Investigation of Transport Processes in Porous Silicon Light-Emitting Structures

Ph.D. THESIS

by
Kund Molnár

HAS Research Institute for Technical Physics and Materials Science (MTA MFA), Budapest, 2002

Related publications:

[K1] K. Molnár, T. Mohácsy, M. Ádám and I. Bársony, "Porous silicon light emitting diodes-mechanisms in the operation", Optical Materials, vol. 17, no. 1-2, pp. 111-116, June-July 2001.

[K2] K. Molnár, T. Mohácsy, P. Varga, É. Vázsonyi and I. Bársony, "Characterization of ITO/porous silicon LED stuctures", Journal of Luminescence, 80, pp. 91-97, 1999.

[K3] K. Molnár, T. Mohácsy, A. H. Abdulhadi, J. Volk, and I. Bársony, "On the nature of Metal-Porous Si-single crystal Silicon (MPS) diodes", Physica Status Solidi (a), vol. 1,2, no. 197, May 2003.

[K10] I. Bársony, K. Molnár, T. Mohácsy, E. Vázsonyi, M. Ádám, T. Lohner, "Porous silicon - promises and prospects", Hungarian - Korean Seminar on Integrated Circuits and Devices, Budapest, Hungary, June 24-26, 1997, pp. 229-238.

[K13] Dr. György Ferenczi foundation, 1998 Ferenczi prize.

Other publication:

K. Molnár, G. Rappitsch, Z. Huszka and E. Seebacher, "MOS varactor modeling with a subcircuit utilizing the BSIM3v3 model", IEEE Transactions on Electron Devices, vol. 49, no. 7, pp. 1206-1211, July 2002.

Abstract

After the discovery of strong visible room-temperature photoluminescence (PL) from porous silicon (PS) in 1990 the ultimate goal of research was to fabricate high quality PS light emitting diodes (LEDs) that can be integrated with silicon microelectronics. Although electroluminescence (EL) in PS has been demonstrated by a number of groups, there is lack of a generally accepted, consistent explanation of the mechanisms of carrier transport in PS and the conditions of light emission.

In this work metal/PS/c-Si type structures have been investigated: Ag/PS/c-Si MESA isolated structure on p-type substrate and ITO/PS/c-Si structure fabricated on anodized p-type and n-type Si substrates. The fabrication of the LED structures is described in detail. In the case of the ITO/PS/c-Si structure halogen lamps of different powers were used during the anodization process to illuminate the wafers. Light assistance was applied even in the case of the p-type wafers to facilitate the formation of smaller particles. The large gradient in the porosity is the result of the illumination.

The sample composition has been analyzed by Rutherford Backscattering Spectrometry. Thin PS layers have been characterized by spectroscopic ellipsometry. SEM and TEM micrographs have been taken on the fracture surfaces of thicker layers. The experimental setups of the electrical measurements are presented.

The effects of high temperature phosphorus doping of PS layers on the performance of the Ag/PS/c-Si MESA type PS LEDs have been investigated. It is shown that any additional doping step affecting the transition region from PS into the single crystal will have a detrimental effect on EL compared to the non diffused case.

The ITO/PS/c-Si structure has been characterized in vacuum by recording the current-voltage characteristics and the

simultaneous light emission at different temperatures. The dominating current carrying mechanism responsible for visible light emission in both substrate types has been identified to be Fowler-Nordheim tunneling. Equivalent circuits supported by the temperature dependence of the current-voltage characteristics and the frequency dependence of the capacitance-voltage characteristics are developed.

Stability and aging in air and vacuum were also investigated, and means for avoiding their detrimental effects in the experiments are suggested. Photosensitivity and the influence of adsorption of moisture are also discussed.

Review of new scientific results (Theses)

1. I fabricated Si based light-emitting diodes (LEDs) with solid-state contacts (Ag, Al and ITO) on different porous structures. I developed the Si-LED planar technology without lateral isolation of the porous diode (blanket) [K2, K4, K9] and with nitride isolation and the MESA etched nonplanar technology on p- and n-type Si substrates [K6, K7, K10, K11].

2. I developed a new method of adjusting the optimum porosity during anodization on p-type Si substrates (without post anodization treatment). The point is the none equilibrium increase of the majority hole concentration with intense illumination during electrochemical etching [K2, K4].

3. I showed that reliable electrical and optical characterization of unpassivated porous Si based LEDs is only possible by excluding the influence of the ambient. According to this finding I developed a device characterization method in controlled atmosphere (in vacuum cryostat) [K2, K4, K9].

4. In the case of the MESA type LED structures I proved experimentally that the change in the electroluminescence spectrum is due to recombination of injected majority carriers from the crystalline substrate in the opposite doping type region, which is created by diffusion [K6, K7, K10, K11].

5. I developed a characterization method of DC and AC electrical and optical behavior of porous Si based LEDs. The setup enables simultaneous temperature dependent recording of the electrical (admittance) and optical (intensity) parameters at different frequencies and bias points [K2].

6. I demonstrated in case of both substrate types that electroluminescence originates from Fowler-Nordheim type of current, which means the inclusion of low dimensional structures (1D quantum wire or 0D quantum dot) in the recombination process [K2, K4, K9, K13].

7. I proved that in porous Si LEDs before breakdown the reverse characteristics can be described similar to traditional p-n junctions.
In structures having different morphologies after breakdown ($V_R>V_{BR}$), in the case of n-type ($V_{BR}<10V$) Fowler-Nordheim current and light emission occurs. In the case of the p-type structures ($V_{BR}>30V$) $V_R<30V$ no light emission can be detected and the traditional reverse characteristics can be observed [K1, K3].

8. I determined the generally valid equivalent circuit of porous Si light emitting devices, which describes the electrical behavior of the LED both under forward and reverse operation in the case of both substrate types. The circuit consist of the substrate-porous Si heterojunction, in series the parallel connection of a nonlinear (F-N) and a linear (porous Si) resistance and the shunting resistance of the crystalline islands. Parameter extraction have been done using the DC characteristics recorded at different temperatures [K1, K3, K5].