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The Importance of Foundries: how technology development will help Testbeds

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1 Introduction

Quantum computing testbeds have started to demonstrate powerful benefits in scientific achievements. However, the hardware needs of these systems have extended beyond capabilities available at university facilities and thus more advanced quantum foundries are needed to support next generation testbed hardware and to allow access to quantum systems for research scientists. At Sandia National Laboratories we have a unique perspective on a critical piece of supporting technology for trapped ion quantum computing experiments, the surface-electrode ion trap. We have extensive experience in both using and fabricating surface ion-traps as part of the DOE Quantum Scientific Computing Open User Testbed (QSCOUT), but also from supporting the ion-trapping community at large. In this white-paper, we discuss the potential for an ion-trap foundry to develop technology and engage across the ion-trapping community, providing an important role in the future of ion-based quantum testbeds. While this is presented from the perspective of trapped-ion based testbeds, similar infrastructure would help other testbed technologies as well.

2 Build and inspire components for future systems

Ion-based testbeds require stable, reliable traps for maximum testbed uptime and best machine performance. In the future, as the systems scale, they will also need devices employing on-chip integrated technologies, such as integrated waveguides, photon detectors and passive and active electronics. While testbeds can drive trap requirements, building a surface-electrode ion trap and testing new features is time consuming, risky, expensive, and requires extensive expertise. At Sandia, a major component in large, well funded ion-trapping programs is often trap development and production. The pressure to quickly create traps to meet project milestones encourages small, low risk, trap improvements or hero-level integration where *maybe* one device from an entire batch is completely functional. These incremental improvements allow for changes with fewer risks, but slower overall development. Thus, to make progress quickly with integrating new technologies, we believe this activity should be done in collaboration with the testbeds, but as a standalone program. In a foundry, time and effort could be devoted solely to process integration allowing for the science to be developed separately from the ion-trap devices. This allows for technology to be incorporated into trap devices following a roadmap. Ultimately, as the technology matures it could be transferred from an R&D fab to a commercial foundry for fast turn around time design and production cycles and to meet the needs of private industry.

This stand-alone trap development also enables developing a solution to surface ion trap scaling using advanced heterogeneous integration techniques. As traps grow larger and more complicated, the fabrication time increases and yield decreases. In a device process flow relying on heterogeneous integration, the trap chip is just one component that gets integrated with a waveguide chip, a detector chip, an electronics chip, or even another trap, to create a final device which is more capable due to the sum of its individual components. This has yet to be demonstrated, but would allow for the complex components to be developed in parallel rather than serially and thus drastically reduce production time. The complex process of fabricating each sub-component might lead to independent co-development of the parts. The results of an uncoordinated endeavor could easily generate poorly matched or even incompatible pieces. Being simultaneously developed in the same foundry would allow for compatible co-design and for changes to be implemented across the entire platform, improving yield and functionality.

As testbeds, and ion-based quantum computers, grow and become more successful it is easy to forget the importance of this fundamental piece of hardware. The ion-trap needs to advance with the testbeds and a foundry would provide an excellent means for that development to occur in parallel with the growth of the testbed systems.

3 Supporting current technology

Another advantage offered by a dedicated foundry is producing sufficient state-of-the-art devices to meet the needs of research scientists which do not currently have access to high quality surface traps. Projects, such as the IARPA programs at Sandia have demonstrated this at a moderate scale. Large projects can fund trap production, but it can take months or years (depending on trap complexity) before new traps are ready, and production difficulties may lead to low trap numbers or delays in functional devices. This ready-made availability would benefit new testbeds as they are brought online and established testbeds that need replacement traps over time. Greater trap availability could also be a boon to small universities, startups and "quantum sandboxes". Such groups do not have the means to produce the high-quality traps required for making high-fidelity qubits but can offer collaboration and a means of increasing the workforce.

This style of support helps with the evolving needs of a testbed over time by keeping a variety of traps on hand. As demonstrated in current ion-trapping experiments, the required complexity depends on the number of qubits. Smaller systems can rely on simpler, easy to use devices, while larger systems will need an appropriately complex trap. A foundry should develop a variety of devices: small, easy, and fast to make devices; mid-scale, medium risk devices; and large, time consuming, expensive devices. Having a foundry supply these devices would increase the availability of a critical piece of infrastructure that supports the growth of the quantum community in parallel with the testbeds themselves.

4 Develop long-lasting collaborations

The ion trap community is notable in its collaborative and open approach to research. In past collaborative trap programs at Sandia, feedback on device performance and use was regular and, as a result, improvements were implemented across all relevant devices. A trap foundry should work on a similar, but expanded principle. By being open with sharing devices and how to use them, the collaborations could extend well past the testbeds themselves. Groups implementing a particular feature or trap function can work together to solve the problem universally. Improvements in ion trapping technology would benefit the entire ion trapping community, and not just quantum information experiments. Inclusion of non-quantum information researchers in the distribution of foundry traps would lead to faster device performance feedback, which in turn leads to more quickly improving trapping devices.

5 Conclusion

The current ion traps are ideal for trapping 10-50 ions, however, testbeds will soon need many more ions. A trap foundry allows for that technology to be developed in a healthy collaboration where all the experiences from trapped ion groups are combined to expedite trap improvements and innovation. Meanwhile, the foundry would maintain current traps in a ready-to-use state for testbeds and even other trapped ion groups. These facilities would develop the next generation technology before it needs to be integrated, reducing the likelihood of device failure and improving the speed and reliability of production. A trap foundry could focus entirely on an essential and complex piece of hardware for ion-based testbeds and push the capabilities of these devices to meet the needs of a universal quantum computer.