3.B Picosecond Switching of a Multi-Kilovolt DC Bias with Laser Activated Silicon at Low Temperature

For the high speed switching described above, the Si wafer was biased with a 20 μsec HV pulse to avoid activation of the switch by thermal carrier excitation. This technology has recently been extended to include the switching of multi-kilovolt DC biases with Au-doped Si at cryogenic temperature[21].

Electro-optic devices working in the picosecond domain often require picosecond switching synchronism and excellent voltage amplitude stability. Signal averaging with a streak camera[22] is one example where amplitude fluctuations of less than 1% are required. This constraint precludes the use of pulse bias techniques in many cases because of the shot to shot voltage variation and the timing fluctuation between the laser and the high voltage bias pulse. An additional bonus with the DC switching at cryogenic temperature is the possibility of attaining kHz repetition rates.

Nearly intrinsic Si (20 k$\Omega \bullet$cm) as is used in pulsed bias room temperature switching devices was found to be an unacceptable switching element at liquid nitrogen temperature. At low voltage a ten-fold increase in resistivity was observed followed by a premature bulk dielectric breakdown that was monitored on a nanosecond time scale for an electric field strength of ~1000 V/cm. This behavior was consistently observed for 100 μm and 2mm gaps. For the 100 μm gap sample a Si disk with electrodes on opposite sides was used, eliminating the possibility of surface breakdown. An interpretation of these results is that at low temperature, the freezing out of phonon motions in pure Si increases the mean free path of the carriers so that the carrier kinetic energy can exceed the impact ionization energy even for small electric field strengths, leading to a dramatic reduction of the dielectric breakdown field strength from 300 kV/cm to 1 kV/cm.

To enhance the dielectric breakdown field strength at liquid nitrogen temperature we used Si doped with deep lying Au impurities to decrease the carrier mean free paths. Au impurities were selected because donor and acceptor levels are both close to the Fermi level, .16 eV and .035 eV respectively. At room temperature the sample resistivity was $> 3\text{k}\Omega \bullet$ cm. The Au concentration was estimated to be $10^{15}/\text{cm}^3$.

The current-voltage characteristics for a Au-doped Si switching element are displayed in Figure 18 for both room and liquid nitrogen temperatures. The gap size is 2mm. The resistivity is enhanced by several orders of magnitude upon cooling, putting the thermal runaway threshold in the kV range. We note that the low temperature dielectric breakdown field strength has been increased so that thermal effects limit voltage hold off capabilities as in room temperature switching devices.

The switching performance of a 2mm gap, Au-doped Si switching element at liquid nitrogen temperature was examined. Efficient switching was observed for applied voltages of up to 4 kV with optical turn on energies of ~50 μJ. Figure 19 shows a typical pulse generated by laser induced photoconductivity switching in Au-doped Si.

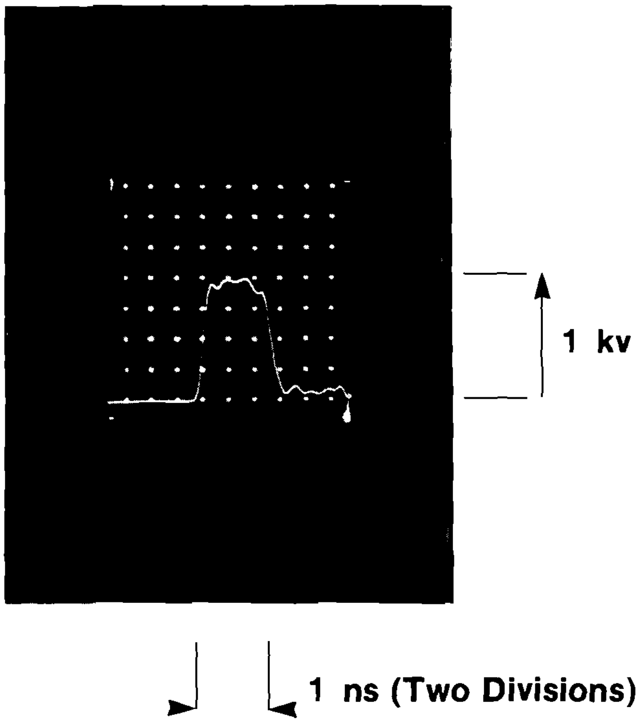

Figure 19 A typical voltage pulse generated by laser induced photoconductivity switching in Au-doped Si.