SANCHIT KHATAVKAR

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EDUCATION:

- **Doctor of Philosophy**: *Solar Photovoltaics*,
  Indian Institute of Technology Bombay; *Mumbai, India**;** 2018*
  Department of Electrical Engineering (CPI: 8.07/10)

- **Master of Science:** *Opto-Electronics*,
  Auburn University; Auburn, AL, USA*; 2004*
  Department of Electrical and Mechanical Engineering

- Bachelor of Engineering,
  Vishwakarma Institute of Technology, University of Pune, India; 2000
  Department of Mechanical Engineering

- Higher Secondary School Certificate (H.S.C.),
  L. Apte Junior College, Pune, India; 1996

- Secondary School Certificate (S.S.C.*),*
  D.E. Society's E.M.S.S, Pune, India; 1994

Ph.D. Thesis:

Topic – "*Electrical and Optical Characterization of silicon heterojunction solar cells*"

Funding – Indo-US collaborative project named *"SERIIUS"*
Guides – Prof. B. M. Arora and Prof. P. R. Nair
RPC committee – Prof. Juzer Vasi, Prof. K. L. Narasimhan and Prof. Anil Kotantharayil

WORK EXPERIENCE:

2019 – Present National Centre for Photovoltaic Education and Research (NCPRE), IIT Bombay
Research Associate II

- Lead state-of-the-art research in luminescence based solar module degradation.

2017 – 2018 Sanjivani College of Engineering, Kopargaon, Maharashtra
Associate Professor

- Teach Bachelor level courses in a way that will suit the needs of students from rural backgrounds.
- Contributing to the development of the institution.

2011 – 2017 National Centre for Photovoltaic Education and Research (NCPRE), IIT Bombay
Senior Research Associate

- Organized and co-ordinated weekly research status meetings where process flows were reviewed.
- Designed and implemented laboratory experiments for teachers across the country through the "Teach 1000 Teachers" program of NCPRE.
- Represented NCPRE at national / international conferences.
- Conducted lab tours for visitors and students.
- Trained students as well as professors from different engineering colleges on certain solar cell characterization tools.

2010 – 2011 Indian Institute of Science, Bangalore
Project Associate

- Modeling and Simulation of optical waveguides for nanoscale sensing.
- Use of FDTD Simulation softwares like MEEP and Rsoft.

2006 – 2010 The Valley School, *KFI*, Bangalore
Teacher and Computer lab in-charge

- Studied Waldorf pedagogy and evolved a Physics curriculum in accordance with the ISC exam board for junior college.
- Teaching students from urban backgrounds.
- Setup and maintain a LAN of 6 to 10 computers.

2004 – 2005 Parametric Technology Corporation, Pune
Software Engineer II (ECAD)

- Investigate, debug, log and track defects in application software with Java front-end and Oracle backend.
- Develop, publish, and implement test plans and cases.
- Organize periodic review and testing of all test result documentation, upgrade processes, and installation process.
- Install and configure all software components and related third party products on various server platforms.

2001 – 2004 Photonic Materials Research Lab, Auburn University, AL
Graduate Research Assistant

- Perform experiments using various dye and gas lasers, FTIR and PL spectroscopy.

- Study conductivity of various conductive polymers and suggest a suitable application based on the study.

SKILLS - post Bachelor's Degree:

Technical Experience

- Precise luminescence based characterization.
- Accurate current – voltage and capacitance – voltage measurements on different setups.
- Precise measurements of solar cell characteristics of 6-inch Industrial grade solar cells.
- Spectroscopic Measurements like DLTS, FTIR and UV-VIS-NIR.
- Experience with thin film deposition techniques like HWCVD and metal evaporation.
- Acquainted with steady state and transient simulations for solar cell structures.

Administrative Experience

- *Lab In-Charge* (2016-2017): NCPRE Characterization lab, IIT Bombay
- *Coordinator* (2011-2017): Weekly research updates meetings of Silicon group of NCPRE
- *Technical Report Writer* (2013-2017): Indo-US Funded project SERIIUS
- *Team member* (2011-2013): Setup of solar energy research facilities in the institute, right from scratch
- *System Owner* (2011- 2017): Various characterization tools like Solar Simulators, UV-VIS-NIR spectrometer and Four probe Tool
- *Vice-President* (2002-2003): Graduate Student Council, Auburn University, USA
- *Cultural Secretary*(2001-2002): Indian Student Association, Auburn University, USA
- *Member* (2002-2003): Traffic Appeals Board, Auburn University, USA

PUBLICATION LIST:

Journals -

- **S. Khatavkar** et al., "Measurement of relaxation time of excess carriers in Si and CIGS solar cells by modulated electroluminescence technique", *Phys. Status Solidi A*, vol. 215, no. 2, January 2018 (DOI:10.1002/pssa.201700267).

- R. Chavali, **S. Khatavkar** et al., "Multi-Probe Characterization of Inversion Charge for Self-consistent Parameterization of HIT™ Cells", *IEEE J. Photovoltaics*, vol. 5, no. 3, pp. 725–735, May 2015 (DOI: 10.1109/JPHOTOV.2014.2388072).

- **S. Khatavkar** et al., "Spatial resolution capabilities of the modulated electroluminescence technique for lifetime mapping of silicon solar cells", *Manuscript under preparation*.

- M. Thakur, **S. Khatavkar** et al., "Polyalloocimene, a Novel Nonconjugated Conductive Polymer: The Correct Fundamental Basis for Conductive Polymers", *Journal of Macromolecular Science*, 2003 *(DOI: 10.1081/MA-120025318)*.

International Conferences -

- **S. Khatavkar** et al., "Deep Level Transient Spectroscopy of silicon heterojunction cells", *44th IEEE Photovoltaic Specialists Conference (PVSC)*, 2017.

- **S. Khatavkar** et al., "Temperature dependent IV characteristics to explore the effect of back surface passivation in Si based heterojunction solar cells", *18th International Workshop on Physics of Semiconductor Devices (IWPSD)*, December 2015.

- N. Chatterji, **S. Khatavkar** et al., "A Critical Analysis on the Role of Back Surface Passivation for a-Si/c-Si Heterojunction Solar Cells", *40th IEEE Photovoltaic Specialists Conference (PVSC)*, 2014, pp. 2456–2458.

- **S. Khatavkar** et al., "Modulated Electroluminescence Technique for Determination of the Minority Carrier Lifetime of Solar Cells", *39th IEEE Photovoltaic Specialists Conference (PVSC)*, 2013, pp. 631–634.

- N. Shiradkar, A. Khan, **S. Khatavkar** et al., "Investigation of anomalous behavior of p-aSi:H/ncSi heterojunction solar cell", *XVIth International Workshop on Physics of Semiconductor Devices (IWPSD)*, December 2011.

AWARDS & HONOURS:

1. Invited as **Judge** for the MSBTE sponsored "*State Level Technical Paper Presentation Competition*" at Sanjivani K.B.P. Polytechnic, Kopargaon, Maharashtra.
2. Recipient of "***Excellence Award***" while working with Parametric Technology Corporation, Pune.

TEACHING PREFERENCES:

Semester 1:

ENR122 - Renewable energy resource characteristics

NRE165 – Introduction to Sustainable Development

Semester 2:

ENR 151 – Solar technologies

ENR 159 – Applied Numerical methods

Semester 3:

ENR 145 – Solar Photovoltaic Power Generation

ENR 147 – Solar Thermal Power Generation

RESEARCH AREAS:

I intend to work on the following research areas, given an opportunity.

a) Grid balancing of solar power plants.

b) Optimization of solar power plant control functions.

c) Development of data model that integrates the various hardware data of a smart grid system.

d) Mitigation of net metering challenges.

e) Dust mitigation of field mounted solar panels.

Dr. Sanchit Khatavkar

Attachments : **First Pages of Publications –**

1)

Measurement of Relaxation Time of Excess Carriers in Si and CIGS Solar Cells by Modulated Electroluminescence Technique

Sanchit Khatavkar, Kulasekaran Muniappan, Chinna V. Kannan, Vijay Kumar, Krishnamachari L. Narsimhan, Pradeep R. Nair, Juzer M. Vasi, Miguel A. Contreras, Maikel F. A. M. van Hest, and Brij M. Arora**

Excess carrier lifetime plays a crucial role in determining the efficiency of solar cells. In this paper, we use the frequency dependence of inphase and quadrature components of modulated electroluminescence (MEL) to measure the relaxation time (decay) of excess carriers. The advantage of the MEL technique is that the relaxation time is obtained directly from the angular frequency at which the quadrature component peaks. It does not need knowledge of the material parameters like mobility, etc., and can be used for any finished solar cells which have detectable light emission. The experiment is easy to perform with standard electrical equipment. For silicon solar cells, the relaxation time is dominated by recombination and hence, the relaxation time is indeed the excess carrier lifetime. In contrast, for the CIGS solar cells investigated here, the relaxation time is dominated by trapping and emission from shallow minority carrier traps.

1. Introduction

There has been a great improvement in solar cell efficiency in recent times. A record efficiency of 26.3% has been achieved in large area hydrogenated amorphous silicon-crystalline silicon heterojunction (Si-HJ) solar cells and further advance is expected.[1] Similarly, high efficiency (close to 25%) p–n junction mono-crystalline silicon cells of large area have been reported.[2] Among the thin film solar cells, $CuIn_{1-x}Ga_xSe_2$ (CIGS) solar cells have exceeded the previous record efficiency of 21.7%.[3,4] There is all-around improvement in the performance parameters of these high efficiency solar cells. The most significant improvement is in the open circuit voltage (V_{OC}) reaching to about 750 mV in Si-HJ solar cells.[1] V_{OC} is closely connected to the effective lifetime (τ_{eff}) of minority carriers, which in turn depends on the quality of bulk base region as well as on the structure and quality of the front and back interfaces. For Si-HJ cells, the improvement in V_{OC} is largely attributed to the processes involving preparation of the crystalline silicon surface and passivation by deposition of thin layers of intrinsic and doped hydrogenated amorphous silicon. It is fairly common to keep track of τ_{eff} at all stages in the fabrication of crystalline silicon-based solar cells for monitoring the process steps. The technique most widely used during these stages is based on contactless quasi steady-state photoconductance (QSSPC) measurement.[5] However, QSSPC cannot be used for finished solar cells. The large conductance of the metallic contacts is in parallel with the sample and dominates the conductance obscuring the QSSPC signal. However, an alternative method, known as Suns-V_{OC}, has been used widely to measure the carrier lifetime in finished silicon solar cells.[6]

Traditionally, the lifetime of excess carriers in most of the semiconductors has been measured by using transient photoluminescence (TRPL) decay.[7] Trupke et al.[8] and Fuyuki et al.[9] used luminescence imaging to map the spatial distribution of parameters such as diffusion length and lifetime. In this measurement, the excitation is generally constant in time (dc) and the required information is obtained from the luminescence intensity. Apart from these, measurements based on modulated excitation-based techniques such as modulated photoluminescence (MPL) have been widely used after the work of Bruggemann et al.,[10] Trupke et al.,[11] and Giesecke et al.[12] With acexcitation, the advantage is that lock-in amplifier based instrumentation can be used to separate the inphase and quadrature components as well as enhance the sensitivity of detecting weak luminescence. Sun et al.[13] incorporated ac lock-in technique in luminescence imaging to enhance the sensitivity of these measurements. Both optical and electrical excitations

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DOI: 10.1002/pssa.201700267

2)

Multiprobe Characterization of Inversion Charge for Self-Consistent Parameterization of HIT Cells

Raghu Vamsi Krishna Chavali, *Student Member, IEEE*, Sanchit Khatavkar, C. V. Kannan, Vijay Kumar, Pradeep R. Nair, *Member, IEEE*, Jeffery Lynn Gray, *Senior Member, IEEE*, and Muhammad Ashraful Alam, *Fellow, IEEE*

***Abstract*—The performance of modern a-Si/c-Si heterojunction (HIT) solar cells is dictated by a complex interplay of multiple device parameters. A single characterization experiment [e.g., light current–voltage (*I–V*)] can be fitted with a set of parameters, but this set may not be unique and is, therefore, questionable as the basis for future design/optimization. In this paper, we use multiple (quasi-orthogonal) measurement techniques to uniquely identify the key parameters that dictate the performance of HIT cells. First, we study the frequency, voltage, and temperature response of inversion charge (Q_{Inv}) to create the theoretical basis for characterization of key device parameters, namely, the thickness of the i-layer at the front interface (t^i_{a-Si}), a-Si/c-Si heterojunction valence band discontinuity (ΔE_V), built-in potentials in a-Si (ϕ_{a-Si}) and c-Si (ϕ_{c-Si}) regions, etc. Next, we *simulate* various characterization measurements, such as capacitance–voltage (*C–V*) and impedance spectroscopy, which probe Q_{Inv} and explain the parameter extraction procedure from these measurements. Subsequently, we use the algorithm/procedure just developed to extract the aforementioned parameters for an industrial-grade HIT sample. Finally, we extend this quasi-orthogonal characterization framework by correlating the *C–V* characteristics with the ubiquitous light and dark *I–V* characteristics to demonstrate the consistency of the developed theory and uniqueness of the parameter extracted. The unique parameter set thus obtained can simultaneously provide a basis for the interpretation of the experimental measurements and can also be used for the design/optimization of these solar cells.**

***Index Terms*—Amorphous semiconductors, capacitance–voltage (*C–V*) characteristics, current–voltage (*I–V*) characteristics, heterojunctions, process control, silicon.**

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R. V. K. Chavali, J. L. Gray, and M. A. Alam are with the School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN 47907 USA (e-mail: c.raghuvamsi@gmail.com; grayj@ecn.purdue.edu; alam@purdue.edu).

S. Khatavkar and P. R. Nair are with the School of Electrical Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India (e-mail: ksanchit10@gmail.com; prnair@ee.iitb.ac.in).

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Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

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I. Introduction

THE COMBINATION of process conditions, material properties, and device geometry that lead to a champion Si heterojunction solar cell remains an enigma and has been a topic of intense research over the last two decades. A physics-based characterization of key parameters that influence the performance of these solar cells is a prerequisite toward resolving this puzzle. It is generally understood that the performance gap between the champion and typical HIT cells [schematic of HIT cell in Fig. 1(a)] can ultimately be traced back to five process-specific parameters [see Fig. 1(b)]: thickness of the i-layer at the front interface (t^i_{a-Si}), a-Si/c-Si heterojunction valence band discontinuity (ΔE_V), interface defect densities (N_{IT}), and built-in potentials in a-Si (ϕ_{a-Si}) and c-Si (ϕ_{c-Si}) regions. It is important to evaluate these parameters individually, because each parameter is controlled by different processing steps, and the failure to optimize them individually would lead to loss of cell efficiency. For example, the deposition time of the a-Si layers controls the p^+ a-Si layer thickness (t^p_{a-Si}; see Fig. 1) and the intrinsic a-Si layer thickness t^i_{a-Si} [1]–[3]. One could control ΔE_V and N_{IT} of the sample by precise control over the a-Si deposition temperature and pressure [4]–[7]. The relative composition of the deposition mixture impacts the achievable emitter doping (N_A) and the deposition conditions and choice of thin conductive oxide (TCO) determines the front contact work function (ψ_c). Both these device parameters (N_A and ψ_c) in turn influence the ϕ_{a-Si} [7]–[9]. Hence, an independent characterization of these key parameters is crucial for process optimization for these solar cells.

It is well known that the classical analysis based on light *I–V* can be used to establish the influence of the parameters. However, unique identification of each of these key parameters exclusively from light *I–V* characteristics may not be possible. Fig. 1(c) shows three sets of light *I–V* characteristics simulated for different t^i_{a-Si}, ΔE_V, and ϕ_{a-Si} (ϕ_{a-Si} is varied by changing N_A). These simulations illustrate that all these parameters influence the light *I–V* characteristics in a similar way, i.e., that they all affect the FF. Hence, it is impossible to use only the light *I–V* characteristics to uniquely identify the influence of each of these individual parameters.

There have been a number of efforts to correlate the light *I–V* and dark *I–V* characteristics as an approach to separate the influence of some of these parameters [10], [11]; however, a unique extraction of these parameters is not achieved. Other characterization approaches, such as *C–V* [12]–[15] and impedance spectroscopy [16], [17] produce complementary information;

3)

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Polyalloocimene, a Novel Nonconjugated Conductive Polymer: The Correct Fundamental Basis for Conductive Polymers

M. Thakur,* S. Khatavkar, and E. J. Parish

Photonic Materials Research Laboratory, College of Engineering and Engineering Experiment Station, Auburn University, Alabama, USA

ABSTRACT

A polymer does not have to be conjugated to become electrically conductive. The correct fundamental basis for a polymer to be conductive is that it must have at least one double bond in the repeat. The magnitude of conductivity increases with the number fraction of the double bonds in the repeat. Polyisoprene, the first known nonconjugated conductive polymer has a double bond number fraction of 1/4 while polyacetylene, the first known conjugated conductive polymer, has a number fraction of 1/2. A new nonconjugated conductive polymer, polyalloocimene, has a double bond number fraction of about 1/3. Consequently, the electrical conductivity, the doping rate and the optical transition energies of polyalloocimene are intermediate between those of polyisoprene and polyacetylene. The magnitude of conductivity has a power law dependence on the number-fraction of double bonds. The optical absorption peak of the radical cation produced upon doping appears at lower energies as the separation between the double bonds decreases. The general mechanism of conductivity going from a nonconjugated structure involving isolated double bonds to a fully conjugated structure has been established.

Key Words: Nonconjugated conductive polymer; Polyalloocimene; Dopant; Radical cation.

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4)

Deep level transient spectroscopy measurements of silicon heterojunction cells

Sanchit Khatavkar[1], C. V. Kannan[2], Vijay Kumar[2], P. R. Nair[1], and B. M. Arora[1]

[1]Dept. of Electrical Engineering, IIT Bombay, Mumbai India; [2]Moser Baer Photovoltaic Pvt. Ltd., Greater Noida, U.P.-201306, India;

***Abstract*— Excellent open circuit voltage (V_{oc})reported by Si Heterojunction (Si-HJ) solar cells has been a topic of considerable interest among the PV community. One of the reasons attributed to this large V_{oc} is the reduction of interface recombination due to the presence of an inversion layer at a-Si:H/cSi interface. Here, we employ deep level transient spectroscopy (DLTS) measurements of silicon heterojunction cells (Si-HJ) to probe process induced interface traps at the a-Si:H/cSi interface. Interestingly, contrary to literature reports, we find both majority and minority peaks in differently processed Si-HJ solar cells – a result which could have interesting implications towards performance optimization.**

***Index Terms* — silicon heterojunction cells, rate window, polarity of DLTS, solar cell processing.**

I. Introduction

Silicon heterojunction cells (Si-HJ) have the potential to achieve high efficiency, which has been amply demonstrated by Panasonic[1]. The main attraction in these cells is the high open circuit voltage (V_{oc}), with Panasonic demonstrating a value of 750mV[1]. A lot of work has gone into finding out the reason for this high V_{oc} and all of the groups attribute this to the low recombination rate between hydrogenated amorphous silicon (a-Si:H) and crystalline silicon (c-Si) [2]–[4]. After the existence of an inversion layer at this heterointerface was proven by Maslova et al.[5], the reason for low recombination rate at the interface was found out to be the repulsion of majority carriers due to this inversion layer. Jian Li et al.[3] has done deep level transient spectroscopy (DLTS) of Si-HJ solar cells and has shown that the DLTS peaks are due to the inversion charge at the heterointerface. The potential of DLTS technique to understand this phenomenon has been harnessed in this work, where DLTS results of four Si-HJ cells having differences in processing conditions are reported and it is interesting to note how the differences in processing lead to difference in DLTS signatures.

II. Experimental

The silicon heterojunction cells investigated in this work were fabricated from CZ n-type monocrystalline silicon substrates of resistivity of about 4 Ω-cm. After the saw damage removal, wafers were textured, and surfaces were passivated. This was followed by deposition of about 3-5 nm i-layer a-Si:H on both sides and subsequent 6-12 nm of p layer a-Si:H deposition on the front side and about 50 nm n-layer a-Si:H on the back side by PECVD for solar cells of Type (A). 100 nm thick TCO layers were then deposited on both, the front and the back sides, followed by the deposition of front silver contact grid and a large area back aluminium contact. For solar cells of Type (B), the sequence of depostion was the same but for two differences, a) the thicknesses of the amorphous layers, viz. 8nm for i-layer a-Si:H, 8nm for p-layer a-Si:H and 24nm n-layer a-Si:H at the backside and b) back contact is screen printed silver.

Deep level transient spectroscopy measurements were done using SULA Technologies DLTS setup. The solar cells were cleeved to an area of ~ 1.5mm² so that the capacitance is less than 1nF, the measurement limit of the SULA setup. A capacitance voltage sweep was performed for each sample prior to the DLTS experiment and the expected C-V behaviour was seen. The DLTS measurements were conducted at a quiescent voltage of -2V and pulse voltage height of 2V, in other words, the solar cells were pulsed from reverse bias to zero bias. The filling pulse width was kept at 300μs and period was 5ms. The DLTS Spectra were taken at rate window values of 0.02ms, 0.05ms, 0.1ms, 0.2ms and 1ms. The temperature was varied from 77K to 350K.

III. Polarity Of DLTS Peaks

The solar cells used for DLTS measurements are of n-type substrate, so the inversion layer will contain holes, which are the minority carriers in the solar cells. It is well known that the interface of a-Si:H/cSi heterojunctions contain traps. The steady state electron occupany of traps is given by Eq. 1.[6]

$$n_T = \frac{c_n n}{c_n n + c_p p} N_T \tag{1}$$

where N_T is trap density, n is number of electrons in conduction band of the semiconductor, p is the number of holes in the valence band of the semiconductor, c_n is the capture coefficient of electrons and c_p is the capture coefficient of holes.

If we assume $c_p \gg c_n$ and $p \approx n$, then most traps will be occupied by holes. At t=0, the traps are neutral with $n_T \approx 0$ and space charge region density $N_{scr} = N_D$, the background doping density. When the device is pulsed from zero to negative bias in a DLTS experiment, minority holes are emitted from the traps, the charge of the traps changes from

5)

Modulated electroluminescence technique for determination of the minority carrier lifetime of solar cells

[1]Sanchit Khatavkar, [1]Kulasekaran M, [2]C V Kannan, [2]Vijay Kumar, [1]Pradeep Nair and [1]B M Arora

[1]Indian Institute of Technology, Powai, Mumbai-400076, India;

[2]Moser Baer Photovoltaic Pvt.Ltd., Greater Noida, U.P.–201306, India

***Abstract* — It is well known that the performance of Heterojunction with Intrinsic Thin Layer (HIT) solar cells depends critically on the quality of hetero-interfaces between the bulk crystalline silicon (c-Si) and intrinsic hydrogenated amorphous silicon (a-Si:H). There has been evolutionary improvement in the open circuit voltage (Voc) of HIT cells over the years primarily due to the improvements in the life time of carriers lost due to recombination at the interfaces. In this work, we present modulated electroluminescence as an alternative technique to determine the effective lifetime of carriers in HIT solar cells.**

***Index Terms* — modulated electroluminescence, effective lifetime, open circuit voltage, emission intensity, Suns-Voc.**

I. Introduction

HIT solar cells are of great interest due to their potential of reaching the Shockley-Queisser limit [1]. Conversion efficiency of 24.7% on area 101.8 cm^2 has already been demonstrated by Panasonic [2]. It is well known that the overall performance of these cells depends critically on the quality of heterojunction interfaces between the bulk crystalline silicon and intrinsic hydrogenated amorphous silicon. Effective lifetime of the excess carriers generated by light excitation is an important metric to characterize the interfaces and thus get an idea about the parameters restricting the performance of the solar cell.

Luminescence techniques are finding increasing use in the area of photovoltaic materials and devices [3] because of the high sensitivity of emission to radiative and non-radiative recombination. Time resolved photoluminescence and modulated photoluminescence techniques have been used to obtain lifetimes directly in solar cells [4, 5]. Photoluminescence (PL) as well as Electroluminescence (EL) imaging has been commonly used for selection of high quality wafers (PL), process optimization (PL) and defect diagnostics in the finished high efficiency silicon solar cells (EL) [6].

In this work we explore the frequency dependence of modulated electroluminescence (MEL) for the characterization of solar cells, in particular, its effective lifetime or the minority carrier lifetime. Results are applied to the study of n type a-Si:H/c-Si heterojunction (HIT) solar cells fabricated at Moser Baer Photovoltaic Pvt.Ltd.

II. Experimental

HIT cells investigated in this work were fabricated from CZ n type monocrystalline silicon substrates of resistivity of about 4 Ω- cm. After the saw damage removal, wafers were textured, and surfaces were passivated. This was followed by deposition of about 3-5 nm i- layer a-Si:H on both sides and subsequent 6-12 nm p layer a-Si:H deposition on the front side and about 50 nm n layer a-Si:H on the back side by PECVD. Deposition of about 100 nm thick TCO layers on both, the front and the back sides, followed by the deposition of front and back contacts completes the device fabrication.

Dark and lighted current-voltage characteristics of the devices were measured by using Sun 3000 Solar Simulator of ABET Technologies.

Spectral response of the EL is measured by using a 750 mm focal length Acton monochromator, fitted with a 600 g/mm grating blazed at 1 μm and liquid nitrogen cooled 1024x1Indium Gallium Arsenide (InGaAs) detector array. The spectral response of both the grating as well as the photodetector was relatively flat over the wavelength range of the measurements, which is 0.95 μm to 1.3 μm

Modulated electroluminescence (MEL) was measured by using the set up shown in Fig. 1. The excitation frequency was varied over the range 100 Hz to 10000 Hz using a signal generator.

The integrated electroluminescence from the devices has been measured using a 6 inch diameter Labsphere integrating sphere fitted with a Judson Germanium (Ge) photodiode. The Ge diode was terminated with a 50 ohm resistance to measure the inphase and quadrature components of EL emission using a Stanford Research Instruments lock-in amplifier. The frequency response of the measurement system was tested by using a Roithner 1060 nm infrared LED. The frequency response of the LED was flat over the range of frequencies used in the present experiments. Both the magnitude and the phase of the EL signal of the HIT solar cell was frequency dependent in this frequency range.