Oral presentations for Session 3.4.1 | Thursday, 27 October | Room 3611

Session Chair:
Kin Man YU (City University of Hong Kong, Hong Kong)
Fen LIN (SERIS, Singapore)

3.4.1a Invited Talk (11:00 – 11:15)
Prof Masafumi Yamaguchi
Toyota Technological Institute, Japan

R&D Activities of Super High Efficiency III-V Multi-Junction and Concentrator Solar Cells in Japan

M. YAMAGUCHI[1], K. ARAKI1,2, T. TAKAMOTO[3]
[1] Toyota Technological Institute, Japan
[2] Daido Steel Co., Japan
[3] Sharp Co., Japan

Abstract
The photovoltaic (PV) solar energy conversion is expected to become the major clean energy source because further installation of nuclear energy in the world is presumed to be very difficult as a result of the most recent crisis of the Fukushima nuclear power plant in Japan. We will have to contribute to creation of clean energy society for the future by using solar energy. The concentrator PV have great potential for very large-scale integration of PV as well as high performance crystalline Si PV.

This paper summarizes fundamental physics of high-efficiency III-V compound semiconductor and multi-junction (MJ) solar cells and their key technologies for realizing higher efficiency. This paper also reviews Japanese research activities for III-V MJ and concentrator solar cells. Concentrator 4-junction or 5-junction solar cells have great potential for realizing super high efficiencies of over 50%. Lattice-mismatched and III-V-N are thought to be promising materials for realizing more than 50% efficiency. Improvement in the 1-sun efficiency of triple-junction solar cells is also possible. Recently, high efficiency (37.9%) at 1-sun (AM1.5G) has been realized with inverted epitaxially-grown InGaP/GaAs/InGaAs 3-junction cells by Sharp. 44.4% efficiency has also been demonstrated with InGaP/GaAs/InGaAs 3-junction solar cells by Sharp under the Europe-Japan Collaborative Project on Concentrator PV (NGCPV Project). Major results attained under the NGCPV Project are also presented. It is clear that Japanese group has greatly contributed to development of high efficiency cells.

III-V/Si tandem solar cells have also great potential of high efficiency and low cost. We will also have to contribute to creation of mobility society by using solar energy throughout further development of high-efficiency, low-cost and highly reliable PV.

Biography
Prof. Masafumi Yamaguchi was born in Hokkaido, Japan and received the Ph.D. degrees from Hokkaido University, Sapporo, Japan in 1978.

He is presently a Distinguished Professor and the Director of the Research Center for Smart Energy Technology at the Toyota Technological Institute, Nagoya, Japan. He is leading Japanese National PV Programs as the Supervisor of the “Creative Clean Energy Generation using Solar Energy” of the Japan Science and Technology Agency (JST).

Dr. Yamaguchi has received several awards such as the Becquerel Prize from the European Commission in 2004, the William Cherry Award from the IEEE in 2008, the WCPEC Award in 2014 for his outstanding contributions to the development of science and technology of photovoltaics such as high-efficiency multi-junction solar cells, space solar cells, concentrator solar cells and as one of the world leaders of the development of photovoltaics and as one of the driving forces for international co-operation

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3.4.1b (11:15 – 11:30)
Prof Alexandre Freundlich
University of Houston, USA

Record Performance 1-1.2 eV III-V Dilute Nitride Solar Cells for Tandem Applications

A. FREUNDLICH[1], W. WANG[1], G. K. VIJAYA[1] et al.
[1] University of Houston, USA

Abstract
Here we report on the development of 1 to 1.2 eV III-V dilute nitride solar cells with open circuit voltages approaching the radiative limit (Woc= Eg-Voc~0.4 eV). These results were made possible by combining (i) a carefully designed quantum engineered dilute nitride absorber design (that alleviates minority carrier lifetime/ poor carrier collection issues encountered in bulk dilute nitrides) with (ii) a somewhat unique optimization of the growth sequence (and plasma N nitrogen delivery system modification) that enabled superior interface sharpness control and improved optoelectronic properties. An extrapolation of experimental data indicates a clear pathway toward extending the multi-junction solar cell efficiencies toward 50%.

Biography
Alexandre (Alex) Freundlich is a Research Professor of Physics with a joint appointment in the Electrical and Computer Engineering Department at the University of Houston and is the Associate Director for Research to University's Center for Advanced Materials. Alex holds 7 issued US patents in the area of high efficiency Photovoltaics. Four of his patents are actively licensed to the industry. He has authored/co-authored over 250 technical papers and over 300 conference presentations (>50 invited/plenary talks). Alex is also a dedicated mentor and during his career has trained and advised many graduate students (44) and post doctoral researchers (15), many of whom have grown to become leading experts in academia and the private sector.

3.4.1c (11:30 – 11:45)
Mr Zekun Ren
Singapore-MIT Alliance for Research and Technology (SMART), Singapore

Performance Potential Analysis of a 21.3% GaAs on Industrial c-Si Tandem Solar Cell

Z. REN[1], N. SAHRAEI[1], Z. LIU[1] et al.
[1] Singapore-MIT Alliance for Research and Technology (SMART), Singapore

Abstract
We present a methodology to optimize performance of photovoltaic tandem devices based on industrial silicon bottom cells via iterative modeling, fabrication, and characterization. We reduce this methodology to practice, improving the efficiency of a mechanically stacked gallium-arsenide-on-silicon four-terminal tandem solar cell to 21.3±1% (uncertified) under standard testing conditions. This efficiency is greater than those of either stand-alone sub-cell. We apply the modeling framework to calculate the performance potential of this approach, suggesting the possibility of a device efficiency of 33.3% for GaAs-on-Si, and 35.8% for optimal bandgap III-V on silicon (assuming top cell is 0.9 of SQ limit). Moreover, comparing state of the art performance of GaAs and InGaP, we find that GaAs currently offers the higher efficiency potential and energy yield in a 4T tandem with silicon under one-sun conditions.

Biography
Zekun is a research engineer from Singapore MIT Alliance for research and technology. His research mainly focuses on troubleshooting obstacles on III-V/Si integration and understanding the operating mechanism for III-V/Si tandem including photon recycling and luminescent coupling effect.

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3.4.1d (11:45 – 12:00)
Mr Maung Thway
Solar Energy Research Institute of Singapore (SERIS), Singapore

Performance Study of Bottom Silicon Solar Cells in Tandem Configuration under Filtered-Light with Different Injection Levels

M. THWAY[1], N. SAHRAEI[2], Z. REN[2] et al.
[1] Solar Energy Research Institute of Singapore (SERIS), Singapore
[2] Singapore-MIT Alliance for Research and Technology (SMART), Singapore

Abstract
Solar cells often operate under various light intensities. Low intensities often occur during outdoor operation. In a tandem solar cell, the bottom cell receives light filtered by the top cell. This reduces the total light intensity additionally by a factor of two or more. The performance under low intensity is, hence, of great significance for tandem cell operation. We have studied commercially available Si solar cells under low intensities and spectrally filtered light. In all measurement conditions, short circuit current changes linearly with the total light intensity. However, under filtered spectrum, when the cut-off wavelength for the long-pass filter increases, the slope for the short circuit current vs. photon flux curve decreases. It was found that such change in the slope is not only the effect of non-ideal quantum efficiency of the solar cells, but also largely related to the changes in the generation profile under the filtered spectrum.

Biography
Maung Thway received the B.E. degree in electrical engineering from National University of Singapore, Singapore, in 2015. Thway is currently working toward the Ph.D. degree in electrical engineering at NUS under the guidance of Professor Armin Aberle. His research interests include III-V/Si tandem solar cell, top GaAs cell and bottom cell characterization, fabrication and integration.

3.4.1e (12:00 – 12:15)
Dr Kevin Nay Yaung
Singapore-MIT Alliance for Research and Technology (SMART), Singapore

Enabling High Efficiency GaAsP Solar Cells on GaP/Si Through Dislocation Engineering

K. NAY YAUNG[1], M. VAISMAN[2], M. LEE[3]
[1] Singapore-MIT Alliance for Research and Technology (SMART), Singapore
[2] Yale University, USA
[3] University of Illinois, Urbana

Abstract
GaAsP on Si tandem cells can theoretically exceed the Shockley-Queisser limit of single-junction Si, potentially enabling high-efficiency, low-cost photovoltaics. However, high dislocation densities in GaAsP cells on Si have hampered the efficiency of such approaches. In this work, we report GaAsP solar cells on GaP/Si with threading dislocation densities that are comparable to more established metamorphic solar cells on GaAs. Our GaAsP solar cells on GaP/Si significantly surpass the power conversion efficiency of previous devices and show a realistic path towards dual-junction GaAsP on Si cells with efficiencies exceeding 30%.

Biography
Graduated from Yale with a PhD in 2016 and won the best student presentation award at PVSC 2014.

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3.4.1f (12:15 – 12:30)

Dr Takeyoshi Sugaya
National Institute of Advanced Industrial Science and Technology (AIST), Japan

The Role of Substrate Miscut on the Properties of InGaP Solar Cells Grown on GaAs(001) by Solid Source Molecular Beam Epitaxy

R. OSHIMA[1], T. SUGAYA[1], Y. NAGATO[2] et al.
[1] National Institute of Advanced Industrial Science and Technology (AIST), Japan
[2] Tokyo City University, Japan

Abstract
We studied the role of the substrate miscut on the properties of lattice-matched InGaP solar cells, which were grown on GaAs(001) by solid source molecular beam epitaxy. The bandgaps (Eg) of alloys grown on the substrates miscut toward (111)A were found to be wider than those of alloys grown on the exact substrate. A larger Eg leads to an enhanced open-circuit voltage (VOC). Conversely, Eg became narrower with an increasing the miscut angle for alloys grown on substrates miscut toward (111)B. Furthermore, both WOC (= Eg/q -VOC) and the fill factor parameter were improved from 0.59 V and 79.1% respectively for the cell grown on the exact substrate to 0.58 V and 86.1% for the cell grown on the substrate miscut 2 degrees toward (111)B. This improvement is possibly due to the enhancement of single variant atomic ordering.

Biography
Takeyoshi Sugaya received the B.E., M.E. and Ph.D. degrees from Tsukuba University, Tsukuba, Japan, in 1989, 1991 and 1994, respectively. In 1994, he joined the Electrotechnical Laboratory, and was been working on MBE growth and quantum devices of compound semiconductors. He was a visiting researcher at the Arizona State University during 2000 – 2001 working on electron transport in quantum nano-structures. Currently, he is conducting research on the fabrication of quantum nano-structures and their application to next generation solar cell devices at Research Center for Photovoltaics, National Institute of Advance Industrial Science and Technology (AIST). Dr. Sugaya is a Member of the Japan Society of Applied Physics and the Institute of electronics, Information and Communication Engineers (IEICE).