. 1.a shows the setup used in the dicing process. Usually, a wafer is held in the chuck with the aid of suction (vacuum pits). The chuck moves at a specific and constant feed rate passing through the dicing blade in X and Y directions for device cutting (see Fig. 1.b). The feed speed or cut speed determines how fast the sample is fed towards the saw blade. The cutting tool is called the dicing blade and is mounted in the spindle of the dicing equipment. The dicing wheel (spindle) spins at a constant rotational velocity, and all experiments were carried out at 30.000 rpm spindle speed. Calibration of the blade height (Z-axis level), must be performed so the blade tip define chuck surface (promoted by electrical contact) and do not damage it at cutting time. Cutting programs for dicing silicon wafers rely mainly on three variables: speed of cut (feed speed); Y-axis step, which determines the distance between two cuts; Z-axis level, which determines the depth of cut: and X-axis step, which sets the cut length. The cut program is performed automatically, altering previous mentioned parameters depending on the fabrication goal. After completion of each sequence of cutting steps, the program repeats itself until the entire wafer is diced.

2.2. Probe manufacturing

The long probe outline is defined by a set of cuts in silicon substrate. These set of cuts and their parameters establish which is refereed as cut program. Probe manufacturing process is accomplish by a careful selection of the dicing process cut parameters. Table 1 summarizes the cut program used to produce planar shafts outline. All cuts were carried out by a DISCO Z05 blade (Z05-SD360-D1-90 52×0.08AS×40). Cutting program consisted on two different y-axis

Parameter	Value
Blade type	Z05
Blade thickness	80 μm
Cut thickness	100 μm
Cut speed	0.5 (mm s^{-1})
Z-axis calibration	0 mm (chuck surface)
X-axis step	24 mm
Y-axis steps	[300, (9×100)] μm

Table 1. Experimental dicing parameters. Square brackets represents sequential Y steps, which were repeated during the cut.

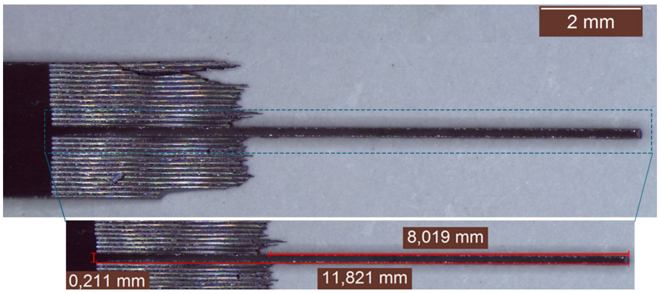

Figure 2. Dicing process resulted in 8 mm long shafts by simply employing a set of dicing parameters in a single cut program (see Table 1).

steps: the first is 300 μm and the second 100 μm. The first step determines the thickness of the shaft, while the second determines their pitch. These two steps are repeated until silicon substrate is completely diced. While probe width is set by programmed Y-axis step (300 μm), its length is accomplished by altering X-axis range of the blade. As the equipment restricts X-axis cut length to a minimum of 24 mm, using a range value inferior to its limits will inevitably result in a 24 mm long cut. Therefore, a particular modification must be made in the way substrate is positioned in the chuck surface. Substrate alignment in preparation for cut time should be made by midline of the chuck surface. This method is illustrated in Fig 1.c. Indeed, by placing the substrate at different distances from the chuck midline, it is possible to increase/decrease shafts length, in order to satisfy the application requirements.

3. Results and Discussion

The result of employing blade dicing technique in the manufacturing process of long shafts is shown in Figure 2. Indeed, in a single program comprising a set of cutting parameters (see Table 1), the outline of the probe is accomplished. Despite performing an approximately 12 mm long cut in X-axis direction, probes length is restricted to 8 mm. This is explained by the round geometry of the blade, which by the end of the cut cannot completely remove the diced substrate. Further optimization could include a combination with wet etching processes so the probe outline could be optimized to the total length of the cut. Nevertheless, an 8 mm long and 200 μm wide probe was successfully manufactured. All photos and measurements were performed with a Leica M80^{TM} stereo microscope and Leica LAS^{TM} software.

Since blade dicing is a purely mechanical process, its employment can produce undesirable mechanical vibrations, stress, and localized defects in the wafer [18]. Therefore, fabrication of challenging high aspect-ratio devices push mechanical dicing process to its limits. Manufacturing of such different designs and fragile devices represents a challenge to the dicing technology and might require modifications to the dicing process. Here an alignment adjustment to the standard operation of the dicing equipment was successfully employed. Although manual substrate alignment is performed, alignments lines in the dicing chuck allows good reproducibility of the results.

Other significant fabrication challenge consists on dicing different materials. Depending on the material, it can exhibit different behavior when diced. Typically, semiconductors like silicon, ceramics, and glasses present brittle mode cutting, which frequently induce microcracks within the material and chipping occurs at the edges [19]. This effect can be minimized by choosing proper blades and dicing parameters, such as low feed speed [20]. The blade employed is suitable for silicon substrate sawing and cuts were optimized to low speeds. As demonstrated elsewhere [21], silicon wafers diced at low speeds (< 0.5 mm s^{-1}) tend to avoid microcracks on the substrate.

4. Conclusion

The paper demonstrated the fabrication process of a long design neural probe. The manufacturing process include exclusively employing of traditional blade dicing technique. High aspect-ratio 8 mm long and 200 μm wide probe was successfully achieved by a single dicing program, which comprises a set of cut steps. The optimization of dicing parameters can broaden the application of most machining processes, allowing blade dicing technology to be employed in the production of various complex parts or devices.

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