Reactive ion etching of single crystal diamond by inductively coupled plasma: State of the art and catalog of recipes

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1. Introduction

Significant technology advances in the growth of single crystal diamond (SCD) have over the past decade led to commercial offerings of high quality SCD substrates, typically available in the form of well specified plates of several square millimeters in size [1]. At the same time, the cost of such plates has considerably decreased [2], which has triggered important research and development efforts aiming to exploit the exceptional optical [3], thermal [4] and mechanical properties [5] of SCD for a variety of applications in electronics [6], photonics [7–10], optics and opto-mechanics [11] and quantum technologies [12]. High quality SCD plates are grown by Chemical Vapor Deposition (CVD) [13,14] or by High Pressure High Temperature (HPHT) [15] techniques. Record demonstrations yielded recently SCD substrates up to wafer size of 10 cm diameter [16], yet more typical dimensions today are 1 mm–10 mm in length and 50 μm–1 mm in thickness. Substrates are offered in categories of different ‘grades’ (e.g. electronic [6,17], optical [18] or mechanical [19]) according to their degree of impurities, which indicate that the substrate properties have been tailored to be particularly suited for a specific application area.

Precision shaping of SCD is predominantly performed using laser cutting and ablation techniques for target dimensions in the millimeter scale with accuracy requirements of several microns, such as for slicing diamond plates or fabricating cutting tools for turning, dressing or milling. Laser processing is also used for micrometer scale patterning of structures such as compound refractive lenses [20–23], buried waveguides [24–26] and microchannels [27,28]. Ion beam etching (IBE) can efficiently smoothen and polish SCD plates [29,30], whereas focused ion beam (FIB) milling has been used to fabricate suspended structures [31–33], anvils [34,35] and solid-immersion-lenses [36–38]. While these patterning techniques are most efficient for a set of specific shapes and devices, reactive ion etching (RIE) based fabrication methods are the most commonly used approach for a broad range of applications requiring sub-micron precision [39,40] such as micro-optics (e.g. for microlenses [41–47] and gratings [48,49]) and photonics (e.g. for couplers [50–54] and resonators [52,55–59]). In contrast with RIE for other materials, such as silicon, which has been extensively studied and for which an established catalog of processes is available, methods for RIE of SCD continue to be subject of active research and development. A variety of recipes has been demonstrated, using a broad range of masking materials, chemistries, etch rates and selectivities.

This review aims at providing an overview on experimentally demonstrated RIE recipes for SCD, serving both as an accurate review of the state of the art and as a practical guide to select the most suited etching approach for a given application. While previous demonstrations include a wealth of recipes for polycrystalline diamond, we here specifically focus on a review of RIE recipes demonstrated for SCD.

2. Chronology of technology developments

The first experimental results on RIE of SCD were reported in the late 1980’s and early 1990’s in parallel plate reactors [60], ion beam [61] or electron-cyclotron-resonance (ECR) etchers [62] with the aim at developing applications in microelectronics, using O2 occasionally in combination with Ar. Simultaneously, developments in ion-beam-assisted etching of SCD using a Xe+ beam and a reactive flux of NO2 resulted in high etch rates and selectivity [63]. In the late 1990’s the first reports on etching with O2 and CF4 in a parallel plate reactor were published [64]. Initial experiments using inductively coupled plasma (ICP) etchers were reported in the early 2000’s using O2 and Ar [65,66]. In the last decade, the vast majority of diamond etching processes have been performed with ICP etchers, owing to the possibility of independently controlling the ion energy and the plasma discharge in a compact sized tool [67–69], which allows controlling the etching process anisotropy. In 2007, the first cyclic etching process was reported, alternating between O2 SCD ICP-RIE steps and micromasking removal steps with O2 and CF4 (Fig. 1, [70]).

Since 2008, Cl2 based SCD ICP-RIE processes resulting in smoother etched surfaces were extensively used as an alternative to O2 based process [72]. Building on the previous 20 years of developments in SCD RIE, advanced etching processes were reported from 2012 onwards. A crucial step was achieved with the development of “angled-etching”
processes (Fig. 2, [73]), allowing fabrication of clamped free-standing structures by using a Faraday cage during the $\text{O}_2$ and $\text{Cl}_2$ release ICP-RIE step.

The same year, an entirely released 2–3 μm thick SCD structure obtained by ICP-RIE was reported, for the use in a diamond scanning nitrogen-vacancy (NV) sensor platform subsequently attached to an AFM tip [74]. In 2015, an approach inspired by the silicon SCREAM process (single crystal reactive etching and metallization [75]) was demonstrated to fabricate partially released structures in SCD (Fig. 3, [58]). The technique is based on an ICP-RIE $\text{O}_2$ anisotropic etch followed by the deposition of a protective layer on the etched sidewalls, and a final “quasi-isotropic” etch to release the structures.

Finally, considerable developments were made during the last years in bulk diamond etching, to transform relatively thick diamond plates into very thin SCD membranes, most notably by using cycles of $\text{SF}_6/\text{Ar}$ and $\text{O}_2/\text{SF}_6/\text{Ar}$ or cycles of $\text{Cl}_2/\text{Ar}$ and $\text{O}_2$ [76]. Based on these advanced etching techniques, the use of SCD in a variety of applications has substantially increased in the last few years. However, it is not straightforward to choose the most appropriate recipe when etching diamond. In the following sections, we will review the main aspects to consider when a SCD IRE step has to be performed, mainly focusing on ICP-RIE processes which are most commonly used nowadays. While we here focus on SCD ICP-RIE, comprehensive references and tutorials covering general RIE aspects include [67–69].

3. Etch process parameters

3.1. Reactants

As in any RIE process, the choice of the reactive species plays a crucial role for the performance of the etch process. First demonstrations were based on $\text{O}_2$, which has remained until now one of the most
common choices. In essence, O\textsubscript{2} radicals form volatile products such as CO and CO\textsubscript{2} when reacting with the C atoms of the exposed SCD surface. However, pure O\textsubscript{2} plasma etching is mainly a chemical process, whereas it is often beneficial to combine chemical and physical etching processes by using neutral species [18, 67, 68], typically Ar, in order to achieve high etch rates (Fig. 4). This not only results in a physical bombardment of the diamond surface, but allows to improve the efficiency of the chemical etching of the diamond by O\textsubscript{2} radicals.

Cl\textsubscript{2} based etching processes using Ar ions to sputter the diamond surface and to enable the reaction between Cl\textsubscript{2} and carbon, thus forming volatile CCl\textsubscript{x} products, were developed in an effort to obtain smoother etched surfaces, and were broadly adapted for the fabrication of optical components (Fig. 5). The use of Ar/Cl\textsubscript{2} based SCD ICP-RIE was first demonstrated in [72], where a comprehensive study of the process is performed, investigating etch rates, selectivity and surface roughness, and demonstrating better surface quality compared with Ar/O\textsubscript{2} plasmas.

In addition to the O\textsubscript{2} and Cl\textsubscript{2} reactive species which are responsible for the chemical etching process, and the Ar neutral species which bring a physical component to the etch, additional gases that have been experimented to a lesser extent for SCD RIE include SF\textsubscript{6} [76, 78–80], providing an advantageous non-toxic and non-corrosive alternative to
Cl$_2$ [76], and CF$_4$ [64,70,79,81–84]. Most frequently, such reactive species which form CF$_x$ products with diamond are used in combination with O$_2$ in order to reduce micromasking and more generally to obtain smoother etched surfaces. Interestingly, it has also been reported that highly anisotropic, pure SF$_6$ SCD RIE can be used to produce smooth microstructures at high etch rates, resulting from the sputtering of SCD by SF$_6$ heavy ions [79].

3.2. Coil and platen power

In a modern ICP-RIE chamber, it is possible to control independently the coil power, which controls the chemical etching via the plasma density, and the platen power, controlling the physical bombardment of the substrate via the ion energy [18]. Typically, coil powers are in the range of 500–2000 W, while the platen power ranges between 0 and 400 W. In essence, the platen power can tune the anisotropy of the etching process, while the coil power can control the density of reactive species available. A detailed study of the influence of platen power on the O$_2$ ICP-RIE process was recently performed in (Fig. 6) [85], demonstrating a crystallographic orientation dependent ICP-RIE technique conceptually similar to etching of silicon with KOH or TMAH, which is particularly adapted to the fabrication of gratings with trapezoidal [49] or V-groove profiles [86]. In contrast, an optimization of the anisotropic O$_2$ SCD ICP-RIE process to obtain vertical and smooth sidewalls by varying both the platen and coil powers is presented in [87]. Finally, ICP coil and platen powers also have a direct influence on the SCD etch rate (Fig. 7) [18,66] and on the selectivity of the ICP-RIE process [72,88].

3.3. Chamber pressure

The chamber pressure influences the etch rate [46], the anisotropy [67,89] and the etched surface smoothness [81]. Typical values are in the range of 1–15 mTorr. Low pressures result in highly anisotropic features due to an increased number of ions reaching the diamond surface at normal incidence, while increasing pressure allows to obtain higher etch rates up to a threshold where the etch rate decreases due to ion-electron recombination (Fig. 7) [18].

3.4. Temperature

ICP tools are generally equipped with a tunable temperature-controlled chuck [67,68]. Usually, substrate holder temperatures set points are not specified in literature when they are in vicinity of room temperature, as it has a minor effect on the etching process compared to the chamber pressure, gases and powers. The evolution of micromasking on a polycrystalline diamond film during an O$_2$ ICP-RIE process at room temperature, 73 °C and 132 °C was investigated in [89], where the best results were obtained at room temperature. Other ICP-RIE processes with temperatures substantially differing from room temperature were reported at 60 °C (with no specific objective highlighted, [32]) and at 250 °C (specifically to increase the etch rate, [58]).

3.5. Masking materials

SCD ICP-RIE can be performed without any mask when thinning substrates to fabricate thin membranes [55,74,90], however in most cases a diamond [59,91] or a quartz frame [76,92] is placed on the SCD.

Fig. 5. SCD micro-lenses fabricated using ICP-RIE with Cl$_2$ and Ar, exhibiting a very smooth surface of 0.18 nm root-mean-square roughness ([45], BCL3). Reprinted from H. Liu, S. Reilly, J. Herrnsdorf, E. Xie, V. G. Savitski, A. J. Kemp, E. Gu, M. D. Dawson, Large radius of curvature micro-lenses on single crystal diamond for application in monolithic diamond Raman lasers, Diam. Relat. Mater. 65 (2016) 37–41.

Fig. 6. SCD nanopillars fabricated by O$_2$ ICP-RIE to investigate the effect of platen power on sidewall verticality. The diamond etching was performed with a coil power of 900 W and a platen power of (a) 120 W, (b) 80 W, (c) 30 W and (d) 20 W ([85]). L. Xie, T. X. Zhou, R. J. Stöhr, A. Yacoby, Crystallographic orientation dependent reactive ion etching in single crystal diamond, Adv. Mater. (2018) 1705501. Copyright WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. Reproduced with permission.
substrate during RIE in order to support and handle the resulting membrane. In the case of shallow etching depths such as for SCD microlenses, standard photoresists can be advantageously patterned by photolithography, optionally reflowed to form hemispherical or cylindrical structures and used as etching masks \[41,42,45,47\]. More recently, 3D laser lithography was used to pattern photoresist and etch 3D micro-optical components in SCD \([93]\). While the low selectivities (typically in the range of 0.1 to 5) obtained during SCD ICP-RIE using photoresists as masks are suited for such shallow structures, other materials including Si \([43,94]\), oxides and metals are more appropriate for deeper etches (Fig. 8).

Al is a popular choice \([65,66,83,96]\). Remarkably, a process to obtain a thick (1.7 μm) aluminum hard mask with smooth and vertical sidewalls was developed in \([48]\) and is particularly suited to etch deep and high aspect ratio features (Fig. 9). SiO2 is also a suitable material and has proven to be particularly well suited for O2 ICP-RIE aiming at very deep etching (etch depths of > 150 μm \([97]\)) (Fig. 9).

Thin Si3N4 layers have been used as hard mask in O2 SCD ICP-RIE, and can be patterned following an optimized process developed in \([87]\) that yields smooth and vertical sidewalls, which is essential to obtain high quality SCD etched sidewalls. In addition, Si3N4 can be deposited conformally by plasma enhanced chemical vapor deposition (PECVD) which is required for sidewall protection in the “quasi-isotropic” release process \([58]\). Other materials used in lesser extents include Al2O3 deposited by atomic layer deposition (ALD), which shows excellent selectivity in O2 crystallographic ICP-RIE processes \([86]\) and Au patterned by a lift-off process \([98]\). Finally, for nanostructuring of SCD using electron-beam lithography, hydrogen silsesquioxane (HSQ) based resists are commonly used as hard mask for shallow etching depths \([77,85,89,92,99,100]\).

4. Etch process characteristics

4.1. Etch rates, selectivity and etch depths

When etching deep structures in SCD, the achievable etch depths are directly related to both mask selectivity and etch rate. The former determines the thickness of the etch mask required to reach a certain etch depth, while the latter determines the overall processing time. SCD etch rates in ICP reactive ion etchers have been reported in the range of 10–700 nm/min. While the etch rates are not of critical importance for shallow etching depths, reasonable etching times are desirable when

![Image](image-url)
etching deep structures. High selectivities are preferable to limit the thickness of the hard mask that has to be deposited and patterned.

In order to provide guidance in selection of a suitable etch recipe and masking material, we present in the following three graphical representations extracted from experimental data reported in literature.

In Fig. 10, we summarize the experimentally demonstrated etch rates and selectivities towards the masking material. The highest selectivities have been reported for metal (Al, Ti), SiO₂ and Si₃N₄ masks, which have primarily been explored for high etch rate recipes with the aim of achieving large etch depths.

In Fig. 11, we visualize the reported etch rates with respect to the most important etch parameters, i.e. the coil and platen powers. The size of the markers is representative for the etch rates, and provides quick access to the selection of fast etch recipes.

In Fig. 12, we provide an overview of reported etch rates versus etch depth. For shallow etches, the etch rate is typically less important, as processing times are not a limiting factor, however, in order to etch deep structures, high etch rates are required to keep processing time in reasonable limits. Obtainable etch depths have also been limited by micromasking effects from metal hard mask materials, therefore the highest etch depths have been achieved with non-metal masks such as SiO₂. These materials form volatile etch byproducts that are more easily evacuated during the etch process, limiting the micromasking effects.

4.2. Uniformity, Aspect Ratio Dependent Etching (ARDE) and trenching

Only few measurements of uniformity during SCD ICP-RIE are reported. Most notably in [76], a uniformity of < 1 μm thickness variations over 200 × 200 μm² is obtained during membrane fabrication, using either SF₆ or Cl₂ based processes. As for silicon and other materials, ICP-RIE produces trenches due to the reflection of ions on the hard mask or on the etched structures. A detailed study on the formation and geometry of such trenches during SCD ICP-RIE can be found in [101]. Finally, the vertical etch rate depends on the width of the mask opening. In general, wider openings are etched faster than narrow openings, as wider openings facilitate the interactions of reactants with the diamond surface, a feature which is commonly referred to in literature as Aspect Ratio Dependent Etching (ARDE). While ARDE can be explored to generate features with varying depth in the substrate [48], a common strategy to obtain trenches of uniform depth consists in designing the etch mask with openings of the same width [97].

4.3. Profile

Vertical sidewalls are most often desired in applications using SCD ICP-RIE. In [87], sidewall angles ranging from 0.6° to 15.6° from vertical are achieved by varying the ICP coil and platen power. However,
specific angles can be preferred for specific applications. In [85], angles of 12° to 35° from vertical are obtained using a low bias crystallographic orientation dependent etching process, while etching without bias can produce sidewall angles of 33° and 3° from vertical depending on the crystal orientation ([102]). An extensively detailed study on the optimization of high aspect ratio structures’ sidewall verticality in polycrystalline diamond ICP-RIE by ICP coil and power adjustments and periodical renewing of hard mask is reported in [103]. Inclined sidewalls (angles from 13° to 31° from vertical) were obtained in polycrystalline diamond by using a hard mask with faceted sidewalls ([104]). Similarly, it is possible to obtain either steep sidewalls, spherical, conical or pyramidal structures by adjusting the dimensions and aspect ratios of the hard mask (i.e. hard mask structures horizontal/vertical dimensions versus hard mask thickness), or by using multilayer, truncated hard masks [79].

4.4. Surface quality

After SCD ICP-RIE, the surface quality of the horizontal etched surfaces substantially differs from the surface quality of the sidewalls. Horizontal etched surfaces quality essentially depends on micromasking mechanisms [70] and on the initial defects found on the diamond top surface (e.g. pits, scratches and diamond particles originating from the mechanical polishing [29]) (Fig. 13). On the other hand, the
sidewalls surface quality mostly depends on the surface quality of the hard mask sidewalls \cite{87}. Interestingly, in the case of crystallographic orientation dependent SCD ICP-RIE, extremely smooth sidewalls can be obtained \cite{102} in contrast with high ICP platen power \cite{97,105} used for deep etches, which tends to produce rougher sidewalls.

5. Catalog of SCD ICP-RIE recipes and applications

The following four tables summarize the most important experimentally demonstrated etch recipes for SCD. They are categorized by the reactants, first listing O\(_2\), Cl\(_2\) and SF\(_6\), and finally cyclic etch recipes involving multiple reactants. The tables are structured by a unique identifier and the reference in the first column, followed by a graphical representation of the main etch parameters (gas flow, coil and platen powers, chamber pressure) and the reported etch rate in the second column, the mask material (and where reported including the mask selectivity) in the third column, including any explanatory comments or specific applications in the fourth and last column. In particular the graphical representation of the etch parameters is intended to provide the reader with a comparative overview of the etch recipes at a glance, to facilitate the selection of a specific base recipe for a specific application. The complete data set is available in the supplementary material.

### O\(_2\) based recipes

| Parameters and etch rate | Mask material (selectivity) | Application/comments |
|-------------------------|-----------------------------|----------------------|
| BO1                     | Al (50)                     | Use of tapered hard mask to obtain conical structures; cylinders |
| [65] Hwang et al. (2004) |                             |                      |
| BO2                     | Al (N/A)                    | Investigation of anisotropic dry etching of boron doped SCD |
| [46] Enlund et al. (2005)|                             |                      |
| BO3                     | Photoresist SPR220 (N/A)    | Etching rate study; Fabrication of positive and negative micro-lenses |
| [46] Lee et al. (2006)  |                             |                      |

Fig. 13. (a) Micromasking during Ar/O\(_2\) SCD ICP-RIE resulting from redeposited particles sputtered from the Al hard mask \cite{97}, BO18 and (b) Comparison of surface roughness evolution after O\(_2\)/CF\(_4\) SCD ICP-RIE at (I) 100 W and (II) 200 W Platen power. While the as-received samples surface roughness was minimally affected with low platen power, it was significantly increased with higher platen power, forming deep etch pits likely located at pre-existing surface defects sites. Furthermore, it was shown that the addition of Ar allowed to decrease the roughness of the as-received samples \cite{82}. (a) Reprinted from A. Toros, M. Kiss, T. Graziosi, H. Sattari, P. Gallo, N. Quack, Precision micro-mechanical components in single crystal diamond by deep reactive ion etching, Microsystems & Nanoengineering 4 (1) (2018). (b) Reprinted from M. L. Hicks, A. C. Pakpour-Tabrizi, V. Zuerbig, L. Kirste, C. Nebel, R. B. Jackman, Optimizing reactive ion etching to remove sub-surface polishing damage on diamond, J. Appl. Phys. 125 (24) (2019) 244502, with the permission of AIP Publishing.
| BO4  | [70] Yamada et al. (2007) | SiO$_2$ (26) Base for development of cyclic recipe to obtain smooth etched surfaces and high selectivity. Pure O$_2$ gives micromasking. (see also cyclic recipe) |
| BO5  | [70] Yamada et al. (2007) | SiO$_2$ (10) Base for development of cyclic recipe to obtain smooth etched surfaces and high selectivity. Addition of CF$_4$ to O$_2$ gives smooth surfaces and lowers selectivity. (see also cyclic recipe) |
| BO6  | [77] Babinec et al. (2010) | E-beam resist FOx 17 (N/A) SCD nanowires. Progressive adjustment of coil power during etch. |
| BO7  | [89] Hausmann et al. (2010) [74] Maletinsky et al. (2012) | Au nanoparticles (8–9); Au on Cr (8.5); E-beam resist FOx (19–24) [89] SCD nanowires; Progressive adjustment of coil power during the etch of some samples. [74] Step of cyclic recipe for substrate thinning & fabrication of nanopillars |
| BO8  | [73] Burek et al. (2012) | Ti (N/A) Demonstration of angled-etching; Anisotropic etch step prior to angled etching; Chlorine prevents mask redeposition |
| BO9  | [48] Forsberg et al. (2013) | Al (50) High aspect ratio gratings. Two recipes optimized for shallow or deep gratings |
| BO10 | [32] Bayn et al. (2014) | Pick and place Si (N/A) SCD triangular waveguide: anisotropic etch step prior to angled etching |
| BO11 | [99] Riedel et al. (2014) | Unmasked/E-beam resist FOx-16 (N/A) | Step of cyclic recipe for substrate thinning and for structured membrane fabrication (see also cyclic recipe) |
| BO12 | [106] Neu et al. (2014) [99] Riedel et al. (2014) [92] Appel et al. (2016) | E-beam resist FOx-16 (N/A) | [106] Diamond nanopillars [99] Step of cyclic recipe for structured membrane fabrication (see also cyclic recipe) [92] Scanning probe on SCD membrane |
| BO13 | [58] Khanaliloo et al. (2015) | Si₃N₄ (40) | Anisotropic etch step for fabricating SCD microdisks |
| BO14 | [92] Appel et al. (2016) [76] Chalvier et al. (2018) | Quartz cover slip (N/A) | Step of cyclic recipe for membrane fabrication (see also cyclic recipe) |
| BO15 | [98] Kehayias et al. (2017) | Au on Cr adhesion layer (N/A) | Diamond nanogratings |
| BO16 | [105] Zhou et al. (2017) | E-beam resist FOx 16 (N/A); Ti (> 200) | Diamond nanopillars and 45 μm deep etch of SCD probe |
| BO17 | [76] Chalvier et al. (2018) | Quartz cover slip (1.7) | Step of cyclic recipe for membrane fabrication (see also cyclic recipe) |
BO18
[97] Toros et al. (2018)

SiO$_2$ (50)
Deep etching for micromechanical parts

BO19
[87] Mitch-ell et al. (2019)

Si$_3$N$_4$ (N/A)
Optimization of anisotropic etch step for fabricating SCD microdisks

BO20
[80] Ruf et al. (2019)

Quartz (32)
Step of cyclic recipe for membrane fabrication (see also cyclic recipe)

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Cl$_2$ based recipes

| Parameters and etch rates | Mask material (selectivity) | Application/comments |
|---------------------------|-----------------------------|----------------------|
|                         | Photoresist SPR220          | [72] Demonstration and study of Cl$_2$ based etching of SCD; Fabrication of micro-lens and micro-structure |
| [72] Lee et al. (2008)    |                             | [74] Step of cyclic recipe for substrate thinning |
| [74] Maletinsky et al.    |                             | [107] Substrate thinning |
| (2012)                    |                             |                     |
| [107] Ovartchauypong et al. (2012) |               |                     |
|                         | Unmasked                    | [99] Riedel et al. (2014) |

BCL2

Step of cyclic recipe for substrate thinning (see also cyclic recipe)

BCL3

Photosresist SPR220
SCD micro-lenses; low selectivity (0.1)
### SF₆ based recipes

| Parameters and etch rates | Mask material (selectivity) | Application/comments |
|---------------------------|----------------------------|----------------------|
| BSF1                      | Quartz (0.39)              | Step of cyclic recipe for membrane fabrication (see also cyclic recipe) |

### Cyclic recipes

| Parameters and etch rate | Mask material (selectivity) | Application/comments |
|--------------------------|----------------------------|----------------------|
| CYC1                     | SiO₂ (26)                   | Development of cyclic recipe to obtain smooth etched surfaces by avoiding micromasking and high selectivity. |

- Cycle:
  - ⊗ 30–1800 s.
  - ⊗ 10–30 s.
CYC2
[74] Maletinsky et al. (2012)

Unmasked Diamond substrate thinning

Cycle:
○ 10 min
○ 30 min
○ 15 min of cooling

CYC3
[99] Riedel et al. (2014)

Unmasked Diamond substrate thinning

Cycle:
○ 10 min
○ 20 min

CYC4
[99] Riedel et al. (2014)

E-beam resist FOx-16 (N/A) Diamond structured membrane fabrication

Cycle:
○ 8 min
○ N/A (until through etching of the substrate)
CYC5
[92] Appel et al. (2016)
[76] Challier et al. (2018)
Quartz cover slip (N/A) Diamond membrane fabrication
[92]
Start: ⬅ 5 min
Cycle:
Ⓕ 5 min
Ⓖ 5 min
Ⓑ 5 min
Each cycle step is separated by 5 min of cooling under Ar (100 sccm, 100 mTorr)
[76]
Start: ⬅ 5 min
Cycle:
Ⓕ 5 min
Ⓖ 10 min
After every 5 min of etching, a cooling step under Ar of 4 min is performed (100 sccm, 100 mTorr)

CYC6
[76] Challier et al. (2018)
Quartz cover slip (1.7 for step ⬗)
Diamond membrane fabrication, SF₆-based
Cycle:
Ⓕ 10 min
Ⓖ 20 min
Ⓖ 5 min
After every 5 min of etching, a cooling step under Ar of 5 min is performed (30 sccm, 7.5 mTorr)

CYC7
[80] Ruf et al. (2019)
Quartz (0.49 for step ⬗, 32 for step ⬗)
Diamond membrane fabrication
Cycle:
Ⓕ 26 min
Ⓖ 45 min
Ⓖ 30 min
Ⓓ 138 min
Ⓕ 30 min
Ⓖ 23 min
6. Conclusion

The broad range of applications of SCD involves different requirements in terms of etching rates, hard mask materials, selectivities and resulting surface qualities. This has resulted in a variety of SCD ICP-RIE processes from which one can select or adapt the most appropriate parameters. In this contribution, we summarize the most important parameters of SCD ICP-RIE, review the resulting characteristics of the obtained structures and present a catalog of SCD ICP-RIE recipes. We propose several guidelines to facilitate the selection of an adapted etching process, aiming to serve as an up to date reference “toolkit” for researchers in the field.

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Declaration of competing interest

R.B., M.N., J.V.P. and P.G. are with LakeDiamond SA, a commercial supplier of single crystal diamond. The remaining authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diamond.2020.107839.

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