ELECTROLUMINESCENCE FROM SILICON TUNNEL DIODES INCORPORATING HIGH-κ DIELECTRICS

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Light emission from crystalline silicon is not strictly limited to the phonon-assisted radiative recombination at the 1.1 eV indirect band gap. Hot-carrier luminescence can produce light emission with a broad spectrum through direct, indirect, intra-band or band-to-band. radiative transitions.

Here we report on visible and near-infrared electroluminescence (EL) spectra and images obtained from metal-insulator-semiconductor (MIS) tunnel diodes during electron injection into crystalline Si. In addition to potential applications in silicon optoelectronics, such measurements also suggest a simple method to visualize current leakage in the gate dielectric of MOSFETs with ultra-thin gate dielectrics.

The MIS devices employed an indium-tin-oxide transparent top electrode. Tunnel barriers were formed by thermal oxidation to form SiO_2, oxidation of Al layers formed by thermal evaporation, reactive sputtering of Al_2O_3, or by metallorganic chemical vapor deposition of HfO_2 layers by liquid injection using tetrakis(diethylamido) hafnium and NO. Interfacial layers under the tunnel barriers were formed by thermal oxidation of the p-type Si(100) substrates or by inadvertent oxidation during the ITO or Al_2O_3 deposition.

Capacitance–voltage characteristics of a $HfO_2/SiO_2/Si$ capacitor with an area of 2.8×10^{-3} cm^2 are shown in Fig. 1. From the capacitance in accumulation the equivalent oxide thickness is 4.9 nm, comprising a 4.5 nm thick HfO_2 layer (estimated by ellipsometry during deposition) on a 4.2 nm SiO_2 layer formed at the interface during air exposure and ITO deposition.

In addition to EL at the Si band edge, we measure EL with low- and high-energy tails extending from 0.7 eV to 2.3 eV (1700 nm to 550 nm), as shown in Fig. 2. Within a mesa with ~100-µm diameter, the visible portion of the light emission appears to originate at multiple isolated sites, each less than 1 µm in size, as shown in Fig. 3.

We associate the EL sites with current concentration at thin or defective regions in the tunnel barrier. Similar isolated EL sites appear during forward-bias stress of devices using (1) Al-oxide over an interfacial SiO_2 layer, or (2) evaporated SiO_2 over thin thermal Si oxide. We have also used electron beam lithography to pattern thin tunnel regions that act as sites for EL in a ~18-nm thick SiO_2 layer, as shown in Fig. 4.

The origin and mechanism responsible for the luminescence will be discussed.

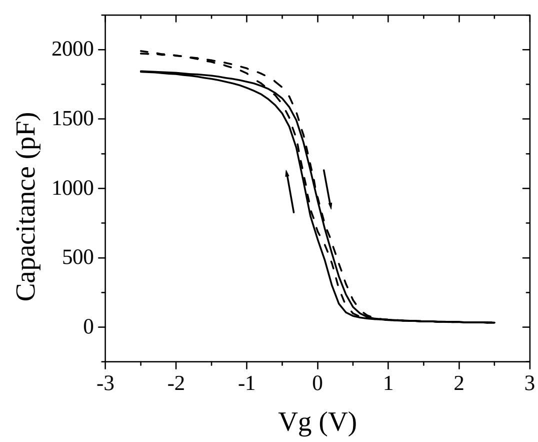

Fig. 1. Capacitance *vs.* potential at 10 kHz (---) and 100 kHz (—) for Hf oxide tunnel barrier with ITO gate.

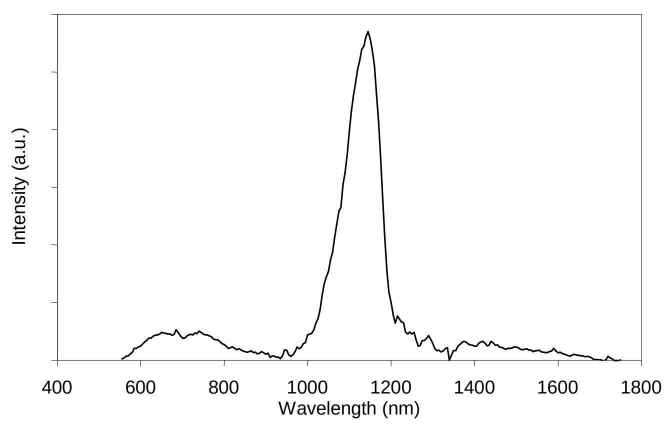

Fig. 2. EL spectrum of Si tunnel diode with Hf oxide tunnel barrier forward biased to 7 V and 90 mA.

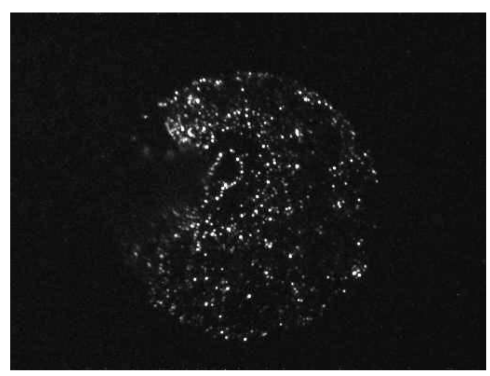

Fig. 3. CCD image of EL from a device with a Hf oxide tunnel barrier.

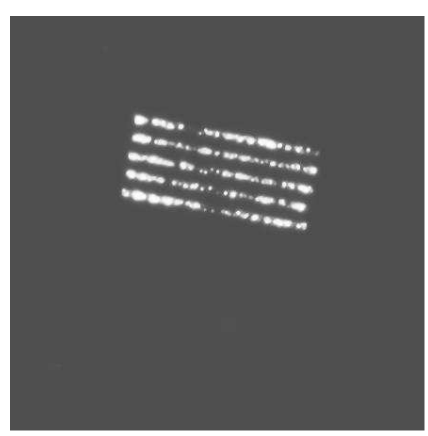

Fig. 4. CCD image of EL from a device with a SiO_2 barrier layer having 5 parallel 1-µm-wide tunnel regions patterned by electron beam lithography.