Electrical Properties of Meso-Porous Silicon: from a surface effect to Coulomb Blockade and more

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Abstract: since the Volker Lehmann's paper "Resistivity of Porous Silicon: a surface effect" published in 1995 [1], a great deal of efforts has been produced in understanding the basic mechanisms ruling the electron transport in Si mesostructures and how these phenomena are affected by external environment. After more than 10 years, new experimental evidences and physical insights have been obtained, like gas sensitivity [2], chemisorption phenomena [3], Coulomb blockade [4] and glassy dynamics [5] at room temperature, but reading that former paper, the feeling of an extraordinary comprehension and intuition of the physical phenomena occurring in this fascinating material is continuously accompanying the reader.
A review of these major results in studying electronic transport in mesoporous silicon will be reported, starting from the still valid intuitions of Volker Lehmann in his paper.

In the first half of the '90s, the most studied porous silicon morphology was from high resistivity p-type wafers, because of the high luminescence efficiency. The Lehmann's paper on electrical properties of porous silicon from p+ doped wafers, addressed few unanswered crucial questions regarding resistivity, impurity role, carrier freeze out and surface conditioning proposing a microscopic model of transport in mesoPS, in analogy to submicron channels of CMOS devices, whose figures of telegraph noise are affected by single charge trapping at the oxide-semiconductor interface.
In 1999, the first report of strong interaction between mesoporous p+ silicon was announced in Strasbourg, EMRS by our group [2]. Volker Lehmann was chairman of that session, and he was sincerely interested in the electrical and infrared striking response of this material to nitrogen dioxide. While a technological CMOS compatible process was easily proposed in 2001 [6] for the front-side fabrication of a porous silicon NO_2 sensor, the origin of this high sensitivity, never reported before for any other gaseous or liquid species, was still unclear.

The successive years were so devoted to a fundamental study of mesoporous silicon in interaction with gas, by means of IR spectroscopy, ESR, NMR and ab-initio calculations [7] in order to understand the basic mechanisms at the origin of such an impressive optical and electrical response to nitrogen dioxide and the role of impurities and morphology in these phenomena [4,8].

Since the former paper of 1999 other groups contributed to study the phenomenon of NO_2 interaction with detailed papers on IR spectroscopy and Drude effect due to free carriers restored by nitrogen dioxide [9] and obtaining new records of sensitivity (15 ppb in dry air) [10].
Since 2005, our work continued focusing on electron transport phenomena in mesoPS in interaction with gas. Thanks to new experimental set-ups, new aspects of the complex phenomena were understood and demonstrated, like electrical anisotropy [11], and the presence of a conductivity threshold voltage ascribable to Coulomb blockade phenomena [4]. This threshold exhibits a direct correlation to temperature variation, giving us a clear evidence of the room temperature Coulomb blockade in porous silicon, a phenomenon predicted by Hamilton and coworkers in 2000 [12].
The surface effect proposed by Lehmann, is still compatible with the more recent model of a network of interconnected nanocrystals. In such a system, localised carriers are able to block sufficiently narrow conduction channels, giving origin to collective Coulomb blockade effects as theoretically predicted by theory [13] and typically observed in granular metallic films at low temperature.
The Lehmann's deep intuitions, after 13 years from his paper on these topics, and 2 years from his early departure, still hold true, and new areas of investigation are emerging also thanks to his first indications.

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