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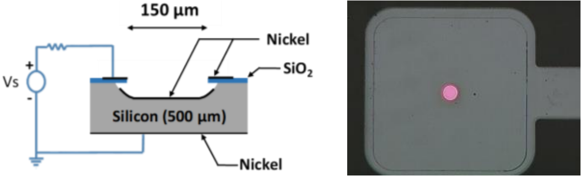
Physical mechanisms involved in silicon based plasma microreactors operating in DC

R. Dussart, R. Michaud, A. Stolz, S. Iseni, O. Aubry, P. Lefaucheux
GREMI, 14 rue d'Issoudun, BP6744, 45067 Orleans Cedex 2, France

Introduced in the mid 90ies [1], Micro-Hollow Cathode Discharges (MHCD) have the ability to operate stably in DC at atmospheric pressure while remaining in non equilibrium regime. This property makes them very interesting for chemistry and local treatment [2].

Due to their dimensions and their large surface to volume ratio, the produced microplasma remains cold and operates in normal regime provided the cathode area is not fully utilized [3]. Microdischarges on silicon substrates were introduced by J. G. Eden's group [4]. Silicon processing used for microelectronic devices offers many opportunities to design new, original and efficient devices to produce high density microplasmas.

At GREMI, microreactors are fabricated from a silicon wafer in a clean room facility, using many different process steps including lithography, deposition, etching,… A schematic showing a microreactor and the electrical circuit is given in figure 1a. The microreactor consists of two nickel electrodes separated by a 8 µm thick thermal SiO_2 layer. The diameter of the cavity is typically between 50 and 150 µm. The cavity depth is of the order of few tens of µm. An example of a single microplasma operating in Ar is shown in figure 1b.

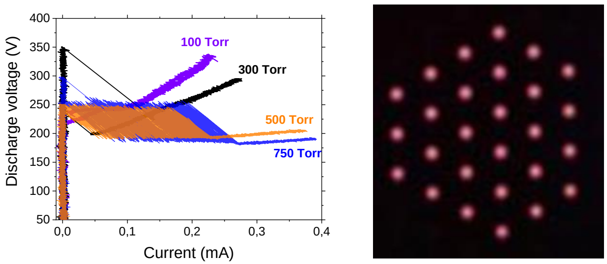


(a) (b)

Figure 1 : (a) schematic of a microdischarge developped at GREMI
(b) Single microdischarge operating in Argon

In the first version of microreactors, the silicon surface was used as a cathode. In this particular case, p-type silicon can interact with the plasma and can be used as a photodetector as reported in [5]. However, we showed that the silicon surface was severely damaged by the ion bombardment, which significantly reduces the lifetime of the microdevice. The physical mechanisms responsible for the degradation of the microreactor are reported in [6]. To enhance the robustness and lifetime of the microreactor, the silicon cathode can be covered by a metallic thin layer (e.g. nickel) as shown in figure 1(a). In this case, the system loses the ability to detect light, but the microplasma is much more stable.

V-I characteristics obtained in Argon with a 150 µm diameter single cavity reactor are given in figure 2(a) for different pressures. At 500 and 750 Torr, the so-called self-pulsing regime [7] is obtained at low current. At these pressures, the voltage, when stabilized (I > 0,3 mA), hardly increases with current, which shows that the microdischarge operates in quasi-normal regime. At lower pressure (< 300 Torr), no self-pulsing regime is observed, but the discharge voltage increases with current (abnormal regime). This behavior at lower pressure favors the ignition of microdischarge arrays [2]. An example of an array containing 27 microdischarges operating in Ar is shown in figure 2(b).



(a) (b)

Figure 2 : (a) V-I characteristics of 150 µm diameter single microplasma at different pressures.
(b) Array of 27 microplamas operating in Ar

Different geometries and arrangements have been investigated. Gas temperature measurements of the neutrals were carried out by optical emission spectroscopy in He and Ar microplasmas [8]. In Ar, the gas temperature reaches 850 K for a current as high as 350 µA. In the same conditions in helium, the gas temperature remains at 350 K. This very different behavior is attributed to the higher thermal conductivity of helium gas. This results was confirmed by SEM observations performed after 24 hours of operation of microdischarge in helium and in argon. The operation in helium did not cause any significant damage of the cavity whereas surface sputtering was clearly identified onthe surface of the cavity operating in argon.

References

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