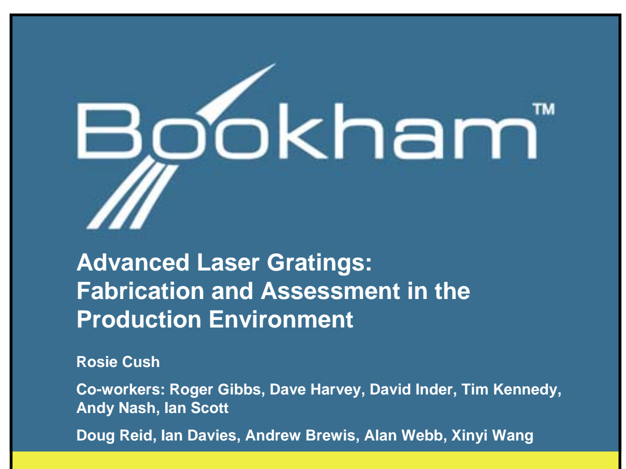
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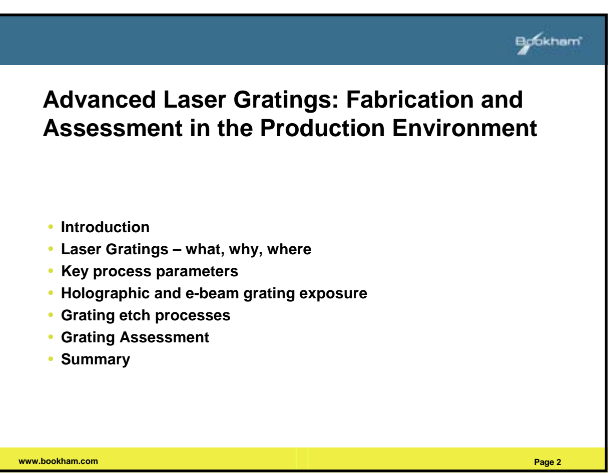
Advanced Laser Gratings:
Fabrication and Assessment in the
Production Environment
Rosie Cush
Co-workers: Roger Gibbs, Dave Harvey, David Inder, Tim Kennedy,
Andy Nash, Ian Scott
Doug Reid, Ian Davies, Andrew Brewis, Alan Webb, Xinyi Wang


Advanced Laser Gratings: Fabrication and
Assessment in the Production Environment
Introduction
Laser Gratings – what, why, where
Key process parameters
Holographic and e-beam grating exposure
Grating etch processes
Grating Assessment
Summary
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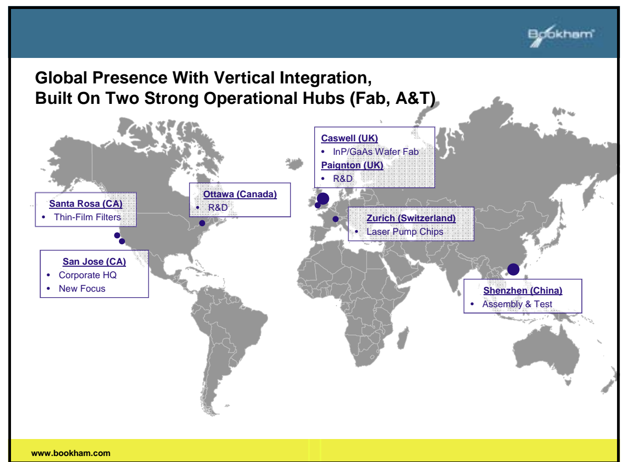
Page 2


Global Presence With Vertical Integration,
Built On Two Strong Operational Hubs (Fab, A&T)
Caswell (UK)
InP/GaAs Wafer Fab
Paignton (UK)
R&D
Ottawa (Canada)
R&D
Santa Rosa (CA)
Thin-Film Filters
Zurich (Switzerland)
Laser Pump Chips
San Jose (CA)
Corporate HQ
New Focus
Shenzhen (China)
Assembly & Test
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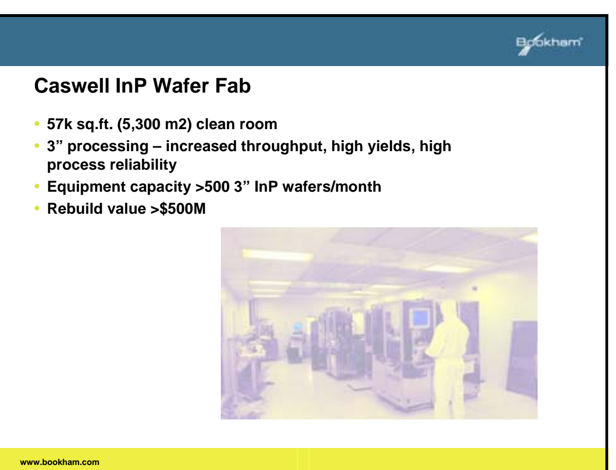
Caswell InP Wafer Fab
57k sq.ft. (5,300 m2) clean room
3" processing – increased throughput, high yields, high process reliability
Equipment capacity >500 3" InP wafers/month
Rebuild value >$500M
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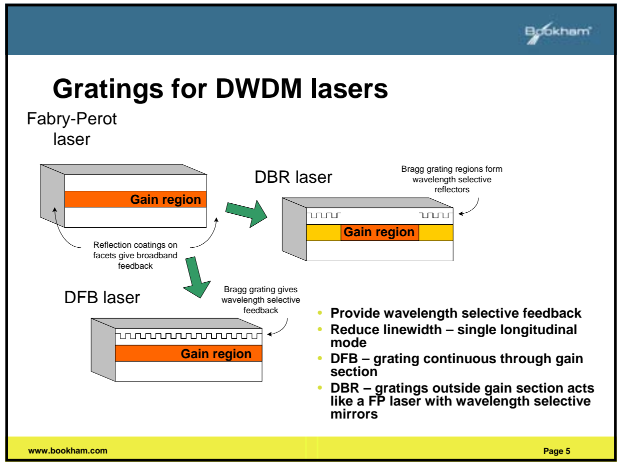
Gratings for DWDM lasers
Fabry-Perot
laser
Gain region
Reflection coatings on facets give broadband feedback
DBR laser
Bragg grating regions form wavelength selective reflectors
Gain region
DFB laser
Bragg grating gives wavelength selective feedback
Gain region
Provide wavelength selective feedback
Reduce linewidth – single longitudinal mode
DFB – grating continuous through gain section
DBR – gratings outside gain section acts like a FP laser with wavelength selective mirrors
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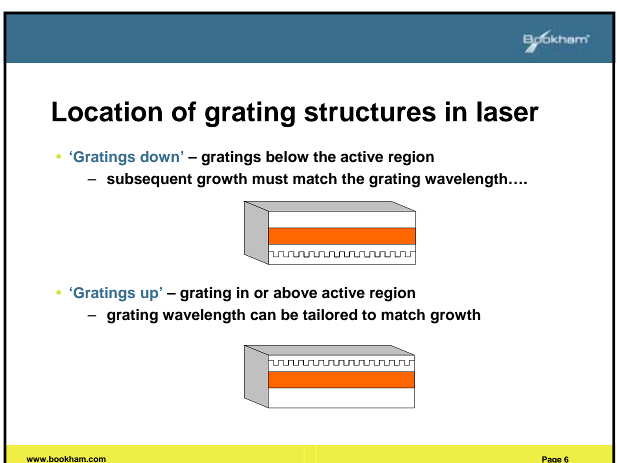
Location of grating structures in laser
'Gratings down' – gratings below the active region
– subsequent growth must match the grating wavelength….
'Gratings up' – grating in or above active region
– grating wavelength can be tailored to match growth
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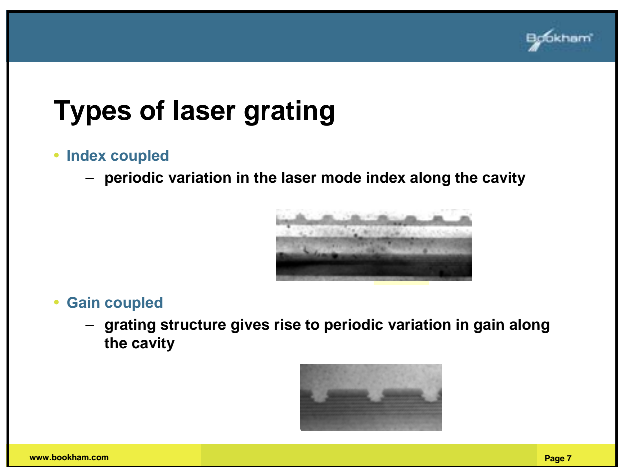
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Types of laser grating
Index coupled
– periodic variation in the laser mode index along the cavity
Gain coupled
– grating structure gives rise to periodic variation in gain along the cavity
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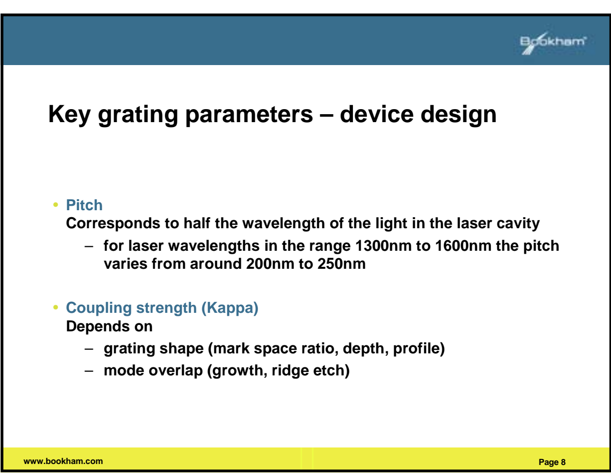
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Key grating parameters – device design
Pitch
Corresponds to half the wavelength of the light in the laser cavity
– for laser wavelengths in the range 1300nm to 1600nm the pitch varies from around 200nm to 250nm
Coupling strength (Kappa)
Depends on
– grating shape (mark space ratio, depth, profile)
– mode overlap (growth, ridge etch)
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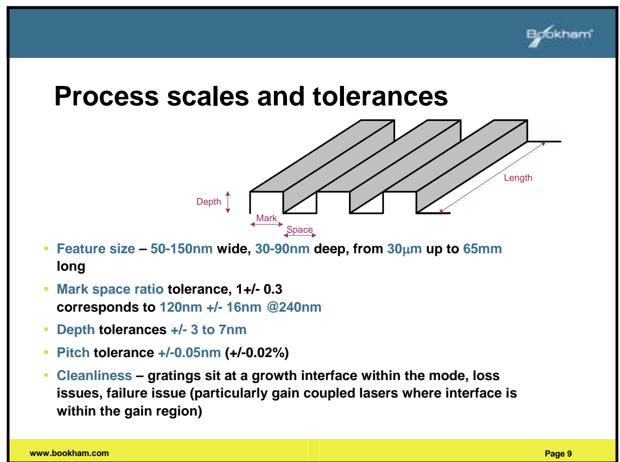
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Process scales and tolerances
Length
Depth
Mark
Space
Feature size – 50-150nm wide, 30-90nm deep, from 30µm up to 65mm long
Mark space ratio tolerance, 1+/- 0.3
corresponds to 120nm +/- 16nm @240nm
Depth tolerances +/- 3 to 7nm
Pitch tolerance +/-0.05nm (+/-0.02%)
Cleanliness – gratings sit at a growth interface within the mode, loss issues, failure issue (particularly gain coupled lasers where interface is within the gain region)
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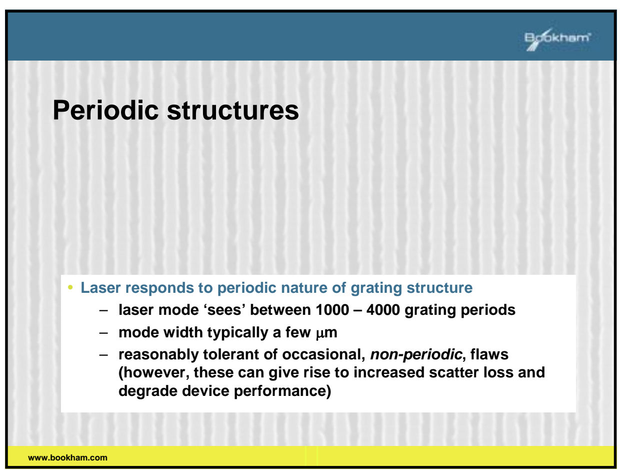
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Periodic structures
Laser responds to periodic nature of grating structure
– laser mode 'sees' between 1000 – 4000 grating periods
– mode width typically a few µm
– reasonably tolerant of occasional, non-periodic, flaws (however, these can give rise to increased scatter loss and degrade device performance)
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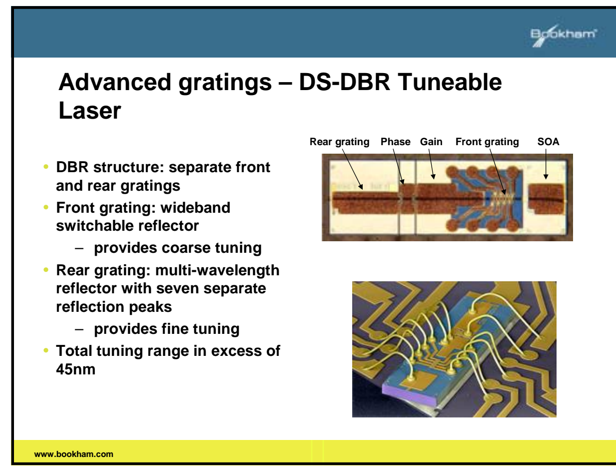
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Advanced gratings – DS-DBR Tuneable Laser
Rear grating
Phase
Gain
Front grating
SOA
DBR structure: separate front and rear gratings
Front grating: wideband switchable reflector
– provides coarse tuning
Rear grating: multi-wavelength reflector with seven separate reflection peaks
– provides fine tuning
Total tuning range in excess of 45nm
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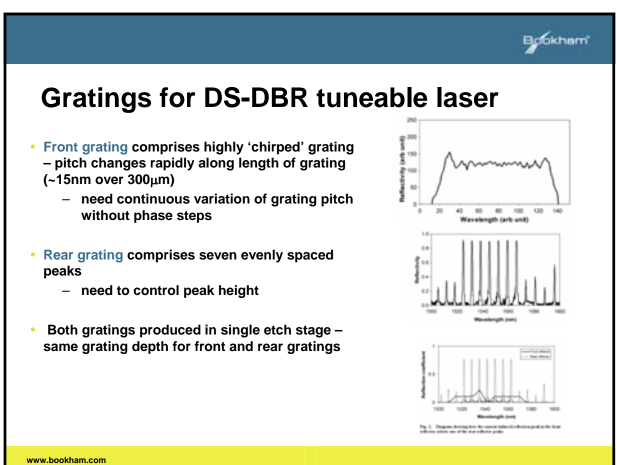
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Gratings for DS-DBR tuneable laser
Front grating comprises highly 'chirped' grating – pitch changes rapidly along length of grating (~15nm over 300µm)
– need continuous variation of grating pitch without phase steps
Rear grating comprises seven evenly spaced peaks
– need to control peak height
Both gratings produced in single etch stage – same grating depth for front and rear gratings
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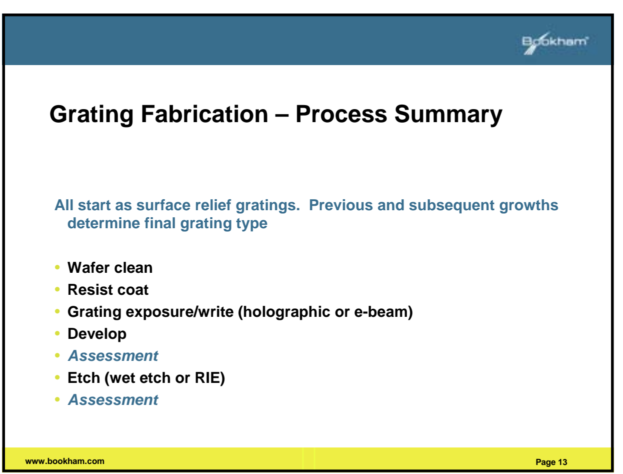
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Grating Fabrication – Process Summary
All start as surface relief gratings. Previous and subsequent growths determine final grating type
Wafer clean
Resist coat
Grating exposure/write (holographic or e-beam)
Develop
Assessment
Etch (wet etch or RIE)
Assessment
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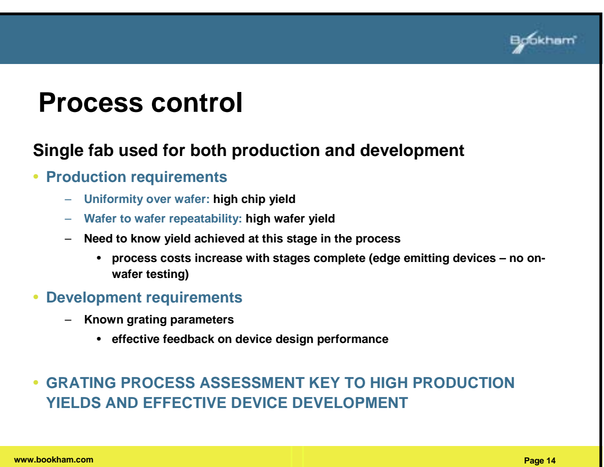
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Process control
Single fab used for both production and development
Production requirements
Uniformity over wafer: high chip yield
Wafer to wafer repeatability: high wafer yield
Need to know yield achieved at this stage in the process
process costs increase with stages complete (edge emitting devices – no on-wafer testing)
Development requirements
Known grating parameters
effective feedback on device design performance
GRATING PROCESS ASSESSMENT KEY TO HIGH PRODUCTION YIELDS AND EFFECTIVE DEVICE DEVELOPMENT
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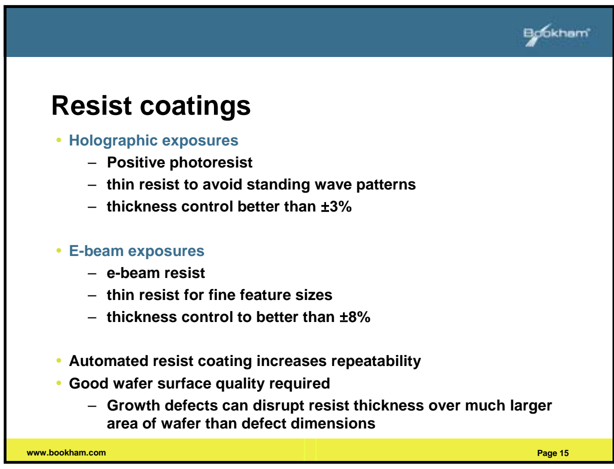
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Resist coatings
Holographic exposures
Positive photoresist
thin resist to avoid standing wave patterns
thickness control better than ±3%
E-beam exposures
e-beam resist
thin resist for fine feature sizes
thickness control to better than ±8%
Automated resist coating increases repeatability
Good wafer surface quality required
Growth defects can disrupt resist thickness over much larger area of wafer than defect dimensions
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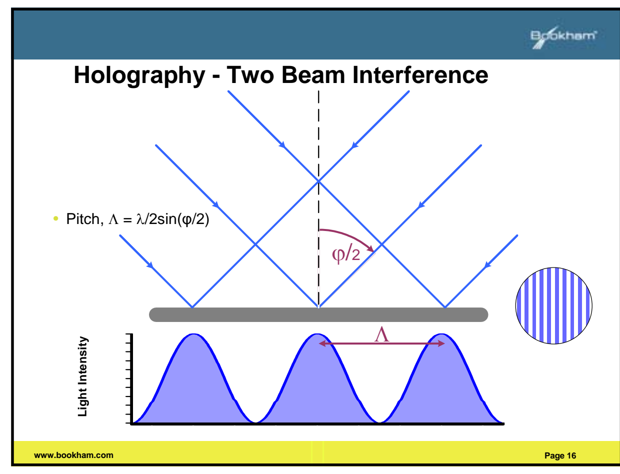
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Holography - Two Beam Interference
Pitch, Λ = λ/2sin(φ/2)
φ/2
Λ
Light Intensity
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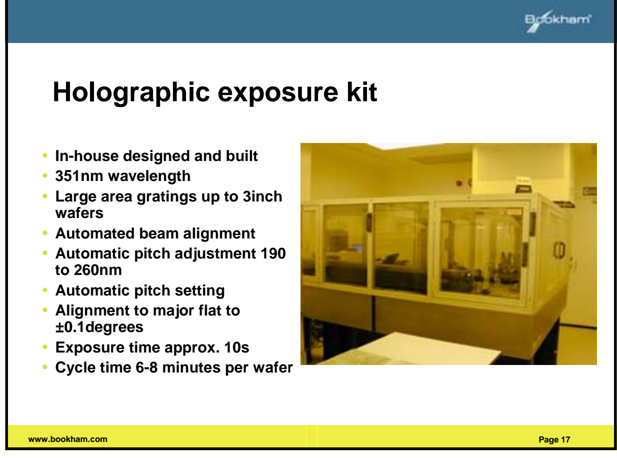
Bookham
Holographic exposure kit
In-house designed and built
351nm wavelength
Large area gratings up to 3inch wafers
Automated beam alignment
Automatic pitch adjustment 190 to 260nm
Automatic pitch setting
Alignment to major flat to ±0.1degrees
Exposure time approx. 10s
Cycle time 6-8 minutes per wafer
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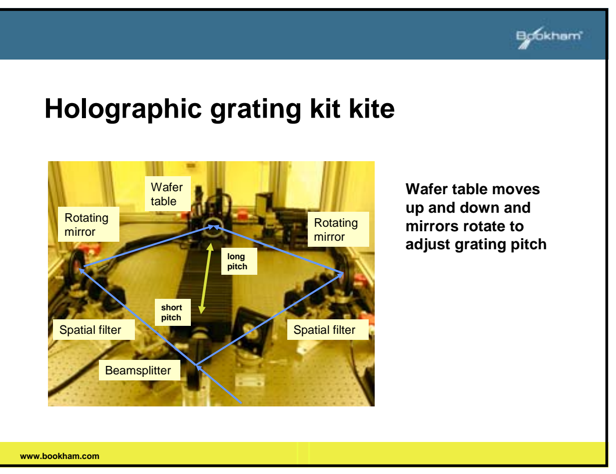
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Holographic grating kit kite
Wafer table
Rotating mirror
Rotating mirror
long pitch
short pitch
Spatial filter
Spatial filter
Beamsplitter
Wafer table moves up and down and mirrors rotate to adjust grating pitch
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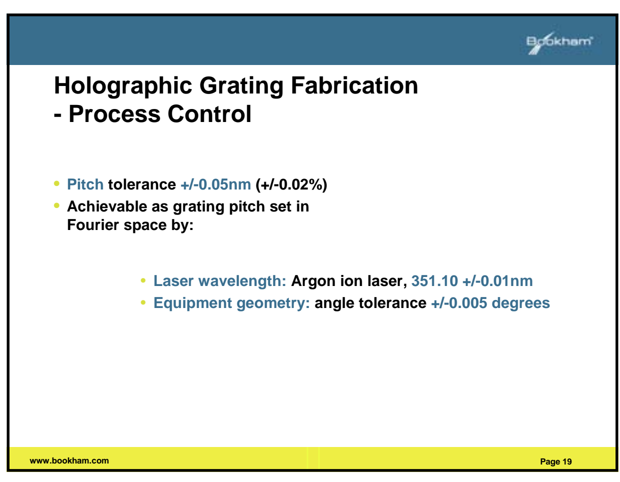
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Holographic Grating Fabrication
- Process Control
Pitch tolerance +/-0.05nm (+/-0.02%)
Achievable as grating pitch set in
Fourier space by:
Laser wavelength: Argon ion laser, 351.10 +/-0.01nm
Equipment geometry: angle tolerance +/-0.005 degrees
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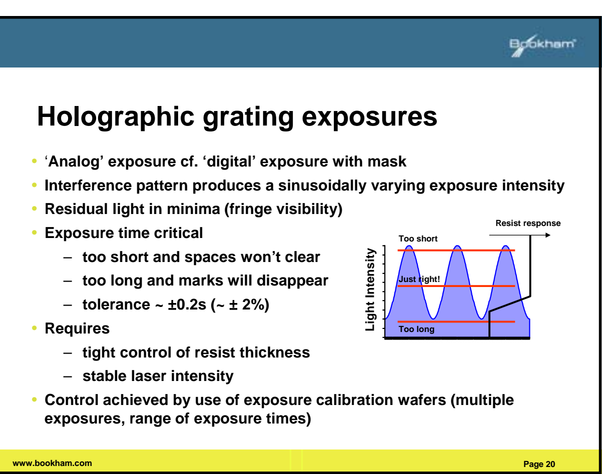
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Holographic grating exposures
'Analog' exposure cf. 'digital' exposure with mask
Interference pattern produces a sinusoidally varying exposure intensity
Residual light in minima (fringe visibility)
Exposure time critical
– too short and spaces won't clear
– too long and marks will disappear
– tolerance ~ ±0.2s (~ ± 2%)
Requires
– tight control of resist thickness
– stable laser intensity
Control achieved by use of exposure calibration wafers (multiple
exposures, range of exposure times)
Resist response
Too short
Just right!
Too long
Light Intensity
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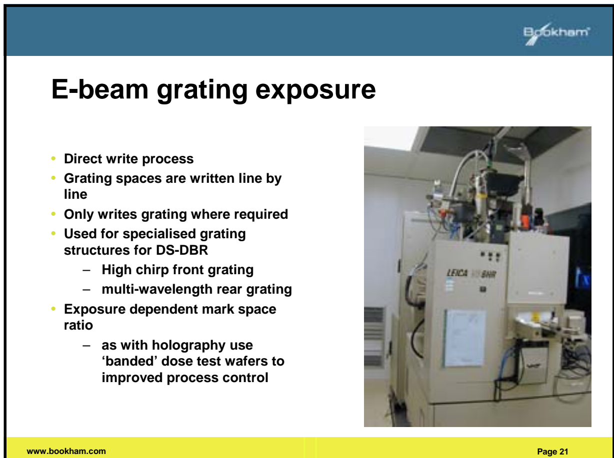
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E-beam grating exposure
Direct write process
Grating spaces are written line by
line
Only writes grating where required
Used for specialised grating
structures for DS-DBR
– High chirp front grating
– multi-wavelength rear grating
Exposure dependent mark space
ratio
– as with holography use
'banded' dose test wafers to
improved process control
LEICA
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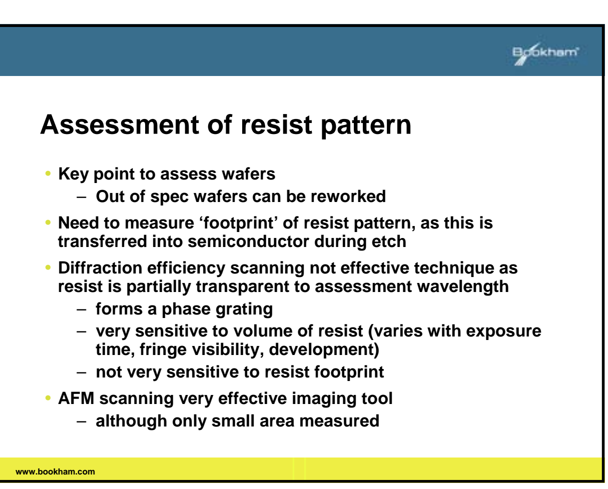
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Assessment of resist pattern
Key point to assess wafers
– Out of spec wafers can be reworked
Need to measure 'footprint' of resist pattern, as this is
transferred into semiconductor during etch
Diffraction efficiency scanning not effective technique as
resist is partially transparent to assessment wavelength
– forms a phase grating
– very sensitive to volume of resist (varies with exposure
time, fringe visibility, development)
– not very sensitive to resist footprint
AFM scanning very effective imaging tool
– although only small area measured
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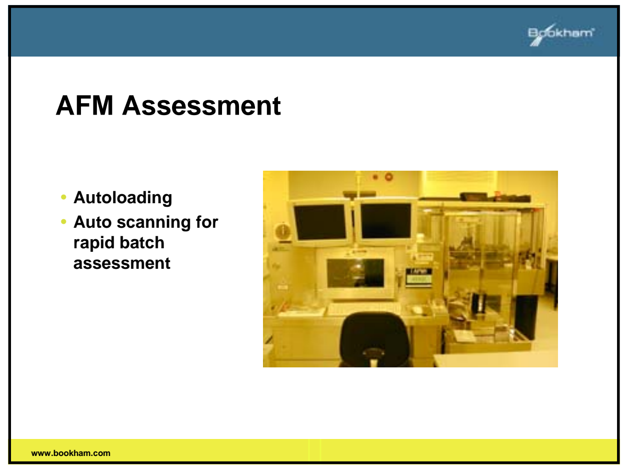
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AFM Assessment
Autoloading
Auto scanning for
rapid batch
assessment
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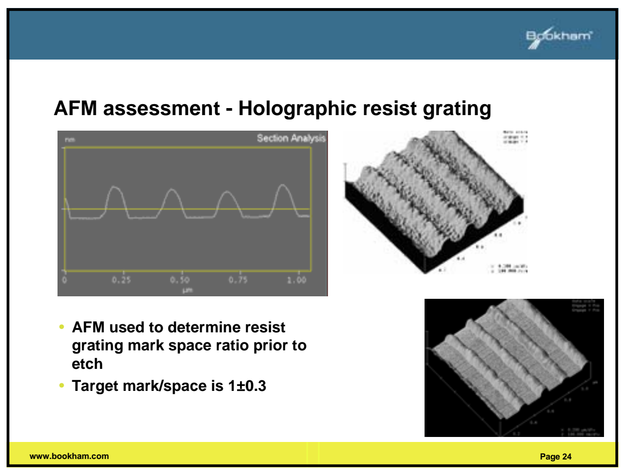
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AFM assessment - Holographic resist grating
Section Analysis
0
0.25
0.50
0.75
1.00
μm
AFM used to determine resist
grating mark space ratio prior to
etch
Target mark/space is 1±0.3
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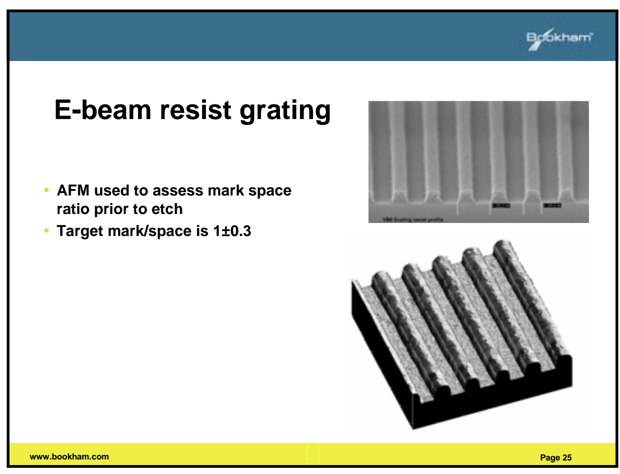
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E-beam resist grating
AFM used to assess mark space ratio prior to etch
Target mark/space is 1±0.3
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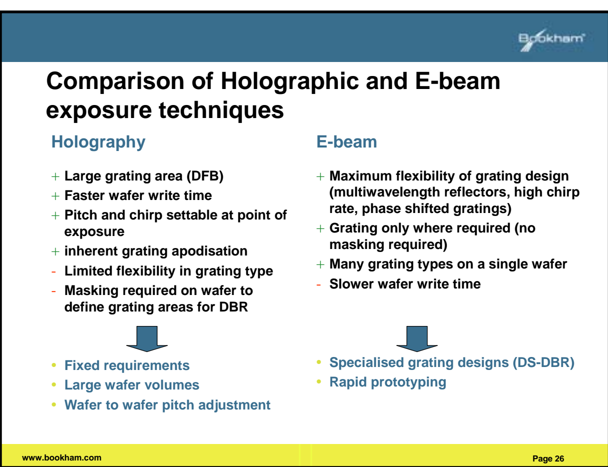
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Comparison of Holographic and E-beam exposure techniques
Holography
+ Large grating area (DFB)
+ Faster wafer write time
+ Pitch and chirp settable at point of exposure
+ inherent grating apodisation
- Limited flexibility in grating type
- Masking required on wafer to define grating areas for DBR
Fixed requirements
Large wafer volumes
Wafer to wafer pitch adjustment
E-beam
+ Maximum flexibility of grating design (multiwavelength reflectors, high chirp rate, phase shifted gratings)
+ Grating only where required (no masking required)
+ Many grating types on a single wafer
- Slower wafer write time
Specialised grating designs (DS-DBR)
Rapid prototyping
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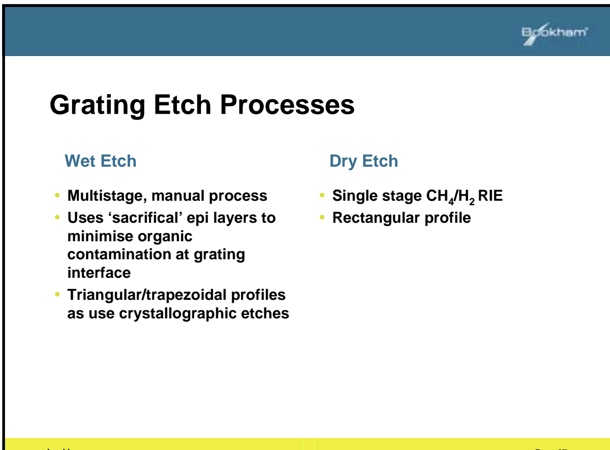
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Grating Etch Processes
Wet Etch
Multistage, manual process
Uses 'sacrificial' epi layers to minimise organic contamination at grating interface
Triangular/trapezoidal profiles as use crystallographic etches
Dry Etch
Single stage CH4/H2 RIE
Rectangular profile
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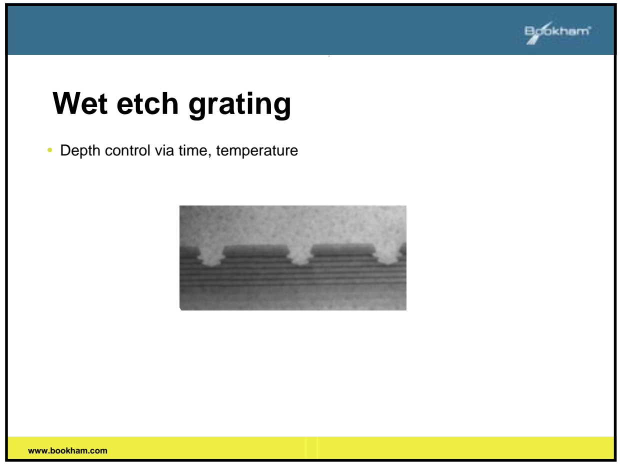
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Wet etch grating
Depth control via time, temperature
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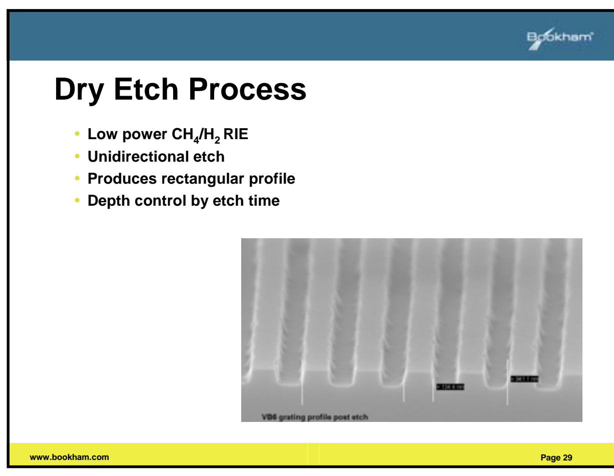
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Dry Etch Process
Low power CH4/H2 RIE
Unidirectional etch
Produces rectangular profile
Depth control by etch time
VB6 grating profile post etch
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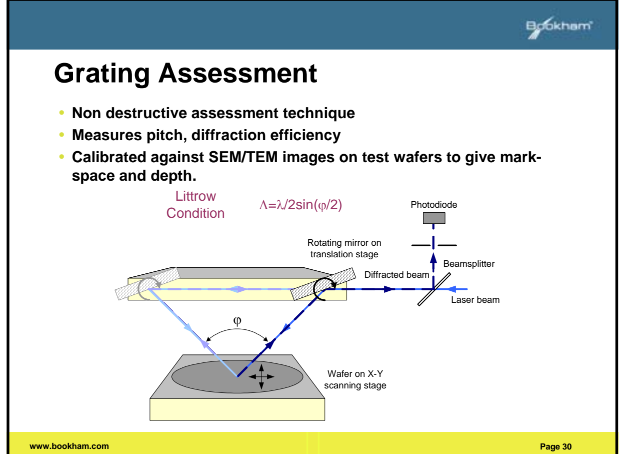
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Grating Assessment
Non destructive assessment technique
Measures pitch, diffraction efficiency
Calibrated against SEM/TEM images on test wafers to give mark-space and depth.
Littrow Condition
Λ=λ/2sin(φ/2)
Photodiode
Rotating mirror on translation stage
Beamsplitter
Diffracted beam
Laser beam
φ
Wafer on X-Y scanning stage
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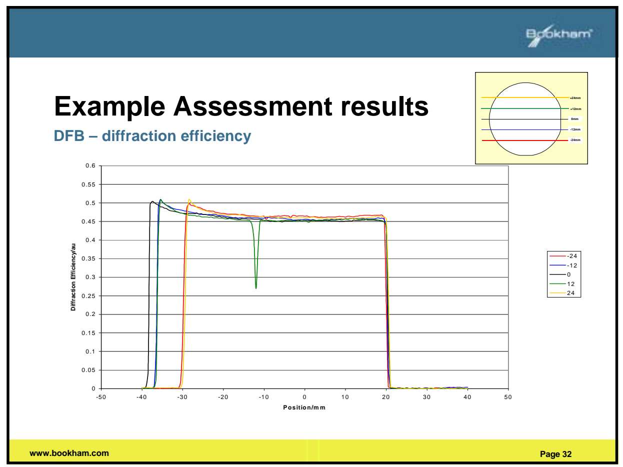

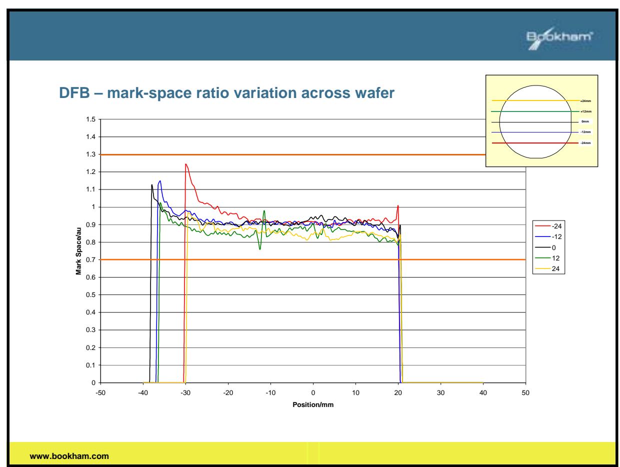

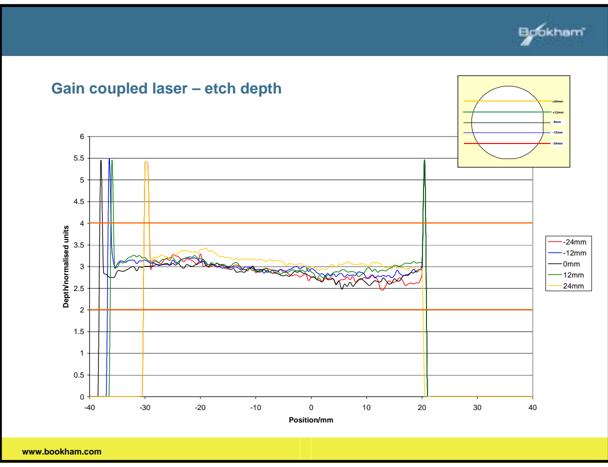

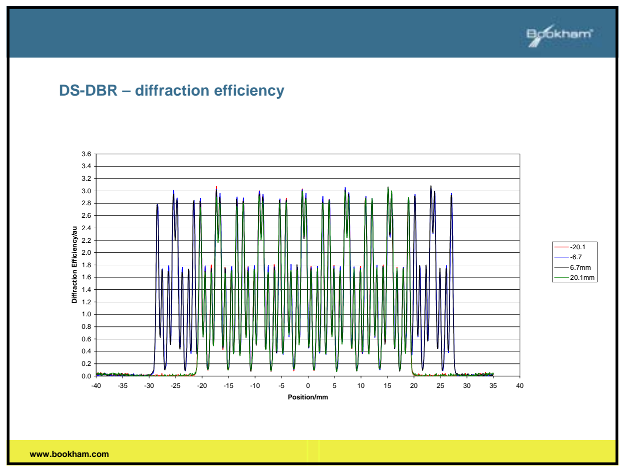

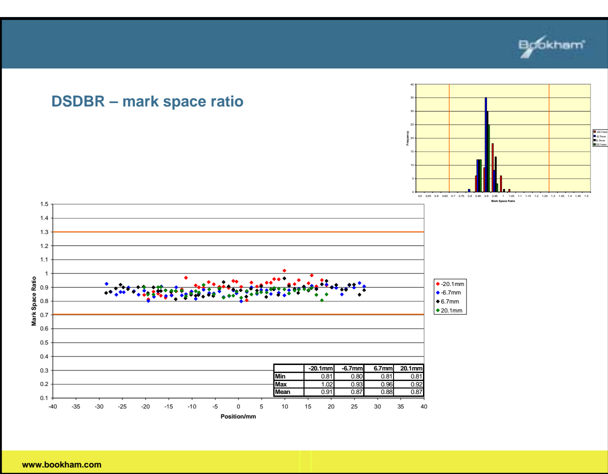

	-20.1mm	-6.7mm	6.7mm	20.1mm
Min	0.81	0.80	0.81	0.81
Max	1.02	0.93	0.96	0.92
Mean	0.91	0.87	0.88	0.87

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Summary

- Laser grating fabrication requires nanometre process control
  - Periodic nature of structures gives rise to different control requirements from discrete nanostructures
- Holographic techniques give speed and continuous parameter control for fixed grating designs
- E-beam techniques give flexibility and adaptability for complex grating designs and rapid prototyping
- Non destructive assessment techniques (AFM, diffraction measurement) essential for tight process control and high yields
- Nanometre scale grating fabrication, using holography or e-beam exposure, is a practical production technique