

# Thursday Afternoon, November 1, 2012

## Electronic Materials and Processing

Room: 14 - Session EM+TF+AS-ThA

### Growth and Characterization of Group III-Nitride Materials

Moderator: N. Dietz, Georgia State University

2:00pm **EM+TF+AS-ThA1 AIN-based Technology for Deep UV and High-power Applications**, Z. Sitar, HexaTech, Inc. & North Carolina State University, B. Moody, S. Craft, R. Schlessler, R. Dalmau, J. Xie, S. Mita, HexaTech, Inc., T. Rice, J. Tweedy, J. LeBeau, L. Hussey, R. Collazo, B. Gaddy, D. Irving, North Carolina State University **INVITED**

For the first time in history of III-nitrides, the availability of low defect density ( $<10^3 \text{ cm}^{-2}$ ) native AlN substrates offers an opportunity for growth of AlGaIn alloys and device layers that exhibit million-fold lower defect densities than the incumbent technologies and enable one to assess and control optical end electrical properties in absence of extended defects. Epitaxial AlN wafers are fabricated from AlN boules grown by physical vapor transport at temperatures between 2200 and 2300°C. Gradual crystal expansion is achieved through a scalable, iterative re-growth process in which the high crystal quality is maintained over many generations of boules. Despite the excellent crystal quality, below bandgap optical absorption bands in the blue/UV range affect the UV transparency of wafers. We use density functional theory (DFT) to develop a model to understand the interplay of point defects responsible for this absorption. We show a direct dependence of the mid-gap absorption band with the carbon concentration within the AlN. Low defect density AlN and AlGaIn epitaxial films are grown upon these wafers that exhibit superior optical properties in terms of emission efficiency and line width and can be doped with an efficiency that is several orders of magnitude higher than possible in technologies using non-native substrates. UV LED structures and Schottky diodes were fabricated on these materials that exhibit low turn-on voltages and breakdown fields greater than 10 MV/cm. This presentation will review state-of-the-art of AlN-based technology and give examples of potential applications in future devices and contrast these with other wide bandgap technologies.

2:40pm **EM+TF+AS-ThA3 Atomic Layer Deposition of AlN Thin Films as Gate Dielectrics for Wide Bandgap Semiconductors**, Y.-C. Perng, J.P. Chang, D. Chien, University of California at Los Angeles

Aluminum nitride (AlN) is a potential dielectric layer for wide bandgap semiconductor based power electronic devices, such as those demanded in radio frequency, high-speed and high-temperature communication, because of its wide bandgap and high dielectric constant. In particular, for 4H-SiC, AlN is also a promising interfacial layer due to their similar atomic arrangement, small lattice mismatch (1.3%) and comparable thermal expansion coefficients. Although various deposition techniques have been investigated to synthesize AlN thin films with atomic controllability over a large substrate remains a challenge. Atomic layer deposition (ALD) was thus used in this work to grow AlN thin films.

AlN deposition was performed in an ultra-high vacuum chamber with base pressure of  $10^{-7}$  Torr using trimethylaluminum (TMA) and ammonia (NH<sub>3</sub>) as precursors. It was discovered that ALD of AlN is possible only when the minute amount of moisture in NH<sub>3</sub>, which competed with and inhibited the nitride growth, was completely eliminated. The ALD window was found to be 500-570°C with a growth rate of 1.5 Å/cycle. The deposited film composition was evaluated via *in-situ* x-ray photoelectron spectroscopy (XPS) with Al/N determined to be 1.2. *In-situ* reflective high-energy electron diffraction (RHEED) measurements showed as-deposited AlN films were crystalline, which was confirmed by x-ray diffraction (XRD). AlN/4H-SiC MIS capacitors were fabricated to examine the electrical properties with the dielectric constant of AlN determined to be 8.3 and a leakage current density of  $10^{-3} \text{ A/cm}^2$  at 4.3 MV/cm. The 150 Å ALD AlN passivated AlGaIn/GaN hetero-structure demonstrated 11% increase in the carrier density and 3% decrease in mobility compared to those of non-passivated hetero-structure as  $8.3 \times 10^{12} \text{ cm}^{-2}$  and  $1100 \text{ cm}^2/\text{V-s}$ . While with amorphous 150 Å Al<sub>2</sub>O<sub>3</sub> surface passivation, the mobility decrease by 22% with carrier density increase by 12%, showing that the crystalline AlN providing a superior property on passivating the hetero-structure.

3:00pm **EM+TF+AS-ThA4 Low-Temperature Behavior of the Surface Photovoltage in p-type GaN**, J.D. McNamara, M. Foussekis, A.A. Baski, M.A. Reshchikov, Virginia Commonwealth University

The effect of low temperature on the surface photovoltage (SPV) in semiconductors is rarely studied and not well understood. We studied the

SPV behavior for Mg-doped, p-type GaN using a Kelvin probe at temperatures from 80 to 300 K. Under band-to-band UV illumination at room temperature, the measured SPV signal in p-type GaN becomes negative as electrons are swept to the surface. However, we observed that at low temperatures, the SPV signal becomes positive under UV illumination, contrary to the SPV behavior of p-type GaN at room temperature. This positive SPV resembles the behavior of an n-type semiconductor. We assume that under UV illumination and at low temperatures, the conductivity of Mg-doped GaN does indeed convert from p- to n-type. This conversion was predicted from photoluminescence studies on Zn-doped GaN.<sup>[1]</sup> At low temperatures, photo-generated electrons may accumulate in the conduction band which causes an upward shift in the bulk Fermi level towards the conduction band. This results in a positive SPV signal, since the Kelvin probe uses the bulk Fermi level as a reference for the measured SPV signal. Interestingly, the characteristic temperature at which we observe this transition from p- to n-type behavior depends on illumination intensity. As the excitation intensity increases from  $10^{15}$  to  $10^{17} \text{ cm}^{-2} \text{ s}^{-1}$ , the characteristic temperature increases from 130 to 170 K. This result also agrees with previously reported photoluminescence data and further authenticates the above assumption.<sup>[1]</sup>

[1] M. A. Reshchikov, A. Kvasov, T. McMullen, M. F. Bishop, A. Usikov, V. Soukhoveev, and V. A. Dmitriev, Phys. Rev. B **84**, 075212 (2011).

3:40pm **EM+TF+AS-ThA6 Controlling GaN Polarity on GaN Substrates**, J.K. Hite, M.E. Twigg, J.A. Freitas, Jr., M.A. Mastro, J.R. Meyer, I. Vurgaftman, S. O'Connor, N.J. Condon, F.J. Kub, S.R. Bowman, C.R. Eddy, Jr., U.S. Naval Research Laboratory

Gallium nitride is a high quality semiconductor widely used in both optical and electronic devices. The polarity of GaN (+/- c-direction) influences many properties of the resultant material, including chemical reactivity and electric field in these 'piezoelectric' materials. Control over the polarity of GaN grown on sapphire and SiC substrates has been previously demonstrated by controlling the growth conditions, doping levels, and buffer or nucleation layer properties. Further, in the case of heavily doped p-type layers, spontaneous polarity inversion has been demonstrated in GaN homoepitaxial layers, switching the doped layer from Ga-polar to N-polar. However, this approach leads to uncontrolled inversion domain boundaries and often results in dopant clustering within the film, impacting film quality and resultant device performance.

In this work we investigate the fabrication of Mg-free inversion layers (ILs) to control the polarity of MOCVD-grown GaN on GaN substrates. By changing the IL material, we demonstrate conversion of GaN polarity in both directions (N-polar to Ga-polar and Ga-polar to N-polar). By employing a patented selective growth method to deposit the IL, the lateral polarity of the GaN can also be alternated, allowing control of the polarity in both vertical and lateral directions. A one-dimensional grating of periodically oriented (PO) GaN stripes was achieved over square-centimeter (or large) areas. The boundaries between polarities are found to be both sharp and vertical, and the growth conditions have been adjusted to result in equal growth rates of both polarities. Chemical etching of the material verifies the polarity of the material. Transmission electron microscopy (TEM) rules out the presence of alternating polar inclusions in the inverted material while showing a strong inversion domain boundary at the vertical interfaces. Dislocation density and grain size are determined through the use of electron channeling contrast imaging. The MOCVD-grown PO GaN structures have been extended in thickness by further HVPE growth. TEM and photoluminescence imaging confirms that the PO GaN structure is maintained throughout the extended growth (up to 80 μm in thickness). This method of GaN polarity inversion offers the promise of engineering both lateral and vertical polarity heterostructures and the potential of novel engineered polarity-based devices.

4:00pm **EM+TF+AS-ThA7 Direct Green and Yellow Light Emitting Diodes – Polarization Control and Epitaxy**, C. Wetzel, T. Detchprohm, Rensselaer Polytechnic Institute **INVITED**

Solid state lighting by means of GaInN/GaN light emitting diodes (LEDs) is rapidly progressing to a major factor in energy savings technology. By convergence of lighting and lighting control, however, smart lighting is an opportunity to elevate lighting to a holistic experience of human wellbeing beyond the obvious economic benefits. Full epitaxial control of the GaInN/GaN active region is prime to fulfill the promise of an optical bandgap tunable across the entire visible spectrum. As such it will serve both, as tunable absorption layer for multijunction solar cells and emitter for direct emitting LEDs. The later aspect is of particular promise to outperform the traditional phosphor conversion approach known from historic fluorescence lamps and current white light LEDs.

Rigorous defect reduction approaches have enabled us to continuously improve the emission efficiency in ever longer wavelength emission reaching beyond green, deep green to yellow and orange (590 nm). In contrast to conventional phosphor or AlGaInP-based LED, such emitters show a superior temperature stability of their light output performance. A further leap in defect reduction has been demonstrated by the implementation of heteroepitaxy on nanotextured templates. Unlike widely explored lateral epitaxial overgrowth, growth zones primarily coalesce without the generation of threading dislocations. Implemented at the sapphire substrate level in green LEDs, the texturing substantially boosts both, internal quantum efficiency and light extraction. Furthermore, by control of the crystallographic orientation of growth we achieve a modulation of the piezoelectric polarization within the active region. This for once results in the emission of highly linear polarized light but on the other hand holds the promise to move the actual sweet spot of LED performance from the blue into the green and yellow spectral region. We discuss our approaches in light of our latest achievements.

This work was supported by a DOE/NETL Solid-State Lighting Contract of Directed Research under DE-EE0000627. This work was supported in part by the Engineering Research Centers Program of the National Science Foundation under NSF Cooperative Agreement No. EEC-0812056.

**4:40pm EM+TF+AS-ThA9 The Influence of Substrate and Gas Phase Temperatures on the Properties of InN Epilayers, M.K.I. Senevirathna, S.D. Gamage, R. Atalay, R.L. Samaraweera, A.G.U. Perera, Georgia State University, B. Kucukgok, A.G. Melton, I. Ferguson, University of North Carolina at Charlotte, N. Dietz, Georgia State University**

The influence of the substrate growth temperature on the structural and optoelectronic properties of group III-nitride layers grown by various growth techniques has been extensively studied and reported on, due to the close relationship of substrate temperature with crystalline quality and the point defect chemistry of the alloy. Most thin film growth systems only control the substrate temperature and have limited control to adjust the gas phase decomposition dynamic independent to influence to growth surface chemistry.

In this contribution, we present results on the growth of InN epilayers grown the high-pressure chemical vapor deposition (HPCVD), studying in influence of and independent from the substrate temperature controlled gas phase temperature above the substrate reactor zone. The HPCVD reactor system has two heater elements: one that controls the substrate temperature and a second radiative heat source above, which allows the control of the gas phase temperature. While the substrate temperature dominantly controls the growth process and the crystalline layer properties, the heater above the substrate surface influences strongly the precursor decomposition processes and the diffusion and concentrations of the precursor fragments in the boundary layer and at the growth surface. InN epilayers grown with different gas phase heating settings where grown and analyzed with the respect to their short- and long-range crystalline ordering and their optoelectronic properties as function of the gas phase temperature. The long-range and the short-range crystalline order of the layers have been analyzed by x-ray diffraction  $2\theta-\omega$  scans FWHM and the Raman  $E_2$  (high) FWHM, respectively. The optoelectronic properties have been studied by reflectance spectroscopy and are related to the structural properties and the additional gas phase heating.

The figure depicts the FWHM values of Raman- $E_2$  (high) peak of the InN epilayers as a function of reactor pressure for higher (red line) and lower (blue line) gas phase temperature. The results indicate that there is an improvement of the short-range crystalline order of the layers with lower gas phase temperature. However, the FWHM values of XRD  $2\theta-\omega$  scans, which are not shown here, are indicating that there is an improvement of long-range crystalline order of the layers with increasing gas phase heating.

**5:00pm EM+TF+AS-ThA10 Absence of Electron Accumulation at InN(11-20) Cleavage Surfaces, H. Eisele, Technische Universität Berlin, Germany, S. Schaafhausen, Forschungszentrum Jülich, Germany, A. Lenz, Technische Universität Berlin, Germany, A. Sabitova, Forschungszentrum Jülich, Germany, L. Ivanova, M. Dähne, Technische Universität Berlin, Germany, Y.-L. Hong, S. Gwo, National Tsing-Hua University, Taiwan, P. Ebert, Forschungszentrum Jülich, Germany**

InN in principle opens up the possibility of using only one ternary III-V semiconductor alloy (InGaN) in optoelectronic devices to cover the whole visible spectral range. Despite this, key material properties of InN are still under debate. The intrinsic energetic position of the Fermi level is unclear, i.e., whether the Fermi level is located within the fundamental band gap or shifted slightly into the conduction band. The latter case induces electron accumulation at the surfaces of the crystal. Such an electron accumulation is typically observed at InN surfaces upon air contact, raising the question whether it is an intrinsic material property or not?

In order to probe intrinsic bulk properties by STM and not only contamination or surface effects, a clean and stoichiometric surface is necessary. This can be achieved by cleaving InN along non-polar planes. To analyze the origin of the different electronic states in detail, we investigated the clean non-polar (11-20) cleavage surface using cross-sectional scanning tunneling microscopy (XSTM) and spectroscopy (XSTS).

Using combined XSTM and XSTS we were able to locate an InN layer grown on an AlN buffer layer on top of a Si(111) substrate [1]. XSTS spectroscopy on the InN(11-20) cleavage surface yield normalized conductivity spectra, where three contributions to the tunneling current can be observed: (i) the contribution from the conduction band density of states for biases above the conduction band minimum at +0.3 V, (ii) a defect induced current, dominating the spectra between biases of 0 and -0.4 V, and (iii) a valence band related tunneling current rising at a bias of about -0.4 V and dominating the spectrum for biases below. The defect induced current arises from semi-filled defect states being present at the surface steps, and probably also from other (point) defects at the surface. Within the bulk band gap of  $E_G = 0.7$  eV no intrinsic surface states could be observed. Furthermore, the Fermi level pinning at about 0.3 eV below the conduction band minimum indicates the absence of an electron accumulation layer.

The results illustrate that electron accumulation at InN surfaces is not a universal property on InN. For clean stoichiometric cleavage surfaces no electron accumulation is observed. Thus, electron accumulation results primarily from the details of the surface structure and is hence not an intrinsic property of the bulk InN material.

[1] Ph. Ebert, S. Schaffhausen, A. Lenz, A. Sabitova, L. Ivanova, M. Dähne, Y.-L. Hong, S. Gwo, and H. Eisele, Appl. Phys. Lett. **98**, in press (2011).

**5:20pm EM+TF+AS-ThA11 Dependence of Gallium Incorporation and Structural Properties of Indium-rich In<sub>x</sub>Ga<sub>1-x</sub>N Epilayers on Ammonia - MO Precursor Pulse Separation, S.D. Gamage, R. Atalay, M.K.I. Senevirathna, R.L. Samaraweera, Georgia State University, A.G. Melton, I. Ferguson, University of North Carolina at Charlotte, N. Dietz, Georgia State University**

The large band gap tunability of ternary In<sub>x</sub>Ga<sub>1-x</sub>N alloys has opened new avenues in the field of advanced optoelectronics devices fabrication. However, the growth process of the epilayers of these materials is yet to be well explored. In this contribution, the growth of In<sub>x</sub>Ga<sub>1-x</sub>N epilayers under super atmospheric pressure is studied. In order to mitigate the gas phase reactions and the gap of dissociation temperatures between the binary alloys GaN and InN, and to improve the phase stability, high growth chamber pressure has been used together with a pulsed precursor injection system. This pulsed precursor injection scheme introduces two important process parameters; the precursor separation times between the metal organic (MO) sources (TMI and TMG) and ammonia (S<sub>1</sub>), and ammonia and MO (S<sub>2</sub>).

With the aim to find the optimum S<sub>2</sub> separation for high quality indium-rich InGaN epilayers, a set of In<sub>x</sub>Ga<sub>1-x</sub>N samples with nominal x=0.9 has been grown with different S<sub>2</sub> timings. It will be shown that the S<sub>2</sub> separation is critical for the incorporation of gallium into the epilayers. In order to maintain single-phase epilayers, the S<sub>2</sub> separation has to be increased from S<sub>2</sub>=400 ms for InN to over 1200 ms for In<sub>x</sub>Ga<sub>1-x</sub>N. Raman spectroscopy and X-ray diffraction (XRD) spectroscopy are used to study the structural properties while the Fourier Transform Infra-red (FTIR) and transmission spectroscopy are utilized to investigate the electrical and optical properties of the epilayers.

**5:40pm EM+TF+AS-ThA12 MBE-Growth of Coherent-Structure InN/GaN Short-Period Superlattices as Ordered InGaN Ternary Alloys for III-N Solar Cell Application, A. Yoshikawa, K. Kusakabe, N. Hashimoto, T. Okuda, T. Itoi, Chiba University, Japan**

We have recently proposed "SMART" III-N tandem solar cells in which all sub-cells could be coherent-structure high-quality pn junctions with low leakage current, resulting in high performance solar cells. SMART means "Superstructure Magic Alloys fabricated at Raised Temperature". The most important feature in the proposed SMART solar cell is a novel idea for realizing ordered and/or quasi InGaN-ternary alloys with InN/GaN Short-Period Superlattices (SPS) enabling coherent-structure band engineering for the (InN)<sub>n</sub>/(GaN)<sub>m</sub> SPSs with simple integer pairs of (n, m) ≤ 4. In this symposium, detailed epitaxy processes, structural and physical properties of SPSs, and also the idea and features of proposed "SMART" III-N tandem solar cells are reported.

We have ever reported successful growth of fine and coherent-structure 1-ML InN/GaN matrix QWs, and they can be fabricated so under self-limiting and self-ordering growth processes at remarkably higher and/or "raised" temperatures (~650 °C) than the critical one (~500 °C) for growing thick InN layer under +c growth regime in MBE. We are now underway to extend this understanding and the corresponding epitaxy technology to realize the proposed (InN)<sub>n</sub>/(GaN)<sub>m</sub> SPSs, and we have started to achieve

$(\text{InN})_1/(\text{GaN})_m$  ( $m=1-20$ ) SPSs. When fabricating high structural quality those SPSs, very careful surface stoichiometry control such as  $(\text{In}+\text{Ga})/\text{N}$  and  $\text{In}/\text{Ga}$  composition in adlayers, and also periodical complete surface dry-up of  $\text{In}$  and  $\text{Ga}$  for each one-cycle growth of SPSs are necessary and quite important.

In brief, 50-100 periods of  $(\text{InN})_1/(\text{GaN})_m$  SPSs were grown on MOCVD-grown  $\text{c-GaN}$  template at  $650^\circ\text{C}$  by a conventional plasma-assisted MBE. Surface stoichiometry and surface dry up were quite carefully monitored and controlled by in-situ Spectroscopic-Ellipsometry. First, structural properties of 50 periods of  $(\text{InN})_1/(\text{GaN})_m$  SPSs were characterized with XRD diffraction patterns taking the  $m$  as a parameter. It was found that coherent structure SPSs could be fairly easily fabricated even when the  $m$  was decreased down to 4. Generally, much more careful surface stoichiometry control was necessary with decreasing the  $m$ , though it was confirmed coherent structure  $(\text{InN})_1/(\text{GaN})_4$  SPSs could be grown finally after quite careful control, such as selective re-evaporation between  $\text{In}$  and  $\text{Ga}$  consuming a long time. This leads to complete  $\text{In}$  re-evaporation leaving only some  $\text{Ga}$  metals on the surface. Of course those  $\text{Ga}$  metals must be completely dried up with irradiating plasma-excited nitrogen just before the following deposition of 1ML  $\text{InN}$  on it. It is still difficult at present, however, to grow fine structure  $\text{InN}/\text{GaN}$  SPSs with the  $m$  below 3.

# Authors Index

**Bold page numbers indicate the presenter**

## — A —

Atalay, R.: EM+TF+AS-ThA11, 2; EM+TF+AS-ThA9, 2

## — B —

Baski, A.A.: EM+TF+AS-ThA4, 1  
Bowman, S.R.: EM+TF+AS-ThA6, 1

## — C —

Chang, J.P.: EM+TF+AS-ThA3, 1  
Chien, D.: EM+TF+AS-ThA3, **1**  
Collazo, R.: EM+TF+AS-ThA1, 1  
Condon, N.J.: EM+TF+AS-ThA6, 1  
Craft, S.: EM+TF+AS-ThA1, 1

## — D —

Dähne, M.: EM+TF+AS-ThA10, 2  
Dalmau, R.: EM+TF+AS-ThA1, 1  
Detchprohm, T.: EM+TF+AS-ThA7, 1  
Dietz, N.: EM+TF+AS-ThA11, 2; EM+TF+AS-ThA9, 2

## — E —

Ebert, P.: EM+TF+AS-ThA10, 2  
Eddy, Jr., C.R.: EM+TF+AS-ThA6, 1  
Eisele, H.: EM+TF+AS-ThA10, **2**

## — F —

Ferguson, I.: EM+TF+AS-ThA11, 2; EM+TF+AS-ThA9, 2  
Foussekis, M.: EM+TF+AS-ThA4, 1  
Freitas, Jr., J.A.: EM+TF+AS-ThA6, 1

## — G —

Gaddy, B.: EM+TF+AS-ThA1, 1

Gamage, S.D.: EM+TF+AS-ThA11, 2;  
EM+TF+AS-ThA9, 2

Gwo, S.: EM+TF+AS-ThA10, 2

## — H —

Hashimoto, N.: EM+TF+AS-ThA12, 2  
Hite, J.K.: EM+TF+AS-ThA6, **1**  
Hong, Y.-L.: EM+TF+AS-ThA10, 2  
Hussey, L.: EM+TF+AS-ThA1, 1

## — I —

Irving, D.: EM+TF+AS-ThA1, 1  
Itoi, T.: EM+TF+AS-ThA12, 2  
Ivanova, L.: EM+TF+AS-ThA10, 2

## — K —

Kub, F.J.: EM+TF+AS-ThA6, 1  
Kucukgok, B.: EM+TF+AS-ThA9, 2  
Kusakabe, K.: EM+TF+AS-ThA12, 2

## — L —

LeBeau, J.: EM+TF+AS-ThA1, 1  
Lenz, A.: EM+TF+AS-ThA10, 2

## — M —

Mastro, M.A.: EM+TF+AS-ThA6, 1  
McNamara, J.D.: EM+TF+AS-ThA4, **1**  
Melton, A.G.: EM+TF+AS-ThA11, 2;  
EM+TF+AS-ThA9, 2  
Meyer, J.R.: EM+TF+AS-ThA6, 1  
Mita, S.: EM+TF+AS-ThA1, 1  
Moody, B.: EM+TF+AS-ThA1, 1

## — O —

O'Connor, S.: EM+TF+AS-ThA6, 1

Okuda, T.: EM+TF+AS-ThA12, 2

## — P —

Perera, A.G.U.: EM+TF+AS-ThA9, 2  
Perng, Y.-C.: EM+TF+AS-ThA3, 1

## — R —

Reshchikov, M.A.: EM+TF+AS-ThA4, 1  
Rice, T.: EM+TF+AS-ThA1, 1

## — S —

Sabitova, A.: EM+TF+AS-ThA10, 2  
Samaraweera, R.L.: EM+TF+AS-ThA11, 2;  
EM+TF+AS-ThA9, 2  
Schaaflhausen, S.: EM+TF+AS-ThA10, 2  
Schlesser, R.: EM+TF+AS-ThA1, 1  
Senevirathna, M.K.I.: EM+TF+AS-ThA11, 2;  
EM+TF+AS-ThA9, **2**  
Sitar, Z.: EM+TF+AS-ThA1, **1**

## — T —

Tweedy, J.: EM+TF+AS-ThA1, 1  
Twigg, M.E.: EM+TF+AS-ThA6, 1

## — V —

Vurgaftman, I.: EM+TF+AS-ThA6, 1

## — W —

Wetzel, C.: EM+TF+AS-ThA7, **1**

## — X —

Xie, J.: EM+TF+AS-ThA1, 1

## — Y —

Yoshikawa, A.: EM+TF+AS-ThA12, 2