A novel application of nuclear microprobe technology: the development of a single atom doping system

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In the near future devices which are fabricated from shallow arrays of few and single atoms will exploit quantum mechanical rules to perform useful functions including quantum computation. Fabrication of these devices presents formidable technological challenges. In this paper we review the development of a single ion implantation system that is capable of verifiable fabrication of single donor devices using 15 keV ^{31}P ions in silicon. Our technique is based on the technique of Ion Beam Induced Charge (IBIC) in which the charge transient from a single ion impact is used to signal the implantation of an ion into the substrate. We have used nuclear microscopy with 2 MeV He IBIC to measure the charge collection efficiency in the development of the detection system which consists of electrodes integrated into the substrate. The volume probed by the 2 MeV He ions is similar to the volume occupied by the charge drift following 15 keV ^{31}P impact. Two detector electrode architectures have been successfully implemented: one consists of a Metal Oxide Silicon (MOS) structure and the other is a PIN structure. In the design of these detector structures the Technology Computer Aided Design (TCAD) package was used to simulate the charge drift and diffusion following ion impact and was in accord with experiment. Devices have been fabricated with both 600 donor clusters and single donors which have been integrated with control electrodes and single electron transistors for state readout. In the cluster devices the signature of controlled single electron transfer events on the scale of sub-100 nm has been achieved opening the way to the construction of a revolutionary quantum computer in silicon.