Bipolar conductivity in nanocrystallized TiO2
D. R. Islamov, V. A. Gritsenko, C. H. Cheng, and A. Chin

Citation: Appl. Phys. Lett. 101, 032101 (2012); doi: 10.1063/1.4737016
View online: http://dx.doi.org/10.1063/1.4737016
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v101/i3
Published by the American Institute of Physics.

Related Articles
Determination of graphene work function and graphene-insulator-semiconductor band alignment by internal photoemission spectroscopy

Increased dissipation from distributed etch holes in a lateral breathing mode silicon micromechanical resonator

Towards spin injection from silicon into topological insulators: Schottky barrier between Si and Bi2Se3

Effect of spin relaxation rate on the interfacial spin depolarization in ferromagnet/oxide/semiconductor contacts

Three-state resistive switching in CoFe2O4/Pb(Zr0.52Ti0.48)O3/ZnO heterostructure

Additional information on Appl. Phys. Lett.
Journal Homepage: http://apl.aip.org/
Journal Information: http://apl.aip.org/about/about_the_journal
Top downloads: http://apl.aip.org/features/most_downloaded
Information for Authors: http://apl.aip.org/authors
Bipolar conductivity in nanocrystallized TiO₂

D. R. Islamov, V. A. Gritsenko, C. H. Cheng, and A. Chin

A. V. Rzhanov Institute of Semiconductor Physics, Siberian Branch of Russian Academy of Sciences, Novosibirsk 630090, Russian Federation
Department of Mechatronic Technology, National Taiwan Normal University, Taipei 106, Taiwan
National Chiao Tung University, Hsinchu 300, Taiwan

(Received 22 April 2012; accepted 27 June 2012; published online 16 July 2012)

This study calculated the contribution of electrons and holes to TiO₂ conductivity in Si/TiO₂/Ni structures by conducting experiments on the injection of minority carriers from n- and p-type silicon. Results show that electrons and holes contribute to the conductivity of TiO₂, enabling two-band conductivity. © 2012 American Institute of Physics.[http://dx.doi.org/10.1063/1.4737016]

Universal memory in electronic devices must have the best properties of modern memory types. It must be as fast as random access memory (RAM), have an unlimited number of write cycles, and must be non-volatile, as in hard drives and flash and solid-state drive (SSD). A recently discovered resistive memory effect in high-k dielectric films provides the opportunity to create such types of universal memory for electronic devices. Because this resistive memory effect was discovered in films of TiO₂, this material may be used in the production of new memory chips in the future.

To obtain silicon devices with most optimal properties, it is crucial to comprehend charge transport mechanisms in dielectrics. The conductivity of dielectrics can be monopolar or bipolar. In other words, the charge carriers can be electrons or holes only, or electrons and holes simultaneously, i.e., the conductivity can be one-band or two-band. For example, the conductivity of metal-insulator-semiconductor (MIS) with thermal SiO₂ (Ref. 3) and the conductivity of Al₂O₃ (Ref. 4) are monopolar (electronic), whereas Si₃N₄ (Refs. 5 and 6) and ZrO₂ (Ref. 7) have bipolar conductivity.

Scientific literature presents theoretical models of charge transport mechanisms in titanium dioxide films, describing a resistive memory effect while considering only electrons as charge carriers. The authors considered the presence of electronic traps in reduced Ti ion centers or oxygen vacancies because of the weak Coulombic interaction. No researcher has yet attempted to evaluate the contribution of holes in the charge transport, neither theoretically nor experimentally. Therefore, this study determines the carriers charge sign in TiO₂ using experimental measurements of the injection of minority carriers from n- and p-type silicon in MIS structures.

Samples were cleaved from Si wafers with TiO₂ film, with a thickness of 150 Å. The TiO₂ films were deposited by physical vapor deposition (PVD) on p- and n-type Si substrates. Low post-deposition annealing (PDA) at 300°C was applied to prevent the growth of interfacial SiOₓ. Structural analysis shows that the resulting TiO₂ films underwent nanocrystallization. The TiO₂ capacitors fabricated at higher temperatures showed a poly-crystalline structure by x-ray diffraction (XRD) spectra and a very large leakage current via grain boundary conduction. The leakage current is greatly reduced by 6 orders of magnitude in a nanocrystallized TiO₂ material without grain boundary conduction. The samples for transport measurements were equipped with Ni gates of a square form of 1.1×1.1 mm² for electrical contact. The Si substrate was used as the ground contact. Current-voltage (I-V) measurements were taken at room temperature. A tungsten lamp was used for illumination.

Fig. 1 shows the energy band diagram of n-Si/TiO₂/Ni (a), (c), (e) and p-Si/TiO₂/Ni (b), (d), (f) structures in flat band mode (a), (b) and with applied bias voltage (c)–(f).

When a positive potential is applied to Ni contact for n-Si/TiO₂/Ni (Fig. 1(c)), the electronic system is in accumulation mode, and conductivity is provided by major carriers

\[ J_e \] and \[ J_h \] are flows of injected electrons/holes from Si into TiO₂,
\[ J_{e/} \] and \[ J_{h/} \] are flows of injected electrons/holes from the metal into TiO₂,
\[ J_{e/} \] and \[ J_{h/} \] are recombination flows of injected electrons/holes from TiO₂ into Si.

FIG. 1. Energy band diagram of n-Si/TiO₂/Ni (a) and p-Si/TiO₂/Ni (b) structures in flat band mode. The same diagrams in accumulation (c), (f) and deple-

a)Electronic mail: damir@isp.nsc.ru.
b)Electronic mail: grits@isp.nsc.ru.
c)Electronic mail: albert_achin@hotmail.com.

003-6951/2012/101(3)/032101/2/$30.00 101, 032101-1 © 2012 American Institute of Physics.
from the metal into TiO₂ and the current in dielectric is a flow of injected electrons. With a negative potential applied to Ni for injected from Si into TiO₂.

In conclusion, this study presents experiments on separating carrier signs in TiO₂ using n- and p-Si in non-equilibrium depletion mode. Results demonstrate that TiO₂ conductivity is two-band, similar to that in Si₃N₄, ZrO₂, and HfO₂. As in Si₃N₄ and HfO₂, the delocalized free electrons recombined with holes trapped at hole traps, and the free holes recombined with electrons localized on the electron traps in the bulk insulator (Fig. 4). The probability of recombining holes and electrons in the surface states on the Si/TiO₂ interface is negligible, similar to that which occurs in HfO₂, which also indicates that the major carriers current from the metal gate Jₑ is much less than the current of minority carriers Jₓ under illumination. The probability of recombination of injected from the insulator holes with electrons in the inversion layer is low, since the thickness of the inversion layer is less than the diffusion length of the holes. The flows of not recombined charge carriers are shown in the Fig. 4 by dashed arrows.

The new results must be considered in further investigations for the creation of more accurate models of transport mechanisms in titanium dioxide films to describe different effects, including the resistive memory effect.

This work was supported by project No. 5 of the Siberian Branch of the Russian Academy of Sciences and the National Science Council, Taiwan, under Grant No. NSC-100-2923-E-009-001-MY3.