

CLAIMS

1. A method for improving lifetime and coherence time of a qubit in a quantum mechanical device, comprising:
 - providing a substrate having a frontside and a backside, the frontside having at least one qubit formed thereon, the at least one qubit comprising capacitor pads; and
 - at least one of removing an amount of substrate material from the backside of the substrate at an area opposite the at least one qubit or depositing a superconducting metal layer at the backside of the substrate at the area opposite the at least one qubit to reduce radiofrequency electrical current loss due to at least one of silicon-air (SA) interface, metal-air (MA) interface or silicon-metal (SM) interface so as to enhance a lifetime (T1) and a coherence time (T2) in the at least one qubit.
2. The method according to the preceding claim, wherein reducing radiofrequency electrical current loss comprises reducing current loss by increasing radiofrequency overlap with lower loss geometric features in the quantum mechanical device and decreasing radiofrequency overlap with higher loss geometric features in the quantum mechanical device.
3. The method according to any of the preceding claims, wherein removing the substrate material from the backside of the substrate at the area opposite the at least one qubit comprises chemically etching the backside of the substrate selectively using a chemical etchant selected depending on the substrate material.
4. The method according to the preceding claim, further comprising, prior to chemically etching the backside of the substrate, forming an initial cavity in the backside of the substrate in a vicinity of the at least one qubit by mechanically removing material from the backside of the substrate and then chemically etching the backside of the substrate at the formed initial cavity.
5. The method according to the preceding claim, wherein forming the initial cavity in the backside of the substrate comprises defining faces of the initial cavity having one or more first

crystal planes and one or more second crystal planes so that the chemical etchant preferentially etches the substrate material from said one or more first crystal planes while substantially not etching substrate material from said one or more second crystal planes to form an etched final cavity in the vicinity of the at least one qubit.

6. The method according to any of the preceding claims, wherein removing the amount of substrate material from the backside of the substrate comprises removing the amount of substrate material in an area of the backside of the substrate to form a trench in a vicinity of a gap between capacitor pads of the at least one qubit.

7. The method according to the preceding claim, wherein removing the amount of substrate material in the area of the backside of the substrate to form the trench in the vicinity of the gap between the capacitor pads of the at least one qubit comprises removing the amount of substrate material so that the trench is substantially centered around the gap between the capacitor pads of the at least one qubit.

8. The method according to the preceding claim, wherein removing the amount of substrate so that the trench is substantially centered around the gap between the capacitor pads of the at least one qubit comprises forming the trench to reduce a participation rate of surface states with RF energy density for silicon-metal (SM) interfaces and increasing a participation rate of surface states with the RF energy density for silicon-air (SA) interfaces.

9. The method according to any of the preceding claims and with features of claim 6, wherein RF energy density overlap with surface states in silicon-metal (SM) interfaces is reduced and the surface state RF energy density overlap for silicon-air (SA) interfaces is increased with increasing depth of the trench.

10. The method according to any of the preceding claims, wherein removing the amount of substrate material from the backside of the substrate comprises removing the amount of substrate material in an area of the backside of the substrate to form a trench in a vicinity of a gap between capacitor pads of the at least one qubit and depositing the superconducting metal

layer within the trench so as to reduce the radiofrequency electrical current loss due to metal-air (MA) interfaces.

11. The method according to the preceding claim, wherein forming the trench in the vicinity of the gap between capacitor pads of the at least one qubit comprises forming the trench below and centered around one of the capacitor pads of the at least one qubit.

12. The method according to any of the two preceding claims, wherein the radiofrequency electrical current loss due to metal-air (MA) interface is decreased based on a backside width of the trench.

13. The method according to any of the preceding claims, wherein removing the substrate material from the backside of the substrate at the area opposite the at least one qubit comprises applying an etch mask film to the backside of the substrate and etching the selected area at the backside of the substrate opposite the at least one qubit.

14. The method according to the preceding claim, further comprising: subsequent to applying the etch film mask to the backside of the substrate and prior to etching the selected area at the backside of the substrate, forming one or more openings in the etch film mask at the selected area.

15. The method according to any of the two preceding claims, wherein etching the selected area at the backside of the substrate opposite the at least one qubit comprises chemically etching a desired thickness of the substrate at the selected areas to form a trench at the selected area.

16. The method according to the preceding claim, further comprising depositing the superconducting metal layer within the trench.

17. The method according to any of the preceding claims, wherein removing the substrate material from the backside of the substrate at the area opposite the at least one qubit comprises

applying a mask film to the backside of the substrate and depositing metal superconductor on masked areas of the backside of the substrate.

18. A quantum mechanical device, comprising:
 - a substrate having a frontside and a backside; and
 - a plurality of qubits formed on the frontside of the substrate, the plurality of qubits comprising a plurality of capacitor pads,
 - wherein the substrate comprises at least one trench formed on the backside of the substrate opposite at least one qubit of the plurality of qubits, and
 - wherein at least one of a size, a shape, or a position of the at least one trench or a superconducting material deposited therein are selected to reduce radiofrequency electrical current loss due to at least one of silicon-air (SA) interface, metal-air (MA) interface or silicon-metal (SM) interface, or any combination thereof, so as to enhance a lifetime (T1) and a coherence time (T2) in the at least one qubit.
19. The quantum mechanical device according to the preceding claim, wherein the substrate is selected from the group consisting of silicon, high resistivity silicon, and sapphire.
20. The quantum mechanical device according to the preceding claim, wherein the plurality of capacitor pads are made from a superconducting material.
21. The quantum mechanical device according to the preceding claim, wherein the superconducting material is selected from the group consisting of aluminum (Al) and niobium (Nb).
22. The quantum mechanical device according to any of the four preceding claims, wherein the trench is provided in a vicinity of a gap between two capacitor pads of the plurality of capacitor pads.
23. The quantum mechanical device according to the preceding claim, wherein the trench is substantially centered around the gap so as to reduce surface state energy density for

silicon-metal (SM) interface and to increase surface state energy density for silicon-air (SA) interface.

24. The quantum mechanical device according to any of the six preceding claims, wherein the superconducting metal layer is provided within the trench so as to reduce the radiofrequency electrical current loss due to metal-air (MA) interface.

25. The quantum mechanical device according to the preceding claim, wherein the trench is formed below and centered around one or more of the plurality of capacitor pads.