Implementation of Grover's Algorithm based on Quantum Reservoir Computing

Shivani Mehta
Department of ECE,
IIITDM Kancheepuram,
Chennai-600127, India.
ec22m2002@iiitdm.ac.in

Sajja Jyothikrishna
Department of ECE,
IIITDM Kancheepuram,
Chennai-600127, India.
ec21b1022@iiitdm.ac.in

V.Praveen Bhallamudi
Department of Physics,
IIITDM Kancheepuram,
Chennai-600036, India.
praveen.bhallamudi@iitm.ac.in

Sumanth Arige
Department of ECE,
IIITDM Kancheepuram,
Chennai-600127, India.
edm20d010@iiitdm.ac.in

Tejendra Dixit, $Member, IEEE$
Department of ECE,
IIITDM Kancheepuram,
Chennai-600127, India.
tdixit@iiitdm.ac.in

***Abstract*—Quantum computing represents the leading edge of computational technology, leveraging the principles of quantum mechanics to execute targeted computations much faster than classical computers. In contrast to classical bits, which are limited to representing either 0 or 1, qubits, or quantum bits, exhibit the extraordinary property of superposition. This distinctive characteristic enables qubits to simultaneously occupy multiple states, empowering quantum computers to explore numerous potential solutions to a problem concurrently. This feature makes quantum computing particularly potent for specific tasks. Recent research endeavors have been sparked by the potential of advanced quantum computing technology, leading to the creation of simulations of quantum computers using classical hardware. Grover's quantum search algorithm serves as a notable illustration of quantum computing application, enabling quantum computers to conduct a database search within an unsorted array with a quadratic speedup in time efficiency compared to classical computers. This document presents the quantum Grover search algorithm and its application through 5-qubit quantum circuits, as well as a design framework to simplify the creation of an oracle for a greater number of qubits.**

***Keywords*—Quantum computation, Qubits, Oracle, Grover's algorithm, IBM Qiskit.**

I. Introduction

The exploration of quantum computing [1][2] falls within the realm of quantum information science, which revolves around the fundamental principles of storing and manipulating information. In this work, we delved into quantum computing, acquiring a comprehensive understanding of quantum bits and their properties, as well as leveraging these properties to tackle problems. We familiarized ourselves with quantum gates and their operations on qubits, simulating all the funda mental quantum gates [3][4]. Additionally, we delved into the Grover search algorithm and implemented quantum gates for Grover operations. Quantum computers exhibit significantly faster speeds compared to classical computers [5][6]. In the case of an unsorted dataset with size N, classical computers usually demand O(N) operations, whereas Grover's algorithm accomplishes this task optimally in O($\sqrt{N}$) operations. We executed the algorithm using Qiskit, an IBM tool for com puting quantum circuits, and conducted simulations for the Grover algorithm [7], presenting the results graphically with the probability of obtaining the correct output.

Within Grover's quantum search algorithm, a network with n qubits harbors 2^n = N states, with each state bearing a probability of $1/N$ for discovery. Consequently, the amplitude of each state is $1/\sqrt{N}$. Conversely, classical systems tackling the same problem necessitate a maximum of O(N) trials.

II. Background and Methodology

The Grover search algorithm, conceived by Lov Grover in 1996, stands as a quantum computing method offering a quadratic acceleration compared to classical counterparts, particularly for solving unstructured search problems [8]. It has gained renown for its proficiency in searching through unsorted databases, but its utility extends to a spectrum of tasks, encompassing cryptographic problem-solving and quantum system simulation. This can speed up a search problem quadratically. For N number of unsorted data classical computer require O (N) operations Whereas Grover is optimal and can do this in O($\sqrt{N}$) operation. The following provides a synopsis of the workings of the Grover search algorithm [9]:

A. Initialisation

Commencing the process involves establishing a superposition of all conceivable states. For instance, when seeking an item in a database housing N item, quantum parallelism is harnessed to generate a superposition of all N states as shown in Fig.1. Achieving this involves a sequence of quantum gate operations.

B. Oracle Function

Grover's algorithm hinges on the application of an oracle function, often denoted as "U_f". This oracle acts to mark the target state(s) by inverting their sign. For instance, if the objective is to locate a specific item in a database, the oracle

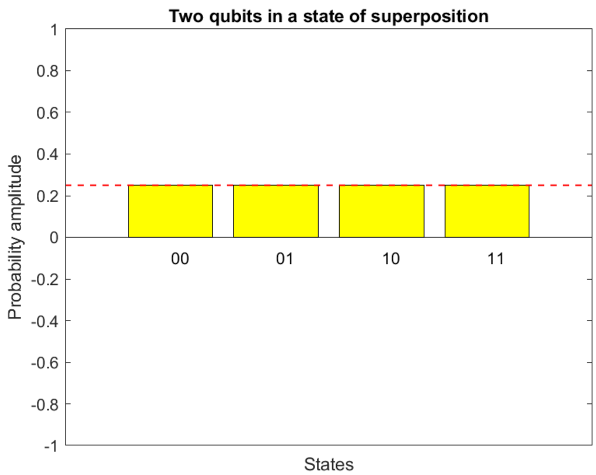

Fig. 1. Superposition of 2 qubits

would negate the amplitude corresponding to the target item. In Fig. 2, it is graphically shown the oracle function flipping the correct target.

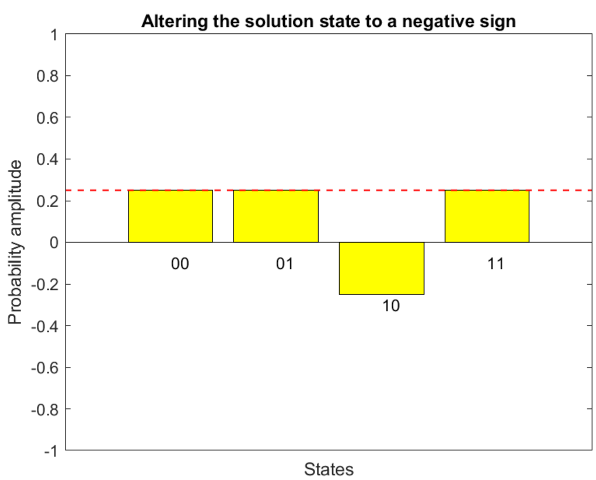

Fig. 2. Altering the sign of solution state(10)

C. Amplitude Amplification

The core of the Grover algorithm is the process of amplitude amplification, which entails two central maneuvers:

- **Inversion around the Mean**: During this stage, the amplitudes are mirrored around their average value, thus boosting the amplitude of the desired state(s) while reducing the amplitudes of the non-desired states.
- **Grover diffusion operator**: In this step, the amplitudes of the target state(s) are further augmented through the application of a suite of quantum gates [10].

After acting of Grover diffusion operator, the final output will have amplified magnitude as shown in Fig. 3.

D. Reiteration

Step. 2 and step. 3 are iterated approximately $\sqrt{N}$ times to maximize the likelihood of detecting the correct state. This number of iterations ensures that the probability of identifying the correct state approaches near certainty.

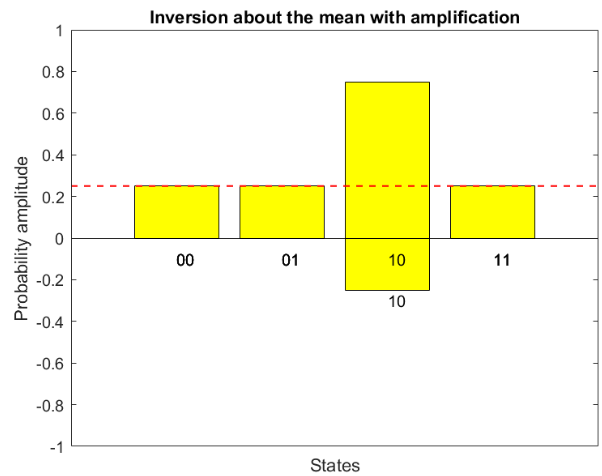

Fig. 3. Inversion about the mean with amplification.

E. Measurement

Ultimately, the quantum state is subjected to measurement. The target state is discerned with notably higher probability in comparison to the non-target state.

III. Conclusion

This study thoroughly investigated and modeled the Mott insulator V_2O_3, exploring its potential for ReRAM technology. The impact of various electrode configurations on device performance was carefully examined, identifying crucial areas for improvement crucial for successful integration. These results are pivotal for advancing the use of Mott materials in emerging memory technologies. The insights gained from this research are particularly valuable for developing a practical, physical model for future applications.

References

[1] T. N. Theis and P. M. Solomon, ”In Quest of the “Next Switch”: Prospects for Greatly Reduced Power Dissipation in a Successor to the Silicon Field-Effect Transistor,” in Proceedings of the IEEE, vol. 98, no. 12, pp. 2005-2014, Dec. 2010.

[2] Molas, G.; Nowak, E. ”Advances in Emerging Memory Technologies: From Data Storage to Artificial Intelligence,” Appl. Sci., vol. 11, no. 23, p. 1254, 2021.

[3] J. H. de Boer, and E. J. W Verwey, ”Semi-conductors with partially and with completely filled 3d-lattice bands,” Proceedings of the Physical Society, vol. 49 (4S), pp. 4S, Aug.1937.

[4] E. Janod, J. Tranchant, B. Corraze, M. Querré, P. Stoliar, M. Rozenberg, T. Cren et al. ”Resistive switching in Mott insulators and correlated systems,” Advanced Functional Materials, vol. 25, no. 40, pp. 6287-6305, Oct.2015.

[5] J. Hubbard, ”Electron correlations in narrow energy bands. II. The degenerate band case.” Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, vol. 277, no. 1369, pp. 237-259, Jan.1964.

[6] C. N. Berglund, ”Thermal filaments in vanadium dioxide,” in IEEE Transactions on Electron Devices, vol. 16, no. 5, pp. 432-437, May 1969.

[7] A. Ronchi et al., ”Light-Assisted Resistance Collapse in a V_2O_3-Based Mott-Insulator Device,” Phys. Rev. Appl., vol. 15, no. 4, pp. 044023, Apr. 2021.

[8] V. N. Andreev et al., ”Thermal conductivity of VO_2, V3O5, and V_2O_3,” physica status solidi (a), vol. 48, no. 2, pp. K153-K156, 1978.

[9] P. Stoliar et al., ”Universal electric-field-driven resistive transition in narrow-gap Mott insulators,” Adv. Mater., vol. 25, pp. 3222, 2013.

[10] S. Guénon et al., ”Electrical breakdown in a V_2O_3 device at the insulator-to-metal transition,” EPL (Europhysics Letters), vol. 101, pp. 57003, 2013.

[11] P. Homm et al., ”Collapse of the low temperature insulating state in Cr-doped V_2O_3 thin films,” Appl. Phys. Lett., vol. 107, pp. 111904, 2015.

[12] Y. Kalcheim et al., ”Non-thermal resistive switching in Mott insulator nanowires,” Nat. Commun., vol. 11, pp. 2985, 2020.

[13] M. M. Qazilbash et al., ”Electrodynamics of the vanadium oxides VO_2 and V_2O_3,” Phys. Rev. B, vol. 77, pp. 115121, 2008.

[14] P. Paweł, J. Jamroz, and T. K. Pietrzak, “Observation of metal–insulator transition (mit) in vanadium oxides V_2O_3 and VO_2 in xrd, dsc and dc experiments,” Crystals, 2023.

[15] P. Homm, M. Menghini, J. W. Seo, S. Peters, and J. P. Locquet, “Room temperature Mott metal–insulator transition in V_2O_3 compounds induced via strain-engineering,” APL Materials, vol. 9, no. 2, pp. 021116, Feb 2021.

[16] F. Mazzola, S. K. Chaluvadi, V. Polewczyk, D. Mondal, J. Fujii, P. Rajak, M. Islam, R. Ciancio, L. Barba, M. Fabrizio, G. Rossi, P. Orgiani, and I. Vobornik, “Disentangling structural and electronic properties in V_2O_3 thin films: A genuine non symmetry breaking mott transition,” Nano Letters, vol. 22, no. 14, pp. 5990–5996, 2022.

[17] H. Kizuka et al., “Temperature dependence of thermal conductivity of VO_2 thin films across metal–insulator transition,” Japanese Journal of Applied Physics, vol. 98, no. 053201, 2015.

[18] H. Y. Peng, L. Pu, J. C. Wu, D. Cha, J. H. Hong, W. N. Lin, Y. Y. Li, J. F. Ding, A. David, K. Li, and T. Wu, “Effects of electrode material and configuration on the characteristics of planar resistive switching devices,” APL Materials, vol. 1, no. 5, pp. 052106, Nov 2013.