www.vbripress.com, www.amlett.com, DOI: 10.5185/amlett.2012.7002

Perspectives of fluorescent and cubic silicon carbide

Mikael Syväjärvi*

Linköping University, Department of Physics, Chemistry and Biology, Linköping 58131, Sweden

*Corresponding author. Tel: (+46) 1328-5708; Fax: (+46) 1314-9403; E-mail: mikael.syvajarvi@ifm.liu.se

Received: 02 June 2012 and Accepted: 03 June 2012

Author's Biography

Mikael Syväjärvi is Associate Professor at Linköping University, Sweden. He received his PhD in 1999 in materials science. As a founder of the Semiconductor Energy and Environmental Materials Initiative at the Department of Physics, Chemistry and Biology, his research interest is in new materials like silicon carbide, aluminium nitride and graphene. He has published more than 150 scientific peers reviewed journal papers, conference papers, book chapters and books related to material science. He is an inventor of the FSGP method, and a founder of Graphensic AB, a spin-off from the research at the university that produces graphene on silicon carbide.

Dear Editor,

The world of materials science is a fascinating dimension. Findings in materials which were first made many years ago may lead to new frontiers for energy technologies. In these days of increasingly urgent needs for environmental progress, it is a pleasure for a materials scientist to explore materials concepts with potential advances in energy and environmental, or even biomedical, engineering.

Already in 1907 it was observed that there could be light emission from an indirect bandgap material namely, carborundum which is an early name of silicon carbide [**1**]. This observation is referred to as the first report of a light emitting diode. Now more than 100 years after, the silicon carbide is revisited to make a rare earth metal free white LED for general lighting purpose from new insightful perspectives regarding materials synthesis and growth technology implementation [**2, 3**].

The first observation in 1907 was likely due to common impurities in silicon carbide which resulted in blue, red, green and yellow luminescence from various silicon carbide polytypes. The polytypes have the same chemical composition, but slight different atomic stacking sequences which causes different bandgaps and light emission with different colours in the visible region. The efficiency was low due to the mixture of polytypes, low material quality and lack in control of impurities which are known to appear in the Acheson process [**4**], the method used at that time to make silicon carbide for grinding and polishing purposes.

The crystal growth technologies developed with the Lely and modified Lely processes in 1955 and 1978 [**5, 6**], respectively, and the silicon carbide matured as material. Recently the Fast Sublimation Growth Process (FSGP) emerged as a method [**7**] to make thick *voluminous* layers needed for fluorescent silicon carbide by a photoluminescence mechanism. In fact, silicon carbide was revisited in 1970'ies as a promising light emitting material [**8-10**], but the use of electroluminescence in pn-junctions caused a carrier crowing which made carriers to find non-radiative recombination paths. In a recent revised view to explore the light properties, it was shown that photoluminescence can be used to make an efficient conversion into visible light using 6H-SiC [**11**]. Thereby the materials science research using common dopant materials nitrogen, boron and aluminum has the potential to make a pure white light emitting diode [**2**]. By a balance of donors and acceptors it is possible to control the ultraviolet to visible light conversion [**12**].

Even though the first report of silicon carbide as light emitting medium was made in 1907, the use of this material is an emerging research field which combines materials science and growth technologies, aligned with structural and optical characterization as well as modeling that further can clarify the fluorescent materials perspective.

Further on, the beautiful formation of polytypes creates surprises when the understanding in the silicon carbide materials steps forward. The common hexagonal polytypes of 6H-SiC and 4H-SiC have for some time been perspective to create better performance transistor type devices. Carrier lifetime is one of the key parameters governing the electronic and optoelectronic devices. The carrier lifetime in 4H-SiC has been intensively investigated in recent years. Although 4H-SiC exhibits the highest maturity among all polytypes, the carrier lifetime is still short. The typical lifetime in as-grown 4H-SiC is around 1 μs under the low injection level. In comparison, the 3C-SiC is metastable and does not form to the same extent as the hexagonal counterparts. Research in this polytype was initiated since 1990'ies. The common approach is to apply silicon as a substrate, and force the 3C-SiC to form on this using a CVD process even though the materials system is highly stressed due to the 20% lattice mismatch and 8% thermal mismatch. As a consequence, a high density of defects appears and the carrier lifetimes have been very modest. The values are ranging from a few to 120 nanoseconds. As an outcome, the 3C-SiC has been lagged behind the hexagonal polytypes.

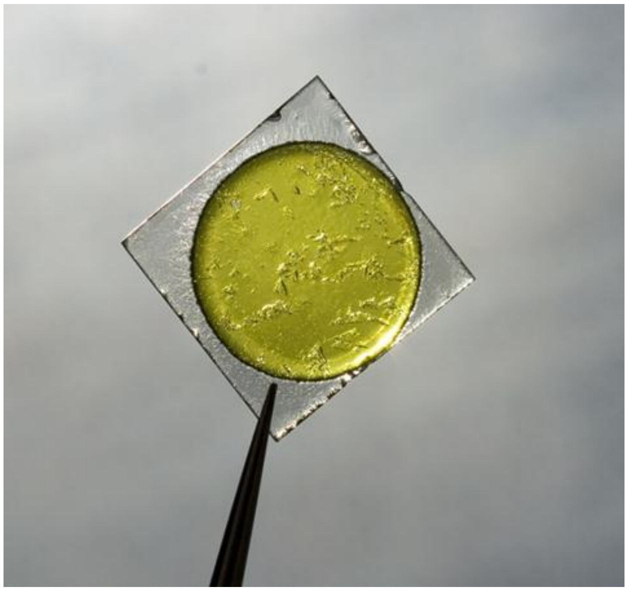

Fig. 1. Cubic silicon carbide formed on 6H-SiC substrate.

Strikingly, the cubic silicon carbide has now taken a leap forward. Very recently it was synthesized by a PVT process on 6H-SiC and with a very high growth rate of 1 mm per hour (**Fig. 1**). The lattice mismatch between 3C-SiC and 6H-SiC is below 0.1% and the thermal mismatch is substantially reduced. The result is a carrier lifetime of 8.2 μs [**12**], and surprisingly this is even higher than in 4H-SiC when comparing carrier lifetimes in as-grown materials. Intriguingly, this finding could pave the way for more efficient solar cells. According to theoretical predictions, solar cells from 3C-SiC using boron as a dopant should have efficiencies up to 48-60% [**13, 14**]. In view of the increasing research in graphene, this two-dimensional material could act as contact layer on solar cell silicon carbide. In perspective due to a lower bandgap than 6H-SiC, the 3C-SiC could be used as a broad band infrared LED using a similar co-doping concept (**Fig. 2**). Also, 3C-SiC has a potential for bioapplications. Many biomedical devices, especially devices meant for long-term use, require the need of materials that are both biocompatible and allow a sensing perspective. Most semiconductors have demonstrated *in vivo* toxicity (i.e. gallium arsenide) or have demonstrated *in vivo* chemical environmental reactivity (i.e. silicon and silicates). The 3C-SiC has a higher biocompatibility compared to silicon or other SiC polytypes [**15**].

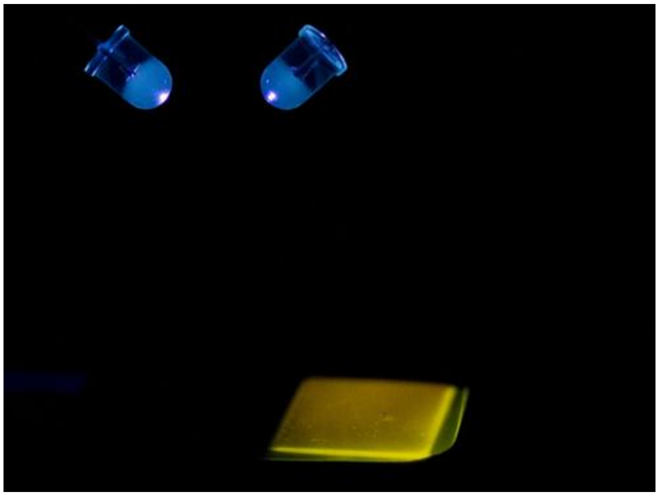

Fig. 2. Luminescence at room temperature from fluorescent silicon carbide excited by two weak UV-LEDs.

These examples of materials revisited in a new understanding are inspiring for materials scientists, and bring materials from being considered as classical materials to be advanced materials which can contribute to new engineering technologies. As we know from your journal, there are plenty of astounding materials from which we can appreciate the physics and nature with our profession.

With warm regards
Mikael Syväjärvi, PhD

Reference

1. Round, H.J., *Electrical World* **1907**, 49, 309.
2. Kamiyama, S., M. Iwaya, T. Takeuchi, I. Akasaki, M. Syväjärvi and R. Yakimova, *Journal of Semiconductors* **2011** 32, 13004.
3. Syväjärvi, M., et al, *Physica Scripta* **2012**, T148, 14002
4. Knippenberg, W.F., *Philips Research. Reports.* **1963**, 18, 161-274.
5. Lely, J.A., *Berichte der Deutschen Keramischen Gesellschafte*, 1955, *32*, 229-236.
6. Tairov, Yu.M. and V.F. Tsvetkov, *Journal of Crystal Growth*, 1978, 43, 209-212.
7. Syväjärvi, M. and R. Yakimova, Elsevier, *The Comprehensive Semiconductor Science & Technology Encyclopedia (SEST)*, Pallab Bhattacharya, Roberto Fornari and Hiroshi Kamimura (Eds), ISBN 978-0-444-53144-5, **2011**, 202-231.
8. Münch, W.v. W. Kürzinger, I. Pfaffeneder, *Solid-State Electronics* **1976**, 19, 871.
9. Hofmann, L., G. Ziegler, D. Theis, C. Weyhrich, *Journal of Applied Physics*, **1982**, 51, 6962.
10. Edmond, J., H. Kong, A. Suvorov, D. Waltz, C. Carter, Jr., *Physica Status Solidi (a)*, **1997**, 162, 481.
11. Kamiyama, S., et al, *Journal of Applied. Physics*, **2006**, 99 093108.
12. Sun, J.W., I. G. Ivanov, R. Liljedahl, P. Wellmann, R. Yakimova, and M. Syväjärvi, *Applied Physics Letters*, in press.
13. Beaucarne, G. et al, *Progress in Photovoltaic Research Applications*, **2002**, 10, 345.
14. Luque, A. and A. Martı´, *Physical Review Letters*, **1997**, 78, 5014.
15. Saddow, S.E., Silicon Carbide Biotechnology: A Biocompatible Semiconductor for Advanced Biomedical Devices and Applications, Elsevier Science (2011), ISBN-10: 0123859069.