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DESIGN AND MANUFACTURE OF NANOMETRE-SCALE SOI LIGHT SOURCES

by

Alfons Willi Bogalecki

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SUMMARY

Keywords: Electron-beam lithography, Impurity redistribution, Nanometre-scale SOI, Quantum confinement, Silicon electroluminescence, Silicon infrared light emission, Silicon light source, SOI buried oxide light reflection, SOI light sources, SOI wafer manufacture.

To investigate quantum confinement effects on silicon (Si) light source electroluminescence (EL) properties like quantum efficiency, external power efficiency and spectral emission, thin Si finger junctions with nanometre-scale dimensions were designed and manufactured in a fully customized silicon-on-insulator (SOI) semiconductor production technology.

Since commonly available photolithography is unusable to consistently define and align nanometre-scale line-widths accurately and electron-beam lithography (EBL) by itself is too time-expensive to expose complete wafers, the wafer manufacturing process employed a selective combination of photolithography and EBL.

The SOI wafers were manufactured in the clean-rooms of both the Carl and Emily Fuchs Institute for Microelectronics (CEFIM) at the University of Pretoria (UP) and the Georgia Institute of Technology's Microelectronic Research Centre (MiRC), which made a JEOL JBX-9300FS electron-beam pattern generator (EPG) available. As far as is known this was the first project in South Africa (and possibly at the MiRC) that employed EBL to define functional nanometre-scale semiconductor devices.

Since no standard process recipe could be employed, the complete design and manufacturing process was based on self-obtained equipment characterization data and material properties.

The manufacturing process was unprecedented in both the CEFIM and MiRC clean-rooms. The manufacture of nanometre-scale Si finger junctions not only approached the manufacturing limits of the employed processing machinery, but also had to overcome undesirable physical effects that in larger-scale semiconductor manufacture usually are negligible. The device design, mask layout and manufacturing process therefore had to incorporate various material, equipment limitation and physical phenomena like impurity redistribution occurring during the physical manufacturing process.

Although the complicated manufacturing process allowed many unexpected problems to occur, it was expected that at least the simple junction breakdown devices be functional and capable of delivering data regarding quantum confinement effects.

Although due to design and processing oversights only 29 out of 505 measured SOI light sources were useful light emitters, the design and manufacture of the SOI light sources was successful in the sense that enough SOI light sources were available to conduct useful optical characterization measurements.

In spite of the fact that the functional light sources did not achieve the desired horizontal (width) confinement, measured optical spectra of certain devices indicate that vertical (thickness) confinement had been achieved.

All spectrometer-measured thickness-confined SOI light sources displayed a pronounced optical power for 600 nm < λ < 1 µm. The SOI light source with the highest optical power output emitted about 8 times more optical power around λ = 850 nm than a 0.35 µm bulk-CMOS avalanche light-source operating at the same current. Possible explanations for this effect are given.

It was shown that the buried oxide (BOX) layer in a SOI process could be used to reflect about 25 % of the light that would usually be lost to downward radiation back up, thereby increasing the external power efficiency of SOI light sources.

This document elaborates on the technical objectives, approach, chip and process design, physical wafer manufacture, production process control and measurement of the nanometre-scale SOI light sources.

Opsomming

Sleutelwoorde: Elektronstraal litografie, Kwantumbeperking, Nanometer-skaal SOI, Onsuiwerheid herdistribusie, Silikon elektroluminensie, Silikon infrarooi lig uitstraling, Silikon ligbron, SOI begraafde oksied lig refleksie, SOI lig bronne, SOI skyf vervaardiging.

Om kwantumbeperkingseffekte op silikon (Si) ligbron elektroluminensie (EL) eienskappe soos kwantum effektiwiteit, eksterne drywing effektiwiteit and spektrale emissie te ondersoek, is dun Si vinger koppelvlakke met nanometer-skaal dimensies ontwerp en vervaardig in ’n ten volle pasgemaakte silikon-op-isolator (SOI) halfgeleier vervaardigingstegnologie.

Omdat die huidig beskikbare fotolitografie onbruikbaar is om herhaaldelik nanometer-skaal lyn-wydtes akkuraat te definieer, en elektron-straal litografie (ESL) alleen te tydsaam is om hele skywe te belig, moes die vervaardigingsproses van ’n selektiewe kombinasie van fotolitografie en ESL gebruik maak.

Die SOI skywe is vervaardig in die skoonkamers van beide die Carl en Emily Fuchs Instituut vir Mikroëlektronika (CEFIM) by die Universiteit van Pretoria (UP) en die Georgia Instituut van Tegnologie se Microelectronic Research Centre (MiRC), wat ’n JEOL JBX-9300FS elektronstraal patroongenerator (EPG) beskikbaar gemaak het. Sovêr bekend, was hierdie die eerste projek in Suid Afrika (en moontlik by die MiRC) waar ESL gebruik was om werkende nanometer-skaal halfgeleier komponente te vervaardig.

Omdat geen standaardproses gebruik kon word nie, moes die ontwerp en vervaardigingsproses op empiriese toerustingkarakteriseringsdata en materiaaleienskappe gebaseer word.

Die ingewikkelde vervaardiging van die nanometerskaal Si koppelvlakke was ongeëwenaard in die CEFIM en MiRC skoonkamers en het nie net die vervaardigingslimiete van die gebruikte prosesapparat benader nie, maar moes ook ongewenste fisiese effekte wat in grootskaal-halfgeleier vervaardiging normaalweg ignoreer word, oorkom. Die komponentontwerp, maskeruitleg en vervaardigingsproses moes dus verskeie materiaal effekte, toerustingbeperkings en fisiese verskynsels soos onsuiwerheid herdistribusie wat gedurende die fisiese vervaardigingsproses gebeur in ag neem.

Alhoewel die komplekse vervaardigingsproses baie onverwagte probleme geopenbaar het, is verwag dat ten minste die eenvoudige koppelvlak avalanche komponente funksioneel sou wees en data oor kwantumbeperking sou oplewer.

Alhoewel weens ontwerp- en prosesseringsfoute net 29 van die 505 gemete SOI komponente bruikbare ligbronne was, was die ontwerp en vervaardiging van die SOI ligbronne steeds suksesvol in die sin dat genoeg SOI ligbronne beskikbaar was om bruikbare optiese karakteriserings te doen.

Ten spyte daarvan dat die funksionele ligbronne nie die gewenste horisontale beperking bereik het nie, het optiese metings van sekere komponente gewys dat die vertikale kwantumbeperking behaal is.

Al die SOI ligbronne het ŉ sterk optiese drywing in die bereik 600 nm $< \lambda <$ 1 µm gewys. Die SOI ligbron met die hoogste optiese drywing het ongeveer 8 keer meer optiese drywing uitgestraal by λ = 850 nm as ŉ 0.35 µm CMOS ligbron by dieselfde stroom. Moontlike redes vir hierdie effek is gegee.

Daar is gewys dat die begraafde oksied (BOX) in ŉ SOI proses gebruik kan word om ongeveer 25 % van die lig wat normaalweg deur afwaartse straling verloor word weer na bo te reflekteer en daardeur die eksterne drywingseffektiwiteit van SOI ligbronne te verbeter.

Omdat hierdie eerste iterasie kwantumbeperkte ligbronne belowende resultate gewys het, is ŉ volgende ontwikkelingsfase beplan. Resultate van hierdie werk kan aangewend word om selfs dunner SOI ligbronne te vervaardig.

Hierdie dokument beskryf die tegniese doel, benadering, vlokkie- en prosesontwerp, fisiese skyf vervaardiging, produksie proseskontrole en meting van die nanometer-skaal SOI ligbronne.

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LIST OF ABBREVIATIONS

BOE	Buffered Oxide Etch
BOX	Buried Oxide
CEFIM	Carl and Emily Fuchs Institute for Microelectronics
CCD	Charge-Coupled Device
CMOS	Complementary Metal-Oxide-Semiconductor
CVD	Chemical Vapour Deposition
DRC	Design Rule Check
EBL	Electron-Beam Lithography
EL	Electroluminescence
EPE	External Power Efficiency
FOX	Field Oxide
GT	Georgia Tech (Georgia Institute of Technology)
HF	Hydrofluoric (Acid)
IC	Integrated Circuit
ICP	Inductively-Coupled Plasma
IPA	Iso-Propanol Alcohol
IR	Infrared
MiRC	Microelectronic Research Centre (at the Georgia Institute of Technology)
NTED	Near-To-Eye Display
PECVD	Plasma-Enhanced Chemical Vapour Deposition
PL	Photoluminescence
PR	Photolithographic Resist
RIE	Reactive Ion Etching
SEM	Scanning Electron Microscope
SOI	Silicon on Insulator
UV	Ultraviolet

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