References

1. Formation of silicon layer through aluminothermic reduction of quartz substrates / M. M. Islam [et al.] // Frontiers in Materials. – 2022. – Vol. 9. – Art. 977869.
2. Magniothermal Methods of Silicon Extraction from Quartz Sands of «Jerdanak» Mine / S. I. Jiyanova [et al.] // J. Engineering Trends and Techn. – 2024. – № 4. – P. 234–245.
3. A Review on Removal of Iron Impurities from Quartz Mineral / C. Liu [et al.] // Minerals. – 2023. – № 9. – Art. 1125.
4. Advanced Processing Techniques and Impurity Management for High-Purity Quartz in Diverse Industrial Applications / H. Long [et al.] // Minerals. – 2024. – Vol. 14, № 6. – Art. 571.
5. Luque, A. Handbook of photovoltaic science and engineering / A. Luque, S. Hegedus. – Chichester: Wiley, 2008. – 1142 p.
6. Mohamed, N. I. Quantification of Silicon (Si) and Silicon Dioxide (SiO_2) from the Nafud Desert-Al-Qassim Region, Kingdom of Saudi Arabia Using XRD Analysis / N. I. Mohamed // Advances in Materials Physics and Chemistry. – 2024. – Vol. 14, № 5. – P. 67–75.
7. Silicon for The Chemical and Solar Industry XIII: proceedings of the 13th International Conference, Trondheim, Norway, June 21-24, 2016 / B. Pachaly [et al.]. – Trondheim: Norwegian University of Science and Technology, 2016. – 428 p.

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THE NEXT FRONTIER: TRANSFORMING ZIMBABWE'S SILICA SAND INTO SMART TECHNOLOGY

Mbanje N., Govha J., Musiwa P. B.

Harare Institute of Technology, Harare, Zimbabwe

Abstract. High-purity silicon is the cornerstone of modern electronics and solar technologies. This study investigates the potential of Zimbabwe's silica sand as a source of raw material for semiconductor-grade silicon. Samples from Mkoba, Gweru were analysed using Inductively Coupled Plasma (ICP) to determine elemental composition and impurity levels. Results show high silica content of 92.38 % with trace impurities such as iron, aluminium, magnesium, calcium and titanium. The findings indicate that, with appropriate purification processes, Zimbabwe's silica sand can serve as a viable feedstock for local semiconductor production and technological development.

Keywords: Silicon, semiconductor, Gweru, purity, photovoltaic, electronic, metallurgical.

Address for correspondence: Joseph Govha, BE277 Belvedere Harare, Zimbabwe
e-mail: jgovha@hit.ac.z

Introduction. High-purity silicon is the cornerstone of modern civilization, serving as the foundational substrate for semiconductor chips that power most digital electronics (Jennings *et al.*, 2024). Its role extends equally to the global energy sector, particularly in solar photovoltaic cells, underscoring its critical importance in both technological and energy landscapes (Asmaa and Saad, 2023; Jennings *et al.*, 2024). This ever-growing demand shifts focus to the foundational raw material, silica sand. The transformation of silica sand into silicon epitomizes one of the most vital value chains in contemporary industry (Tandersen et al., 2024). Despite silicon being one of Earth's most abundant elements, it does not occur in native (elemental) form and must be produced via energy-intensive and highly selective chemical and metallurgical processes (Jiyanova et al., 2024; Tandersen et al., 2024). The quality of the silica has a profound influence on the efficiency, cost and environmental footprint of downstream silicon production (Asmaa and Saad, 2023). Among the challenges, silica seldom meets the impurity specifications required for semiconductor or photovoltaic applications (Khalifa et al., 2025). Deep purification steps (physical, chemical, thermal) are needed to eliminate trace metal ions (e.g., Fe, Ti, Al), hydroxyl groups, and other contaminants before reduction to metallurgical-grade or higher purity silicon (Asmaa and Saad, 2023). In this sense, the "sand-to-silicon" chain is not just a matter of scale, but of achieving extreme purity with minimal losses, energy consumption, and environmental impact (Jennings *et al.*, 2024).

Gweru's silica sand composition. The ICP characterization as shown from Table 1 reveals that the silica sand from Gweru contains 92.38 % SiO_2, a relatively high silica content but well below the thresholds required for high-purity silicon feedstock. Of all the impurities, FeO (0.312 % which is approximately 3 120 ppm) is particularly problematic as iron tends to form colored inclusions and can act as a recombination center for charge carriers in silicon and photovoltaic devices, significantly impairing electrical performance. Zhang et al., 2023; Long, Zhu, Pan, Li, Guo, et al., 2024; Long, Zhu, Pan, Li, Yang, et al., 2024).

Table 1 – ICP characterisation results of silica sand

Silica sand purity					
%SiO_2	%FeO	%MgO	%CaO	%Al_2O_3	%TiO_2
92.38	0.312	0.422	0.098	0.49	0.057

According to standards for high-purity quartz, metallic impurity levels must often be reduced to single to low double digit ppm levels (e. g., the IOTA series quartz sands achieve impurity totals under 10 mg/kg). The Al_2O_3 content (0.49 %) is likewise high. Aluminum in quartz can substitute into the lattice, making removal difficult. It also contributes to defects in downstream silicon processing and optical transmission losses. Literature on purification of quartz emphasizes that lattice Al is one of the hardest impurities to eliminate (Long, Zhu, Pan, Li, Yang, *et al.*, 2024). Other impurities such as MgO (0.422 %), CaO (0.098 %) and TiO_2 (0.057 %) are lower, but still significant. Titanium is especially problematic because even trace Ti can diffuse during high temperature processing and cause deep-level electronic traps. The presence of Mg and Ca is typically easier to remove via acid leaching or flotation, but their concentrations here remain non-negligible (Khalifa *et al.*, 2025).

Conclusion. The ICP characterization of Gweru's silica sand demonstrates promising yet imperfect purity for high-value applications. With 92.38 % SiO_2, the silica sand exhibits potential as a feedstock for silicon production but remains below the required purity for electronic-grade use. The elevated FeO (0.312 %) and Al_2O_3 (0.49 %) contents are the principal limiting factors, as these impurities degrade semiconductor performance and optical clarity. However, studies indicate that sequential acid leaching, magnetic separation, and flotation can effectively reduce Fe and Al impurities to acceptable limits (Liu et al., 2023; Long et al., 2024; Pachaly et al., 2022). Therefore, with targeted beneficiation and purification technologies, Zimbabwe's silica sand could transition from a low-value construction material to a strategic mineral resource underpinning local semiconductor and photovoltaic industries.

References

1. Asmaa, Z. Extraction of silica from natural deposits for the production of silicon in photovoltaic applications / Z. Asmaa, H. Saad // Open Journal of Bacteriology. – 2023. – Vol. 7, № 1. – P. 011–015.

2. A review of high-purity quartz for silicon production in Australia / A. Jennings [et al.] // Australian Journal of Earth Sciences. – 2024. – Vol. 71, № 8. – P. 1085–1097.

3. Magniothermal Methods of Silicon Extraction from Quartz Sands of "Jerdanak" Mine / S. I. Jiyanova [et al.] // International Journal of Engineering Trends and Technology. – 2024. – Vol. 72, № 10. – P. 316–322.

4. High-Purity Silica Produced from Sand Using a Novel Method Combining Acid Leaching and Thermal Processing / M. Khalifa [et al.] // Arabian Journal for Science and Engineering. – 2025. – Vol. 50, № 6. – P. 4129–4135.

5. Advanced Processing Techniques and Impurity Management for High-Purity Quartz in Diverse Industrial Applications / H. Long [et al.] // Minerals. – 2024. – № 6. – Art. 571.

6. Innovative process for the extraction of 99.99% high-purity quartz from high-silicon iron ore tailings / H. Long [et al.] // Journal of Materials Research and Technology. – 2024. – P. 2094–2102.

7. Mudimbo, D. Hydrogeology of Zimbabwe / D. Mudimbo. – Harare: Geological Survey of Zimbabwe, 2018. – 245 p.

8. Extraction of Silicon from Silica Sand by Carbothermic Reduction in Mini DC-EAF / D. Tandersen, L. Müller, P. Schmidt [et al.] // E3S Web of Conferences. – 2024. – Vol. 543. – Art. 02006.

9. Research Status and Challenges of High-Purity Quartz Processing Technology from a Mineralogical Perspective in China / R. Zhang, W. Li, X. Chen [et al.] // Minerals. – 2023. – Vol. 13, № 12. – Art. 1505.

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EFFECTS OF DEAD-TIME IN DUAL ACTIVE BRIDGE

Machongwe T , Musiiwa P. B., Mutamba C. T., Makusha D. T., Kapuya E. T. , Musademba D.

Harare Institute of Technology, Harare, Zimbabwe

Abstract. The article explores the effect of dead-time in the operation of a Dual Active Bridge (DAB). DABs consist of high-speed switching devices (usually MOSFETS) as the main architecture component. The switches turn off and on at frequencies greater than 50 MHz. During this switching period, switches change from their low state to high state. If the fall time is greater than the time between switching changes, a short circuit is created leading to the damage of the switching devices. Therefore, it is very important to critically analyze the effect of dead-time during the design of the dual active bridge topology.

Keywords: dual active bridge, dead-time, bidirectional converters.

Address for correspondence: Peter B. Musiiwa, BE277 Belvedere Harare Zimbabwe
e-mail: pbmusiiwa@hit.ac.zw

Introduction. A dual active bridge is a commonly used topology in the development of dc-dc converters. It comprises two PWM controlled active primary and secondary full H-bridges, connected through a high-frequency transformer.

The primary function of the DAB is to facilitate controlled, bidirectional power flow between two DC sources or loads, such as a battery and a DC bus, while providing galvanic isolation. This makes it exceptionally suitable for applications like electric vehicle charging, renewable energy integration, solid-state transformers, and aerospace power systems. As can be observed from Figure 1, there are four power switches on each side of the high-frequency transformer, and the transformer provides isolation between the primary and secondary sides. Controlling the magnitude and direction of the phase shift between the four bridge arms, energy flows between the two DC power sources.

Dead time effect. The dead time effect is a phenomenon during the switching transition; this event is deliberately included during the switching phases in which both switches in a half bridge are commanded to be in the OFF state. The fundamental and most critical reason for implementing dead time is to prevent a condition known as shoot-through or cross-conduction. Another important reason for implementing the dead time phenomenon is its ability to create a safety margin. Hence it accounts for the non-ideal characteristics of real-world components. Shoot-through is a fault that occurs when both the high side and low side switches in a leg are turned ON simultaneously, even for a very short time [1, 2].This creates a low-impedance path directly from the DC supply rail to ground, resulting in a very high, destructive surge of current that can permanently damage the semiconductor switches. Effects of increasing deadtime Power Transfer Reduction: As