Physicists set guidelines for qubit candidates

May 4 2010, By Lisa Zyga

(PhysOrg.com) -- To build a quantum computer, it's essential to be able to quickly and efficiently manipulate the quantum states of qubits. The qubits, which are the basic unit of quantum information, can be composed of many different kinds of materials, although some work much better than others. With the goal of identifying which physical entities make the best qubits, a team of physicists from the University of California, Santa Barbara, has developed a list of characteristics and qualities that a material defect called deep centers should have in order to exhibit superior quantum mechanical properties.

“The qubits in a quantum computer must be able to retain the quantum information they are given long enough to perform quantum logic operations across them,” coauthor David Awschalom of UCSB told *PhysOrg.com*. “In general, this means that the qubits must not interact strongly with the other particles that make up their surroundings. However, if the qubits interact with their environment too weakly, you won’t able to controllably manipulate them in the first place. Therefore, it is important to find quantum systems that interact strongly with their environments in the ways we can control (so that we can manipulate them), but that don’t interact strongly in the other, more random ways that are not easily controllable (so that they don’t lose the information they are given). These kinds of quantum systems will make the best qubit candidates.”

During the past two decades, qubits have been implemented in a range of materials including atoms, liquids, and solids (such as semiconductors, superconductors, and insulators). However, a deep center defect in diamond called the nitrogen vacancy center has emerged as a leading qubit candidate due to its attractive quantum mechanical properties. Specifically, the defect enables high quality quantum entanglement at room temperature that persists for milliseconds. This means that the diamond defect's quantum state can be easily controlled and measured, making it a good candidate for a qubit.

"In many cases, a defect in a crystalline material (such as diamond) can cause a single quantum state to form that does not interact strongly with the surrounding atoms that make up the remainder of the material," Awschalom said. "This is the case for the nitrogen-vacancy (NV) center in diamond, which can retain the quantum information imparted to it for many milliseconds even at room temperature. In addition, the quantum state of the NV center in diamond can be easily controlled with a laser and microwave source, even though it does not interact strongly with the huge numbers of atoms that surround the defect. While the quantum states of most defects can not be controlled in the same way, the NV center owes these promising properties to its origin as a defect in diamond."

However, since growing and fabricating devices from diamond is difficult from an engineering perspective, finding a similar defect in another material is desirable. As the physicists explain, defects in a more technologically mature host material could allow for more sophisticated single- and multiqubit devices and innovations in device functionality.

In their study, the physicists based their criteria for qubit candidates on the diamond deep center defect, with the hope of finding defects with similar properties in other materials. The scientists explained that the diamond defect has two important features that distinguish it from other qubit systems. First, the defect is well isolated from possible sources of decoherence, enabling it to have long coherence times. Second, the defect's excited state manifold has a structure that allows it to be optically initialized and measured at room temperature, whereas many other solid state systems require cryogenic operating temperatures. The physicists identified several physical characteristics that a candidate defect should have in order to reproduce these two important features.

Finally, the scientists compared the diamond defects with deep center defects in another material, 4H silicon carbide. They noted that future work is needed to determine which other classes of deep centers follow the guidelines presented here, which could eventually lead to the qubits in tomorrow's quantum computers.

"We have several goals," Awschalom said. "For instance, we would like to identify other defects that can be used as qubits so that we can better understand what combination of material properties lead to the most robust and easily controllable defect qubits. In addition, we'd like to find defect qubits in other materials that can be more easily grown and fabricated than diamond. We are also hopeful that this research will lead us to discover defects with quantum properties that have useful applications beyond those of quantum computing."

More information: J.R. Weber, et al. "Quantum computing with defects." *PNAS*. To be published. Doi:10.1073/pnas.1003052107