Measurement of Fermi Level Pinning at Si-SiO_2 Interfaces: Implications for TED in Spike Anneals

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INTRODUCTION

There is increasing evidence that surface proximity need to be incorporated into models for transient enhanced diffusion (TED) for ultrashallow junction formation in transistor devices. Recently this laboratory examined by simulations the possible effects of Fermi level pinning that can occur at a free Si surface (no oxide) or a damaged Si-oxide interface[1)]. Fundamentally, this pinning occurs in response to the presence of dangling bonds that introduce energy states into the surface bandgap. The simulations showed clear differences for the pinned and unpinned conditions. Pinning had the effect of deepening the junction significantly while at the same time inducing a pileup of dopant very close to the surface. The effects were traced to the fact that pinning transforms the surface into a reflector of charged interstitials (*i.e.*, no flux), even if the surface would otherwise serve as a good sink for these defects. That work also pointed out how the effective boundary condition for interstitials can be expected to vary with time during a typical spike anneal.

At the time, there was significant evidence for pinning on atomically clean Si(100) surfaces, but the status of Si-SiO_2 interfaces during the spike remained unclear. Only about 10^{12} defects/cm^{-2} are required for pinning, *i.e.*, a fractional surface coverage of 0.01 to 0.001. It is quite reasonable to expect rupture of roughly 1 to 0.1% of the interface bonds, corresponding to the fraction of bonds broken in the nearby bulk region. Thus it is plausible that the interface is pinned just after implant, but becomes unpinned at some point during the spike as the defects heal.

The present work uses the optical technique of photoreflectance to demonstrate experimentally that these effects indeed exist and to measure their kinetics.

EXPERIMENT

Photoreflectance (PR) is one of a class of modulation spectroscopies in which a semiconductor is periodically perturbed, and the resulting change in dielectric constant is detected by reflectance. Photoreflectance accomplishes the modulation with a chopped laser beam having $h\nu \geq E_g$, where E_g is the fundamental band-gap energy. Photogenerated minority carriers migrate to the surface and recombine with charge stored there. The resulting change in built-in surface field changes the surface reflectance R in narrow regions of wavelength corresponding to optical transitions of the substrate material. The normalized reflectance change $\Delta R/R$ exhibits a spectral dependence that is monitored with a separate probe that is much weaker than the perturbing light. The presence of a PR spectrum demonstrates unequivocally the existence of Fermi level pinning. The spectral amplitude scales linearly with the magnitude of built-in surface potential. Thus, we can deduce the pinning kinetics from the variation in amplitude. Our experimental setup is shown in Fig. 1, with a sample spectrum in Fig. 2. The optical system is coupled to a chamber equipped with a variable energy ion gun, which can be used for implant. A 1000W xenon arc lamp provide the capacity for rapid heating (~100°C/s).

RESULTS AND DISCUSSION

Our data indeed demonstrate the existence of substantial pinning just after implant with 500 eV ions. Healing begins to occur in the vicinity of 400°C – within the temperature stabilization step in which interstitial clusters form. We also show evidence that the surface may re-pin at higher temperatures. Water and/or residual oxygen initiates the growth of *Si* oxide, whose growth process has been shown to generate on the order of 10^{12} cm^{-2} interface states[2)]. In other words, although a fully annealed oxide yields an unpinned surface, a *growing* oxide may cause pinning.

1) M. Y. L. Jung, R. Gunawan, R. D. Braatz and E. G. Seebauer, *Rapid Thermal and Other Short-Time Processing Technologies II* (ECS Vol. 2000-9, 2000) 15.

2) A. T. Fiory, J. Zhang, P. Frisella, J. Hebb and A. Agarwal, “Corona Charge Evaluation of Thermal SiO_2 Growth by Single Wafer and Batch Methods,” *Rapid Thermal and Other Short-Time Processing Technologies II* (ECS Vol. 2000-9, 2000), 215.

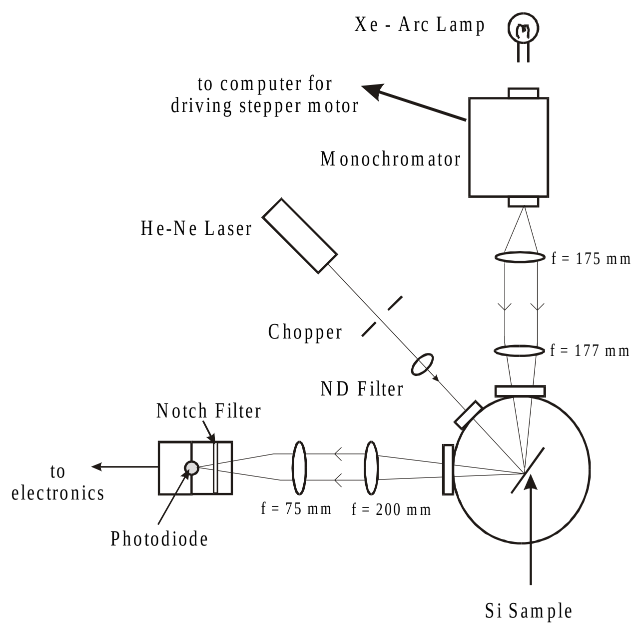

Fig. 1 – Schematic of photoreflectance setup.

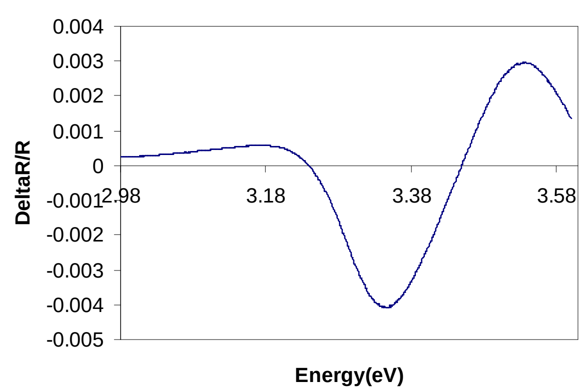

Fig. 2 – Sample PR spectrum taken in our laboratory from n-doped Si.