**Supplementary Information**

**Table 1:** The voltages V1 and V4 measured on the wire probe during phases 1 and 4 respectively, as a function of the voltage applied to the hollow cathode electrode, the pressure and the on-time of the pulses. Phase 2 and Phase 4 implanted charge are calculated from equations (3.14) and (4.15) as discussed in the text.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | Phase 2 | | Phase 4 | | | |
| V applied (V) | Error (V) | Pressure (mTorr) | Pulse length (μs) | Qimplant (C) | Error (C) | V4 (V) | Error (V) | Qimplant (C) | Error (C) |
| -3000 | 10 | 200 | 5 | 4.35E-06 | 1.45E-08 | 468.3 | 0.9 | 2.06E-06 | 3.98E-09 |
|  |  | 300 |  |  |  | 656.2 | 0.4 | 2.89E-06 | 1.89E-09 |
|  |  | 400 |  |  |  | 681.3 | 0.3 | 3.00E-06 | 1.21E-09 |
|  |  | 500 |  |  |  | 685.7 | 0.4 | 3.02E-06 | 1.54E-09 |
|  |  | 600 |  |  |  | 700.4 | 1.4 | 3.08E-06 | 6.23E-09 |
| -5000 | 15 | 200 | 5 | 7.25E-06 | 2.18E-08 | 669.7 | 5.0 | 2.95E-06 | 2.19E-08 |
|  |  | 300 |  |  |  | 718.7 | 1.2 | 3.16E-06 | 5.19E-09 |
|  |  | 400 |  |  |  | 720.2 | 2.2 | 3.17E-06 | 9.68E-09 |
|  |  | 500 |  |  |  | 732.5 | 8.2 | 3.22E-06 | 3.60E-08 |
|  |  | 600 |  |  |  | 765.8 | 7.4 | 3.37E-06 | 3.25E-08 |
| -7000 | 20 | 200 | 5 | 1.02E-05 | 2.90E-08 | 706.7 | 0.1 | 3.11E-06 | 3.52E-10 |
|  |  | 300 |  |  |  | 725.4 | 0.4 | 3.19E-06 | 1.89E-09 |
|  |  | 400 |  |  |  | 731.7 | 0.6 | 3.22E-06 | 2.60E-09 |
|  |  | 500 |  |  |  | 743.4 | 1.1 | 3.27E-06 | 5.02E-09 |
|  |  | 600 |  |  |  | 774.9 | 0.1 | 3.41E-06 | 3.30E-10 |
| -3000 | 10 | 200 | 10 | 4.35E-06 | 1.45E-08 | 588.5 | 3.5 | 2.59E-06 | 1.52E-08 |
|  |  | 300 |  |  |  | 594.2 | 0.2 | 2.61E-06 | 6.82E-10 |
|  |  | 400 |  |  |  | 685.0 | 0.5 | 3.01E-06 | 2.13E-09 |
|  |  | 500 |  |  |  | 689.9 | 2.5 | 3.04E-06 | 1.10E-08 |
|  |  | 600 |  |  |  | 703.7 | 1.4 | 3.10E-06 | 6.05E-09 |
| -5000 | 15 | 200 | 10 | 7.25E-06 | 2.18E-08 | 637.5 | 1.5 | 2.81E-06 | 6.56E-09 |
|  |  | 300 |  |  |  | 712.0 | 3.0 | 3.13E-06 | 1.32E-08 |
|  |  | 400 |  |  |  | 731.4 | 0.6 | 3.22E-06 | 2.60E-09 |
|  |  | 500 |  |  |  | 740.8 | 4.2 | 3.26E-06 | 1.87E-08 |
|  |  | 600 |  |  |  | 771.8 | 3.5 | 3.40E-06 | 1.52E-08 |
| -7000 | 20 | 200 | 10 | 1.02E-05 | 2.90E-08 | 701.4 | 0.4 | 3.09E-06 | 1.56E-09 |
|  |  | 300 |  |  |  | 737.8 | 1.0 | 3.25E-06 | 4.33E-09 |
|  |  | 400 |  |  |  | 756.9 | 0.7 | 3.33E-06 | 3.12E-09 |
|  |  | 500 |  |  |  | 754.4 | 1.7 | 3.32E-06 | 7.26E-09 |
|  |  | 600 |  |  |  | 778.3 | 3.1 | 3.42E-06 | 1.36E-08 |
| -3000 | 10 | 200 | 20 | 4.35E-06 | 1.45E-08 | 1064.0 | 12.6 | 4.68E-06 | 5.56E-08 |
|  |  | 300 |  |  |  | 749.6 | 2.9 | 3.30E-06 | 1.26E-08 |
|  |  | 400 |  |  |  | 942.5 | 8.4 | 4.15E-06 | 3.72E-08 |
|  |  | 500 |  |  |  | 753.2 | 12.3 | 3.31E-06 | 5.42E-08 |
|  |  | 600 |  |  |  | 698.3 | 0.8 | 3.07E-06 | 3.30E-09 |
| -5000 | 15 | 200 | 20 | 7.25E-06 | 2.18E-08 | 725.0 | 1.8 | 3.19E-06 | 7.99E-09 |
|  |  | 300 |  |  |  | 909.4 | 13.1 | 4.00E-06 | 5.76E-08 |
|  |  | 400 |  |  |  | 737.2 | 2.3 | 3.24E-06 | 1.00E-08 |
|  |  | 500 |  |  |  | 765.1 | 1.3 | 3.37E-06 | 5.54E-09 |
|  |  | 600 |  |  |  | 788.7 | 4.0 | 3.47E-06 | 1.76E-08 |
| -7000 | 20 | 200 | 20 | 1.02E-05 | 2.90E-08 | 803.5 | 4.8 | 3.54E-06 | 2.13E-08 |
|  |  | 300 |  |  |  | 741.9 | 1.0 | 3.26E-06 | 4.31E-09 |
|  |  | 400 |  |  |  | 774.4 | 0.9 | 3.41E-06 | 3.85E-09 |
|  |  | 500 |  |  |  | 777.9 | 1.0 | 3.42E-06 | 4.49E-09 |
|  |  | 600 |  |  |  | 804.8 | 1.3 | 3.54E-06 | 5.54E-09 |
| -3000 | 10 | 200 | 40 | 4.35E-06 | 1.45E-08 | 1152.2 | 5.9 | 5.07E-06 | 2.57E-08 |
|  |  | 300 |  |  |  | 994.9 | 8.2 | 4.38E-06 | 3.61E-08 |
|  |  | 400 |  |  |  | 965.4 | 12.8 | 4.25E-06 | 5.65E-08 |
|  |  | 500 |  |  |  | 916.5 | 7.0 | 4.03E-06 | 3.07E-08 |
|  |  | 600 |  |  |  | 863.5 | 6.2 | 3.80E-06 | 2.71E-08 |
| -5000 | 15 | 200 | 40 | 7.25E-06 | 2.18E-08 | 1454.5 | 33.3 | 6.40E-06 | 1.46E-07 |
|  |  | 300 |  |  |  | 1207.8 | 37.2 | 5.31E-06 | 1.63E-07 |
|  |  | 400 |  |  |  | 1019.5 | 9.0 | 4.49E-06 | 3.96E-08 |
|  |  | 500 |  |  |  | 911.4 | 22.2 | 4.01E-06 | 9.75E-08 |
|  |  | 600 |  |  |  | 803.6 | 10.8 | 3.54E-06 | 4.73E-08 |
| -7000 | 20 | 200 | 40 | 1.02E-05 | 2.90E-08 | 1052.5 | 14.2 | 4.63E-06 | 6.24E-08 |
|  |  | 300 |  |  |  | 1306.7 | 6.4 | 5.75E-06 | 2.83E-08 |
|  |  | 400 |  |  |  | 1004.9 | 5.6 | 4.42E-06 | 2.45E-08 |
|  |  | 500 |  |  |  | 808.0 | 2.4 | 3.56E-06 | 1.05E-08 |
|  |  | 600 |  |  |  | 839.6 | 2.4 | 3.69E-06 | 1.07E-08 |