

n L I G H T

nLIGHT 光纤事业部
nLIGHT Fiber Division

2013年2月

February 2013

nLIGHT 洛赫亚, 芬兰 nLIGHT Lohja, Finland

- **成立于2000年, 致力于生产L-band掺铒光纤**

Founded in 2000 for telecom L-band erbium fiber supply

- **Liekki Oy于2007年11月被nLight 收购** Liekki Oy acquired by nLight in November 2007:

- 带来稳定性以专注产品质量提升 Stability allowed fundamental product improvements
- 带来显著的公司内部光纤供应和协作 Significant internal supply of fiber and other synergies
- 带来新的美国国防/政府相关机遇 New opportunities in U.S. DOD/Government market
- 通讯相关工作很少 Very little telecom work

- **全套的光纤生产能力** Integrated fiber facility:

- 纤芯掺杂 Deposition
- 预制棒制备 Glass works
- 光纤拉制和披覆 Draw and coatings
- 质量检测和可靠性测试 Quality & reliability

- **自2001年起通过ISO9001:2000认证** Factory ISO9001:2000 certified since 2001

- **自2010年起通过ISO9001:2008认证** Factory ISO9001:2008 certified since 2010

- **独有专利的光纤生产工艺-直接纳米粒子沉积(DND)**

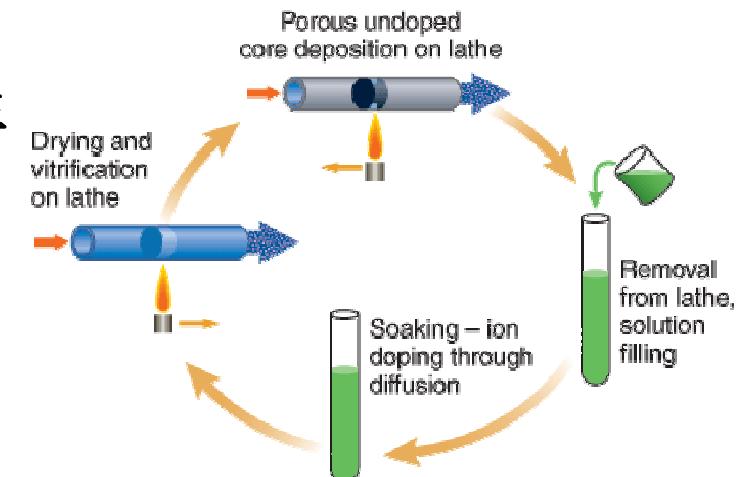
Proprietary fiber manufacturing process – Direct Nanoparticle Deposition (DND)

- **拥有73个授权专利和22个专利申请** 73 granted patents and 22 patent applications

- **大多数其他厂商使用改进的化学气相沉积(MCVD)和溶液掺杂(solution doping)技术生产用于光纤激光器的光纤**

Most fiber lasers employ fibers manufactured using modified chemical vapor deposition (MCVD) and solution doping

- 工艺需反复重复一系列的步骤 iterative, multi-step process
- 掺杂不均匀 compositional inhomogeneity
- 镧(Yb)掺杂浓度受到其集聚效应或其他元素的限制 [Yb] limited by clustering or need for co-dopants
- 纤芯通常由6-10层构成(无法精细控制掺杂分布) typically 6 – 10 core layers (coarse profile control)



- **nLIGHT光纤由直接纳米粒子沉积法(DND)制备**

nLIGHT fibers employ DND (direct nanoparticle deposition)

The diagram shows the DND process:

- Liquids and Vapors are introduced into a Burner.
- Mass flow controllers regulate the flow of liquids and vapors.
- A Real-time computer control system monitors the process.
- Doped nanoparticles are produced at the burner tip.
- The doped nanoparticles are deposited onto a fiber core.

- 所有掺杂元素在同一步骤中同时沉积 simultaneous, single-step deposition of all elements
- 掺杂均匀 compositional uniformity
- 可达到更高的镱(Yb)掺杂浓度 high [Yb]
- 纤芯由数百折射率和掺杂浓度独立精密控制的层构成 hundreds of core layers (precise profile control) with independent control of refractive-index and Yb-doping profiles

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nLight Confidential and Proprietary Information

n L I G H T

DND光纤的优势 Advantages of DND fibers

- **高掺杂浓度且极低的光子暗化效应**

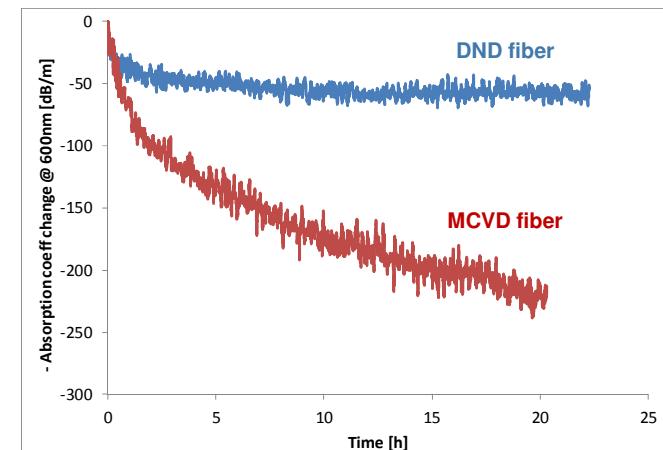
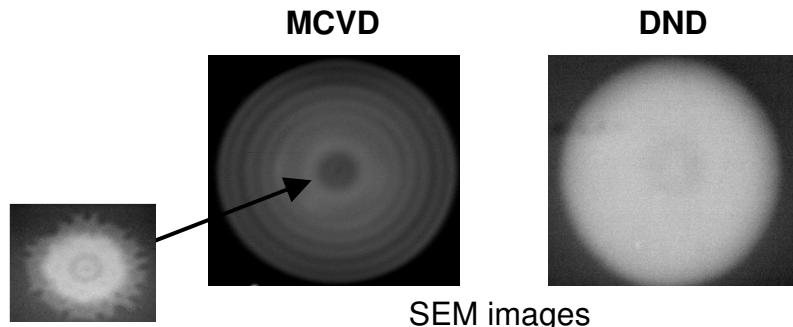
High doping level without photodarkening

- 高效率 high efficiency
- 高非线性效应阈值（功率扩展性好）
high threshold for nonlinear processes (power scaling)

- **精密控制掺杂粒子的径向分布**

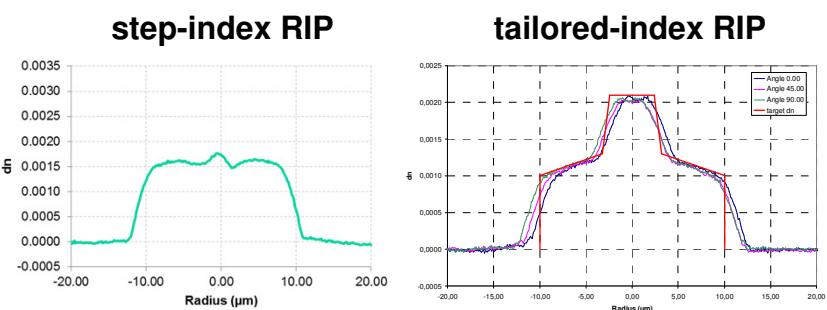
Precise control of dopant radial distribution

- 优异的光束质量 excellent beam quality
- 优秀的一致性 consistent performance
 - 批次一致性, 熔接特性, 等 batch-to-batch uniformity, splicing characteristics,...
- 创新的光纤设计 innovative fiber designs



DND fiber

- 20% higher pump absorption
- > 4x lower photodarkening
- similar initial efficiency (75 – 80% @ 920 nm pumping)



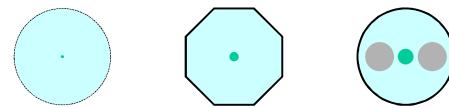
- **工艺耗时短, 可生产多种预制棒尺寸, 高纤芯/包层比**

Short cycle time, range of preform sizes, and large core / cladding ratio

- 成本低 cost reduction

标准光纤产品-掺镱 (Yb) Standard Fiber Products – Ytterbium-doped

Cladding diameter
包层直径
125μm

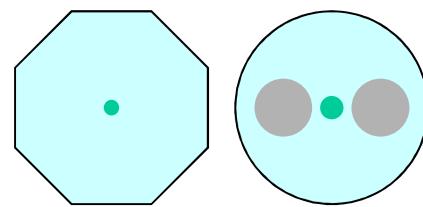


Available core types 可提供的纤芯类型			
Yb level	SC	DC	DC-PM
700		20μm	
800	4μm		
1200	4μm	6μm 10μm 12μm 20μm	6μm 10μm 12μm 20μm

SC = single-clad 单包层 = high-index coated 高折射率涂覆层
DC = double-clad 双包层 = low-index coated 低折射率涂覆层

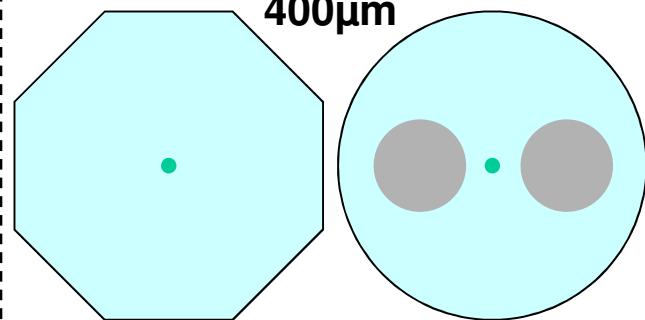
Numerical apertures 数值孔径	
Core diameter 芯径	NA
4μm	0.2
6μm	0.15
10μm	0.08
12μm	0.08
20μm	0.08

Cladding diameter
包层直径
250μm



Available core types 可提供的纤芯类型		
Yb level	DC	DC-PM
700	25μm 30μm	25μm 30μm
1200	12μm 20μm 25μm 30μm	25μm 30μm

Cladding diameter
包层直径
400μm



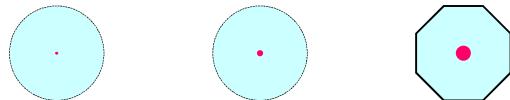
Available core types 可提供的纤芯类型		
Yb level	DC	DC-PM
1200	20μm 40μm	20μm

Numerical apertures 数值孔径	
Core diameter 芯径	NA
12μm	0.08
20μm	0.07
25μm	0.07
30μm	0.07

Numerical apertures 数值孔径	
Core diameter 芯径	NA
20μm	0.07
40μm	0.07

标准光纤产品-掺铒(Er) Standard Fiber Products – Erbium-doped

**Cladding diameter
内包层直径
125 μm**



Available core types 可提供的纤芯类型

Er level	SC	DC
16	8 μm	
20	4 μm HC	
30	4 μm , 4 μm HC	
40	4 μm	
60		20 μm
80	4 μm 8 μm	
110	4 μm	
120		20 μm

SC = single-clad 单包层 = high-index coated 高折射率涂覆层

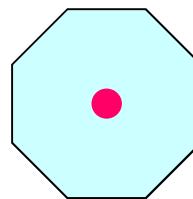
DC = double-clad 双包层 = low-index coated 低折射率涂覆层

HC = high cutoff variant 高截止版本

Numerical apertures 数值孔径

Core diameter 芯径	NA
4 μm	0.2
8 μm	0.13
20 μm	0.09

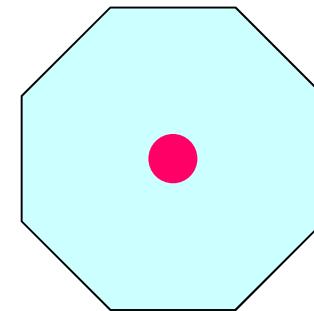
**Cladding diameter
内包层直径
250 μm**



Available core types 可提供的纤芯类型

Er level	DC
60	40 μm

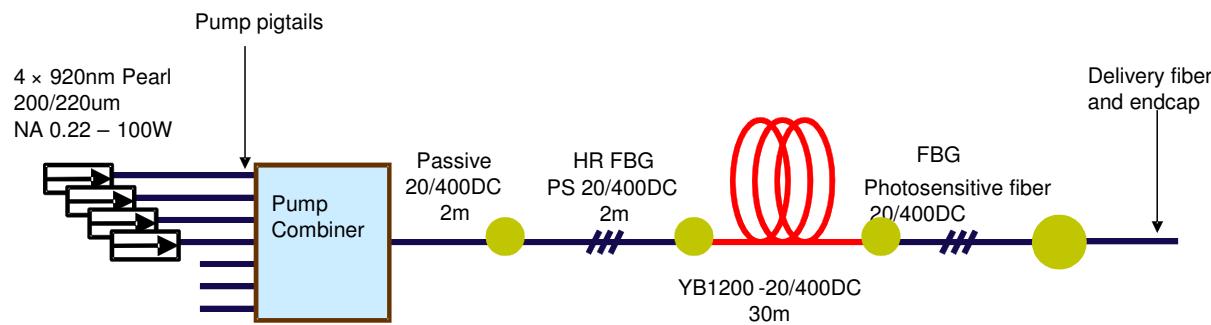
**Cladding diameter
内包层直径 400 μm**



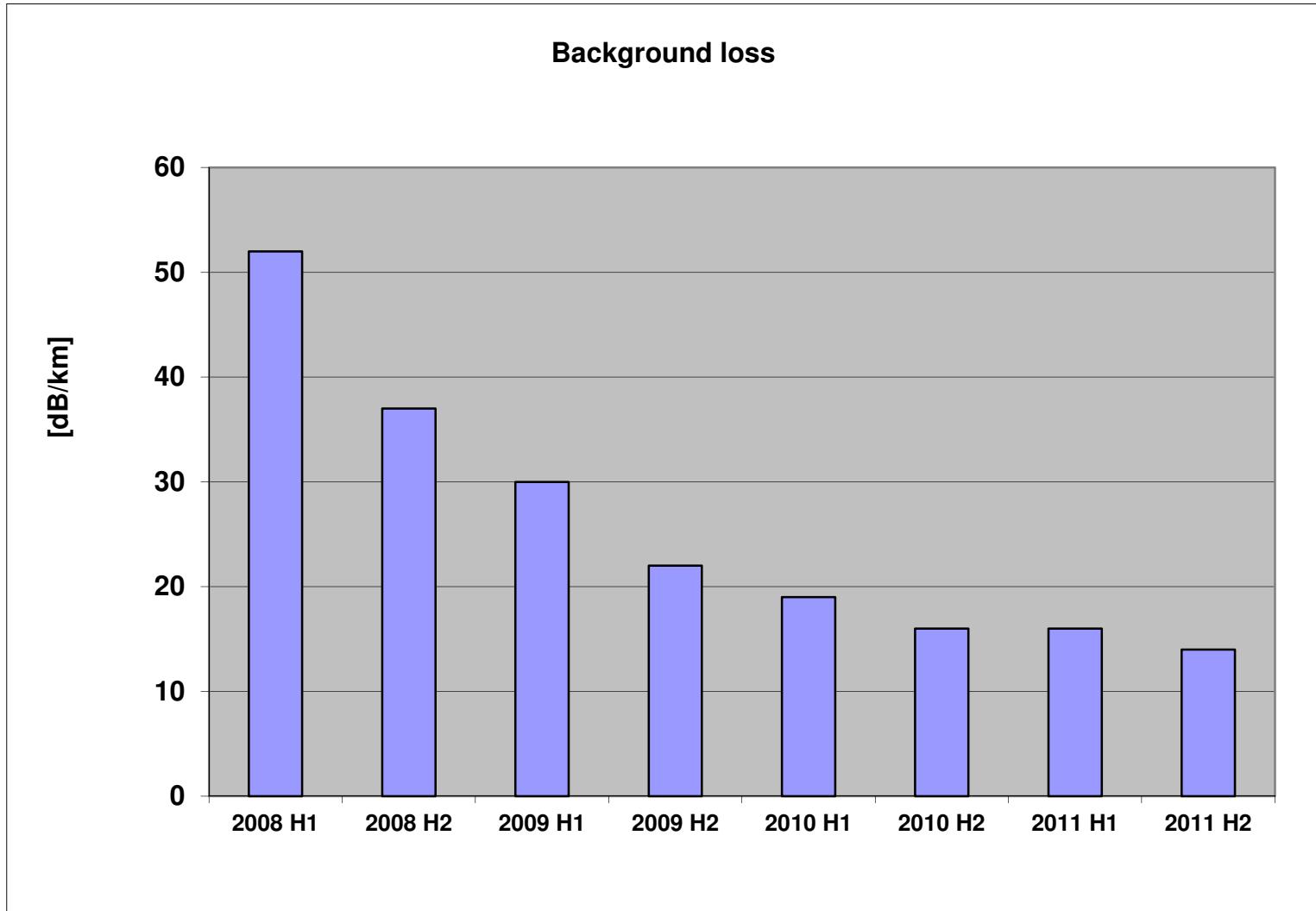
Available core types 可提供的纤芯类型

Er level	DC
60	65 μm

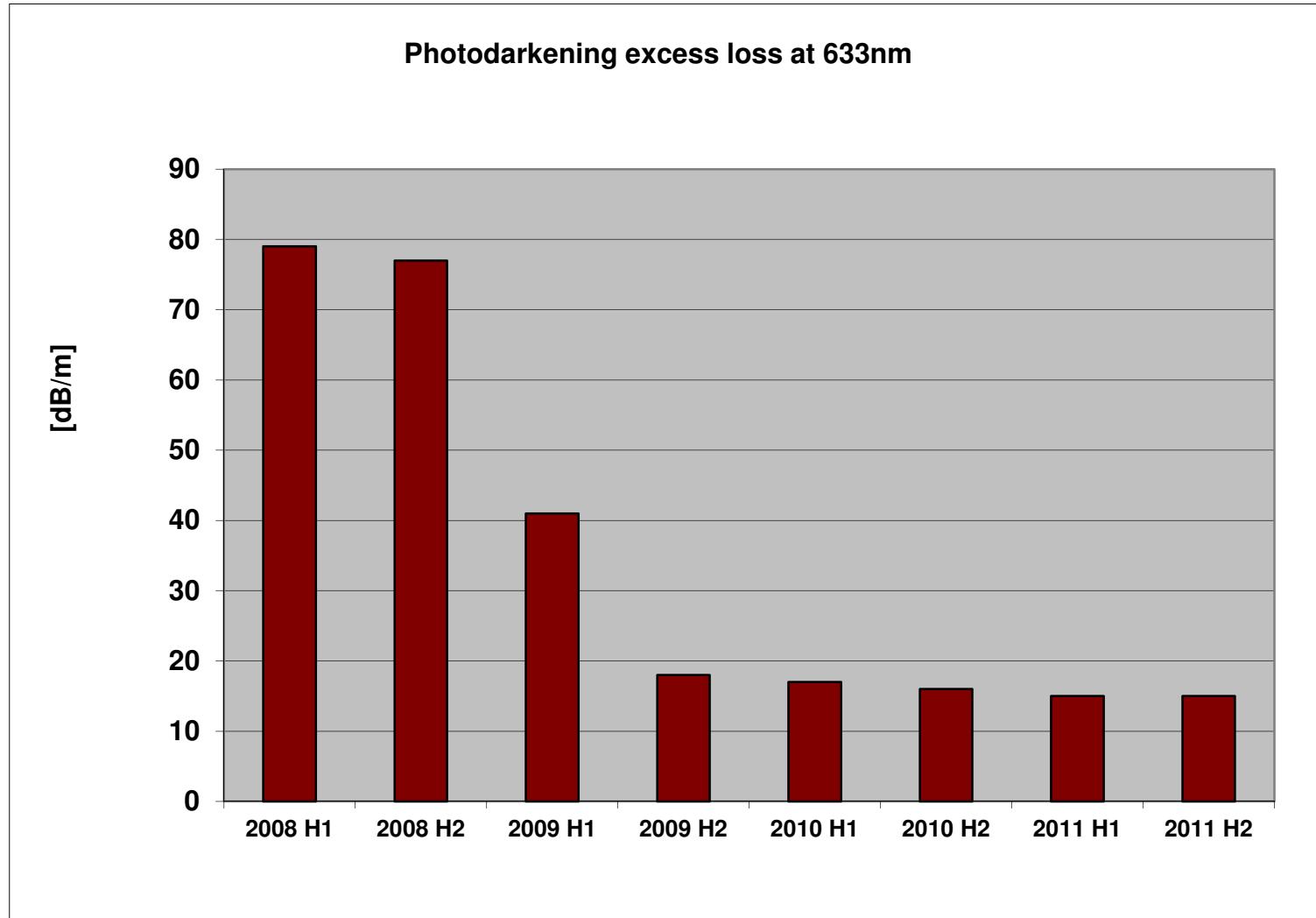
- **目标是优化光纤激光器、放大器中所有元件的模场匹配**
Goal is to optimize mode coupling between all the elements of a fiber laser/amplifier
- **我们提供：** We offer:
 - 匹配的无源单/双包层光纤，以用于元器件、接续和传输
Matching passive single clad and double clad fibers for components, relay and delivery fibers
 - 匹配的光纤端帽 Matching end cap fibers
 - 匹配的光纤布拉格光栅 Matching Fiber Bragg Gratings (FBG's)
 - 匹配的泵浦耦合器 Matching pump combiners
 - 匹配的泵浦尾纤 Matching pump pigtail fibers



背景损耗的优化 BG loss improvement



光子暗化损耗的优化 PD loss improvement



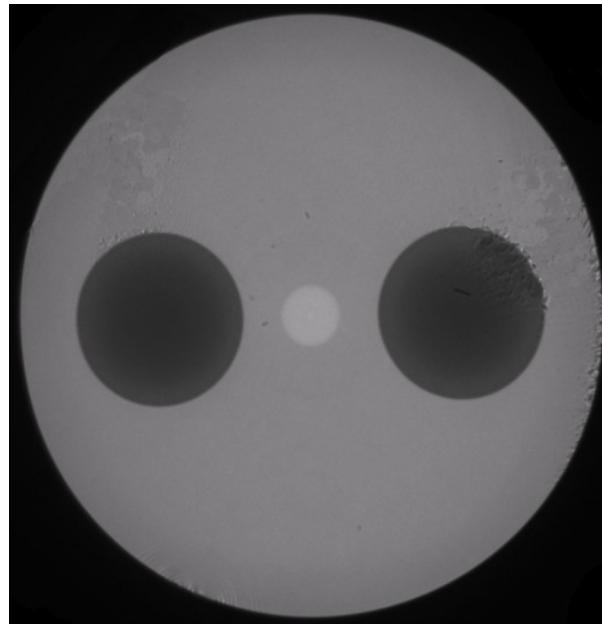
更高双折射的保偏光纤正在优化中

Higher birefringence polarization maintaining fibers being improved

- 我们将不断更新保偏光纤产品线， 提供更高的双折射 We're updating our line of PM fibers with higher birefringence versions

- 2013年将继续保偏光纤的优化工作

The work will be continued through 2013



2013年第一季度的指标变化 Changes during Q1'13

光纤类型 Fiber type	新指标 New specification	库存光纤的实测参数 Fiber in std stock
Passive-12/125DC-PM	> 1.6e-4	1.7e-4
Yb1200-12/125DC-PM	> 1.6e-4	1.7e-4
Passive-25/250DC-PM	> 1.6e-4	1.9e-4
Yb1200-25/250DC-PM	> 1.6e-4	1.6e-4

双包层光纤将采用新一代的涂覆层材料，能够在更高温湿度下稳定工作
The DC coating will be changed to operate in higher temperatures

- 我们研发了全新的双包层光纤涂覆层材料和工艺，能够保证光纤在更高温度和更高功率水平下稳定工作** The new coating process for double clad fibers was developed to sustain higher temperatures and higher power operation
- 我们考察了下列特性，并在实验中对比了新旧光纤涂覆层的性能**
The following characteristics were considered and tested when comparing the new coating to the old

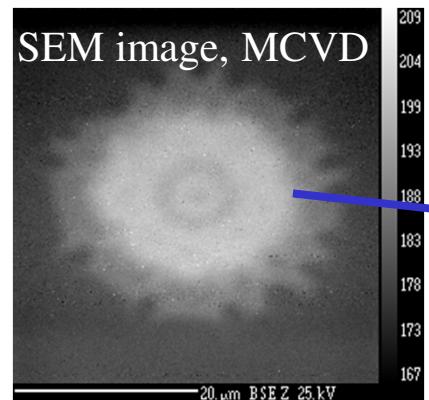
光纤特性 Fiber property	旧涂覆层 Old DC coating	新涂覆层 New DC coating
包层数值孔径 Cladding NA	>0.48	>0.48
工作温度 Operating temperature	-40 to +85 °C	-40 to +120 °C
工作湿度 Operating humidity	Non-condensing	Non-condensing
剥离特性 Strippability	好 Good	好 Good
二次披覆材料 Recoating material	有 Available	有 (和前代兼容) Available (also compatible with old)
机械强度(典型) Mechanical strength (typical)	Proof level >100 kpsi n > 20	Proof level >100 kpsi n > 20

- 将在2013年第一季度应用到标准光纤产品** To be introduced in standard fibers during Q1'13

竞争对手的掺杂光纤由相对较少的层数构成，层较厚

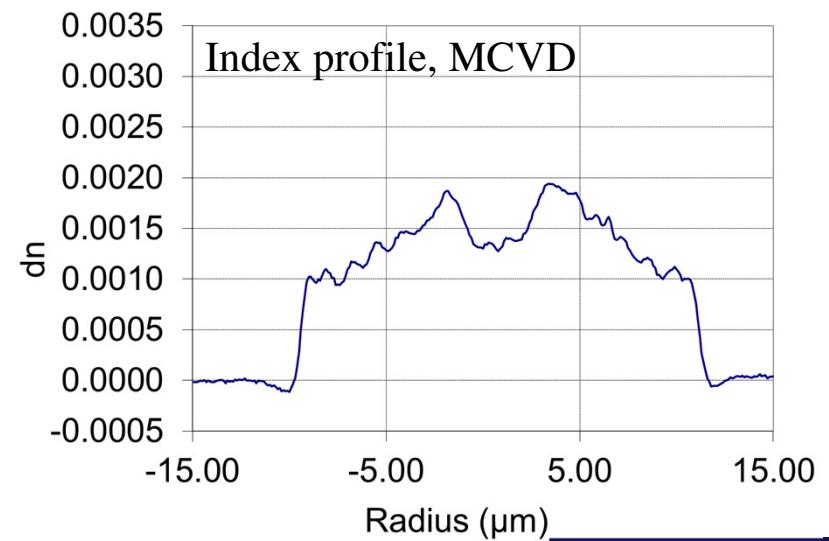
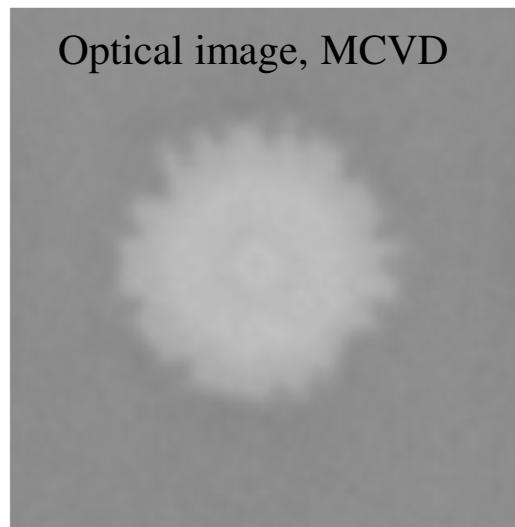
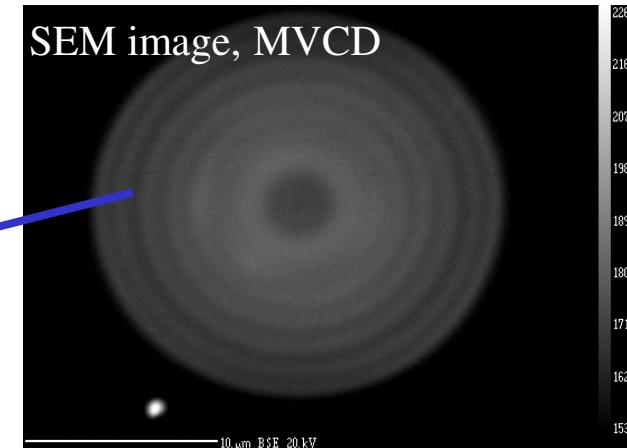
Competitive doped fibers comprised of relatively few and thick layers

MCVD COTS 25/250 fiber
purchased in 2011



Rings caused by 4-10 layers of doping
=> unhomogeneous composition
圆环结构清晰可见，
由于纤芯是由4-10层的掺杂构成
=>纤芯组分均匀性差

MCVD COTS 20/400 fiber
purchased in 2011

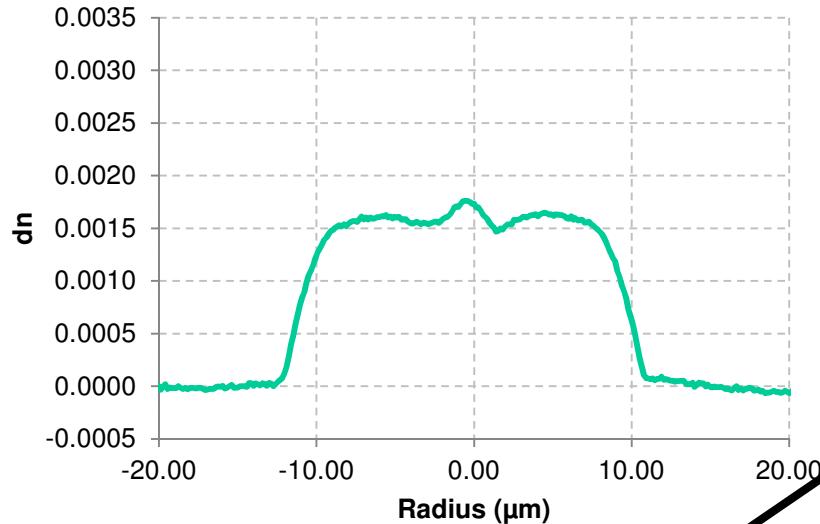


DND的折射率分布可以被精确地控制-径向

Refractive index of DND can be accurately controlled – radially

DND可以实现阶跃型...

DND can do step index ...

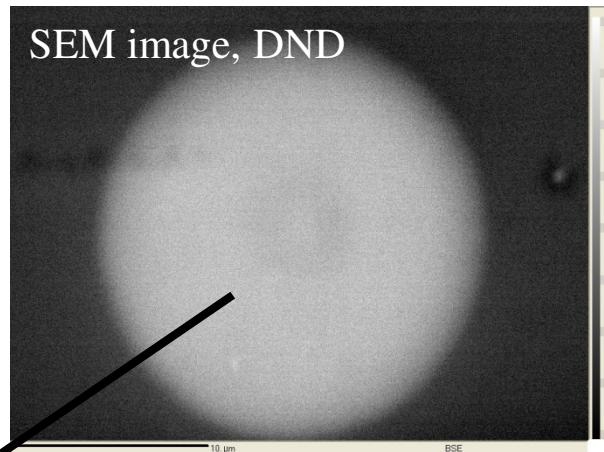


两种光纤均为20/400结构

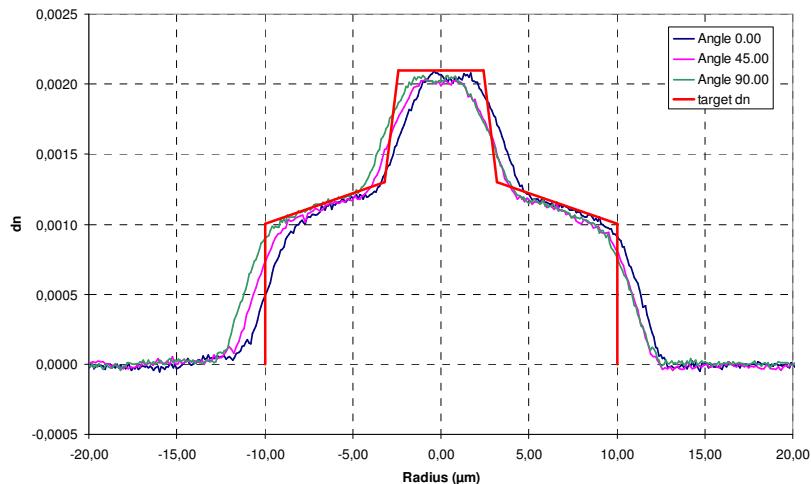
Both fibers are 20/400 geometry

⇒ 数百层的掺杂的层数
纤芯组分均匀性优异

⇒ Hundreds of doped layers
Homogeneous composition



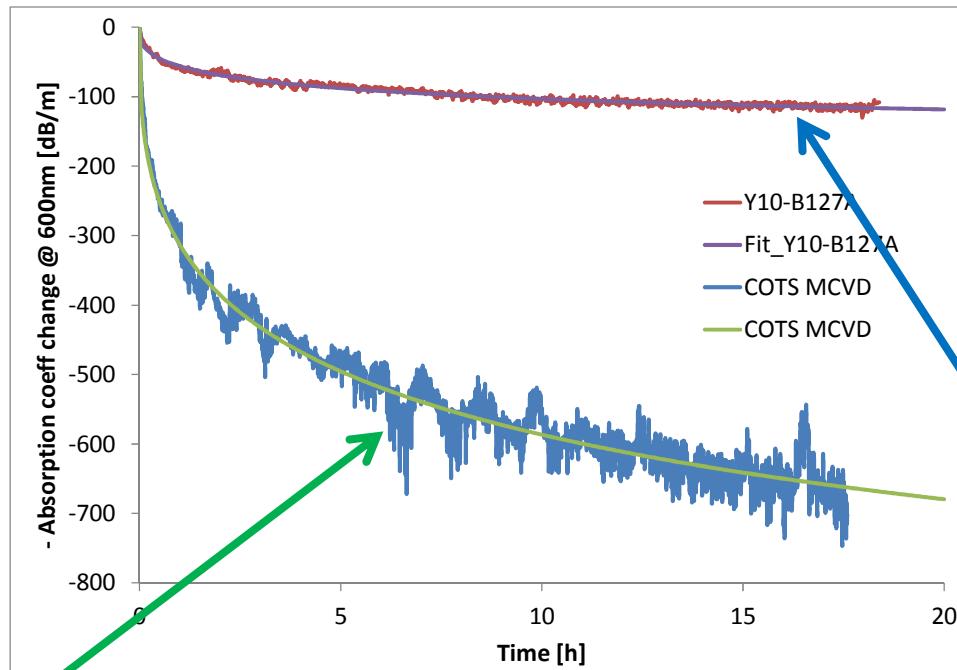
...或者复杂的折射率分布，用以控制模场分布
... or profiled index for modal discrimination



可忽略不计的光暗化效应，高效率-nLIGHT Yb1200-20/400DC光纤

Negligible photodarkening & high efficiency in nLIGHT Yb1200-20/400DC

加速的光暗化测试，70%上能级粒子数
Accelerated PD test at 70% inversion



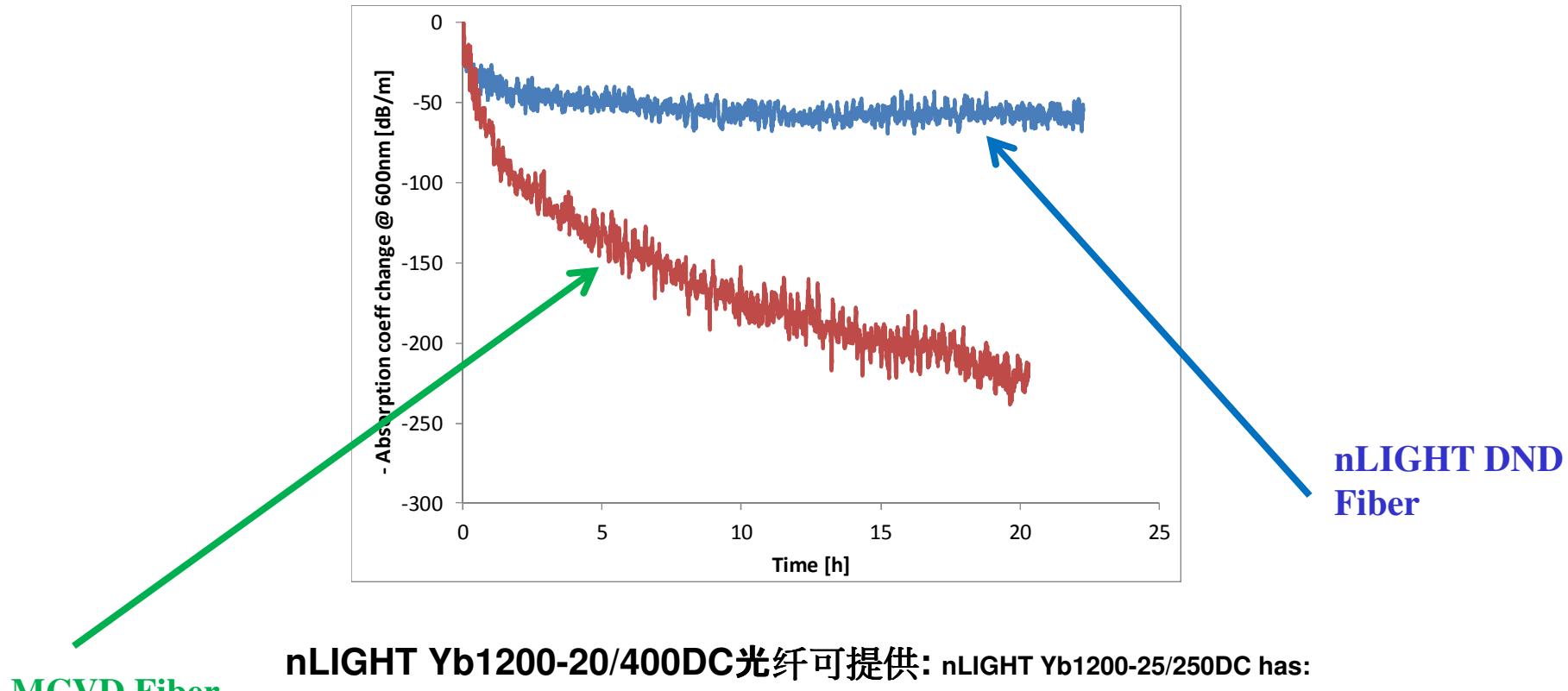
nLIGHT DND
Fiber

MCVD Fiber

- nLIGHT Yb1200-20/400DC光纤可提供: nLIGHT Yb1200-20/400DC has:
- **13-20% 更高的包层泵浦吸收** 13-20% higher cladding absorption
 - **光暗化效应低6倍 (注意：竞争对手的光纤的PD损耗尚未饱和)** 6X lower photodarkening (reference fiber not yet saturated)
 - **同等的高效率, 75-80% @ 920nm泵浦**
Similar high efficiency, 75-80% @ 920nm pumping

可忽略不计的光暗化效应，高效率- nLIGHT Yb1200-25/250DC光纤

Negligible photodarkening & high efficiency in nLIGHT Yb1200-25/250DC

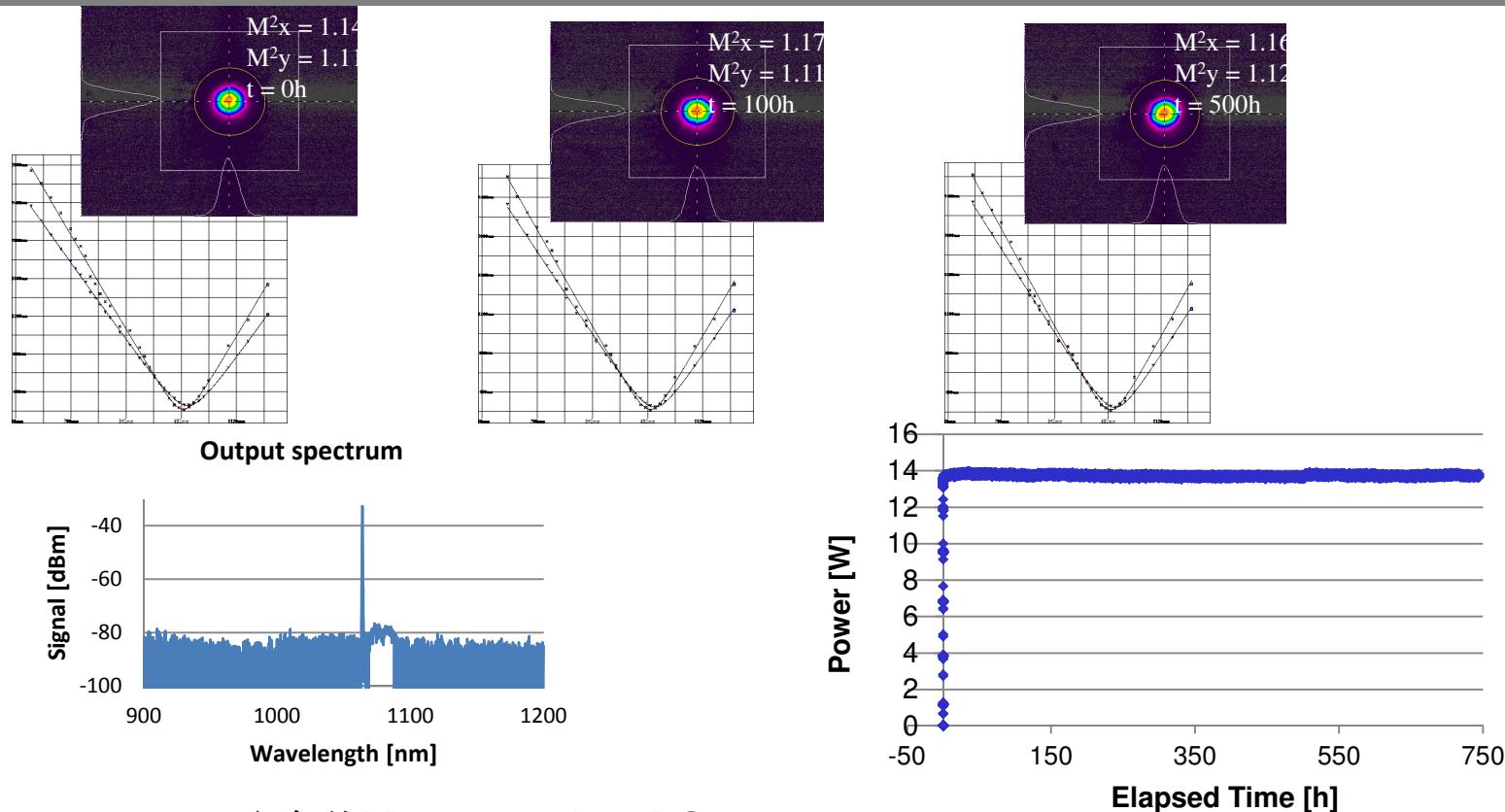


nLIGHT Yb1200-20/400DC光纤可提供: nLIGHT Yb1200-25/250DC has:

- ~20% **更高的包层泵浦吸收**
~20% higher cladding absorption
- **光暗化效应低4倍 (注意：竞争对手的光纤的PD损耗尚未饱和)**
4X lower photodarkening (reference fiber not yet saturated)
- **同等的高效率, 75-80% @ 920nm泵浦**
Similar high efficiency, 75-80% @ 920nm pumping

卓越的光束质量长时间稳定性-Yb1200-25/250DC

Exceptional Long-term Beam Quality Stability in Yb1200-25/250DC



- 库存的Yb1200-25/250DC
Yb1200-25/250DC from stock
- 高增益-> 21.5dB, CW种子源 (输出功率14W)
Higher gain - >21.5dB with cw seed (power about 14 W)
- 目标为一月底达到1000h
Target is 1000h by the end of January
- 种子源为1064nm CW, ~0.09W
Seed is 1064nm cw, ~0.09W
- 测试还将继续
Test will continue

光束质量总结 Summary of the beam quality results

- 所有的测试均为1000小时 (Y10-B019A 为2000小时)
All measurements 1000h (Y10-B019A was 2000h)
- 未观察到光束质量恶化
No beam quality degradation observed

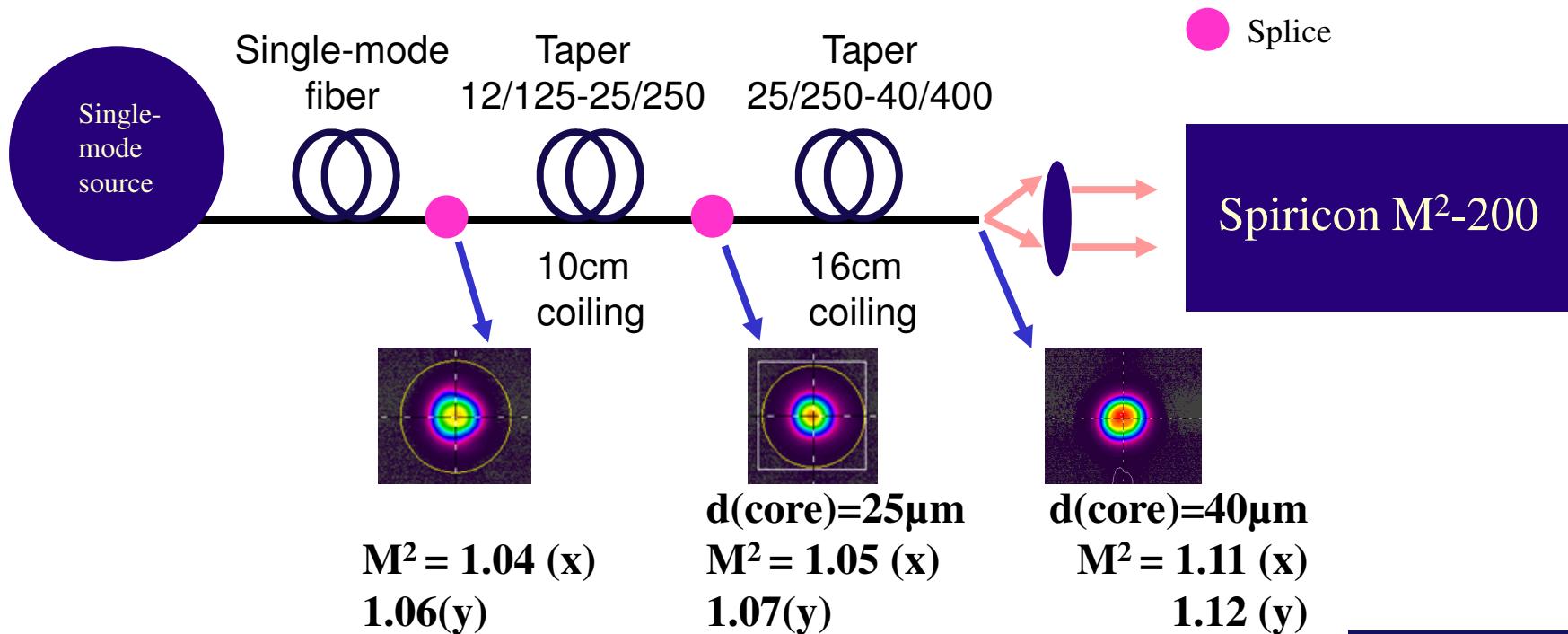
Fiber type	Fiber code	Length [m]	Gain [dB]	Power [W]	NA	Coiling Ø [cm]	M ² Start x/y	M ² End x/y
Yb700-25/250DC	Y10-B019A-01-1A out	4	10	20	0.071	8 (3D)	1.15/1.16	1.15/1.11
Yb700-30/250DC	Y10-B084A-01-1B1 out	3	20.8	11.4	0.068	8 (3D)	1.16/1.13	1.11/1.11
Yb1200-25/250DC	Y10-B306A-01-1F in	3	21.5	13.7	0.070	8 (3D)	1.14/1.11	1.14/1.11
Yb1200-25/250DC	Y11-B052A-01-1A2 out	2.5	22.2	14.8	0.059	16	1.18/1.08	1.16/1.09
Yb1200-30/250DC	Y11-B027A-01-1B4B out	2.5	21.4	12.5	0.069	8 (3D)	1.18/1.08	1.16/1.09

无源模场匹配器/拉锥光纤 Passive Mode Field Adapters/Taper

nLIGHT无源拉锥光纤能够在大纤芯尺寸下保持高光束质量

nLIGHT passive tapers enable good beam quality with large core sizes

- **拉锥光纤的芯径由单模光纤尺寸变化至40μm**
Scaled from a single mode fiber core to 40 μm core
- **M² 保持小于1.15.**
 M^2 remained below 1.15.
- **拉锥光纤是通过改变拉丝塔的拉丝速度制备，可大批量生产**
Tapers fabricated in mass by changing drawing speed on the tower
- **可用于减小半导体激光器尾纤的模场尺寸**
Can be used for diode pigtail mode field reduction



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nLIGHT 拉锥光纤-没有任何熔接点和其他的不连续

nLIGHT tapers are free of splices and other discontinuities

- **拉锥光纤由光纤拉丝工艺制备，与通常的预制棒拉丝工艺兼容**

The tapers are manufactured during fiber draw – process is compatible with typical preforms

- **纤芯/包层比保持不变**

Core / cladding ratio is preserved

- **细端光学特性与标准光纤(12/125, 25/250)匹配**

Small end optically matched to standard fibers (12/125, 25/250)

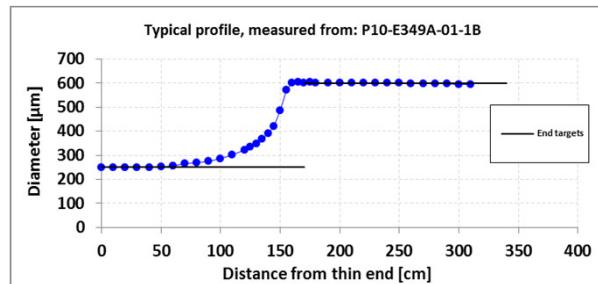
- **可保持优异的光束质量**

Excellent beam quality preservation

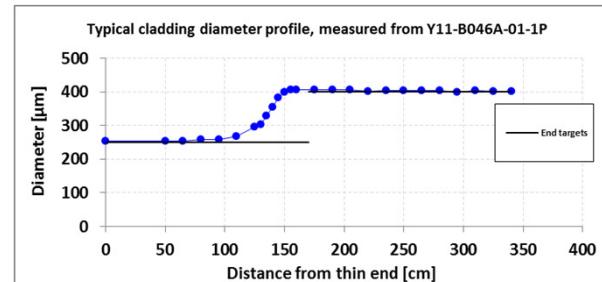
- **保偏拉锥光纤典型的偏振消光比>20dB**

Typical PER >20 dB over PM tapers

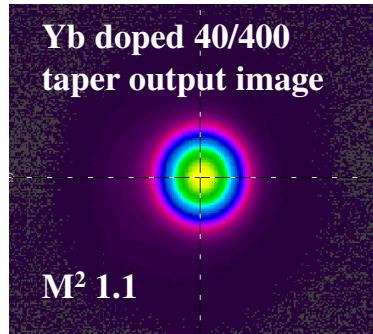
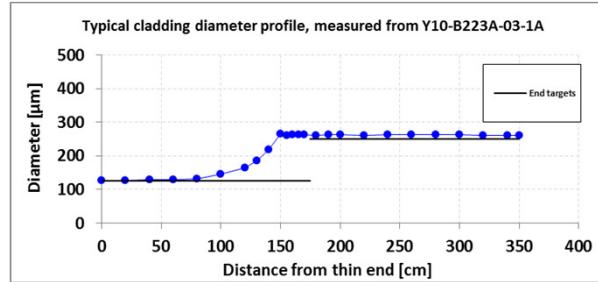
25/250-60/600



25/250-40/400



12/125-25/250



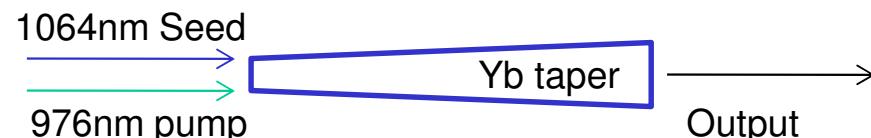
拉锥光纤放大器用于>200kW 峰值功率/ 17ps 脉冲光纤激光器

Tapered amplifiers enable >200kW peak / 17 ps pulsed fiber lasers

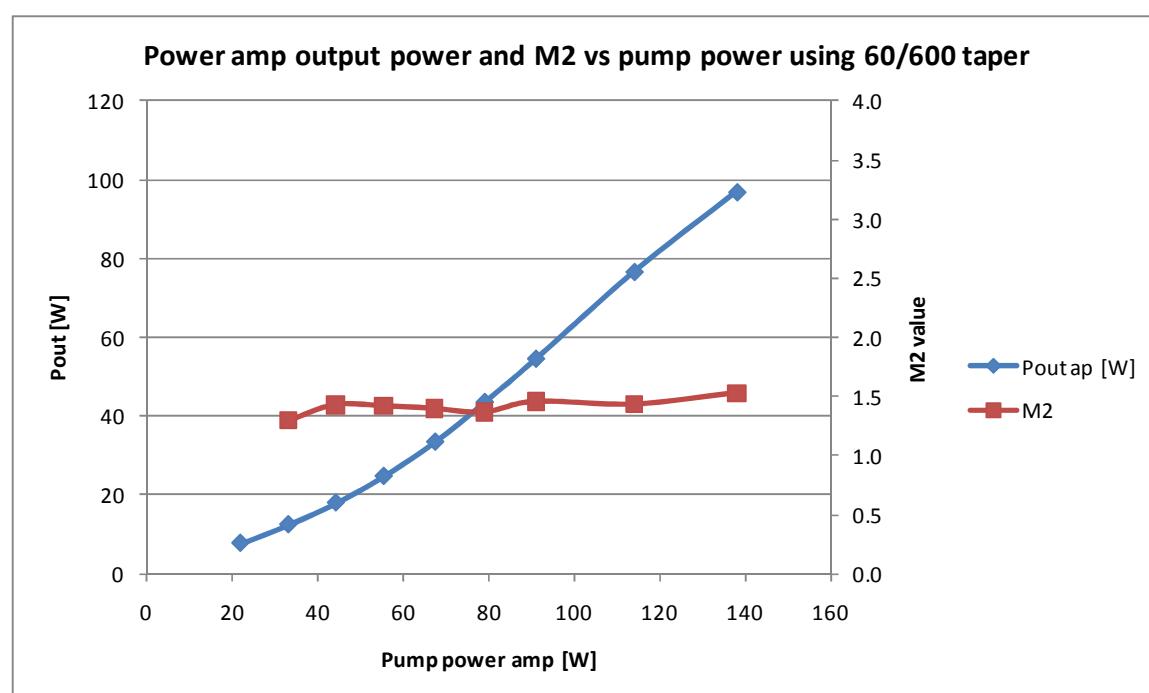
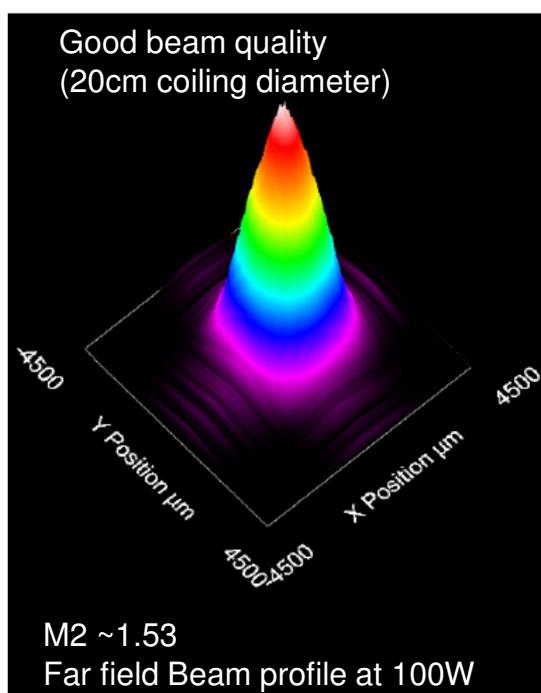
种子功率 Seed power [W]	5W
平均功率 Average power [W]	100W
峰值功率 Peak power [W]	200kW*
脉宽 Pulse duration [ps]	~17*
重频 Repetition rate [MHz]	~30
光束质量 M2	<1.5
偏振消光比 PER [dB]	>12

拉锥光纤用于同向泵浦光纤放大器

Fiber Amplifier using a taper in co-pumped configuration



(*) Assuming no pulse broadening 假定无脉冲展宽



DND- 直接纳米粒子沉积可实现径向掺杂控制

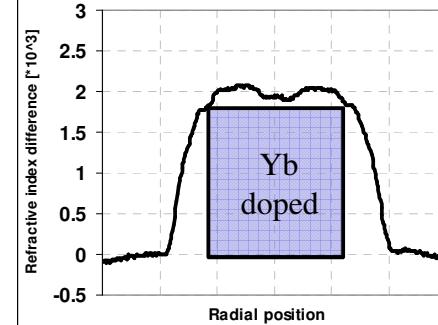
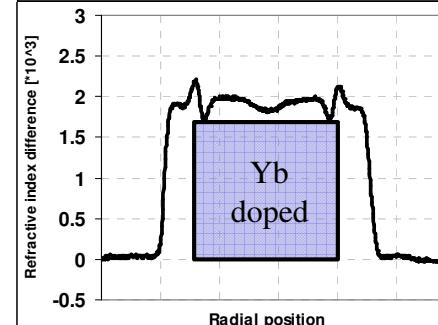
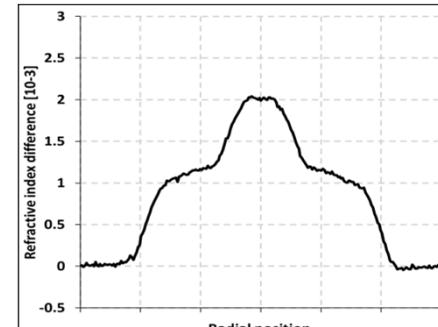
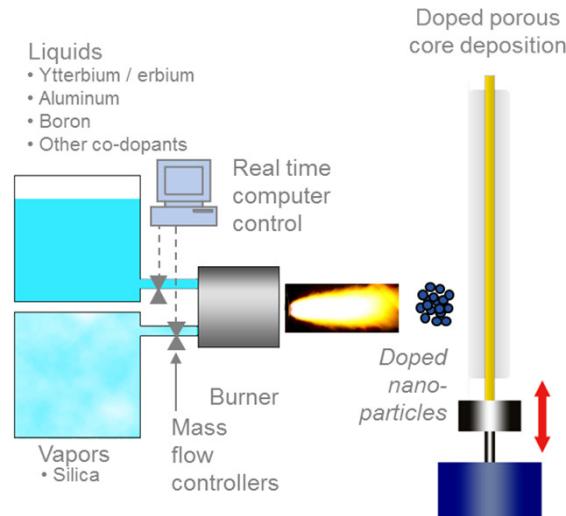
DND – Direct Nanoparticle Deposition enables radial dopant control

折射率和掺杂控制实例（近期）

Examples of index & dopant control (recent)

沉积系统示意图

Schematic of the deposition system



折射率特别定制
纤芯整体掺杂
Shaped index
Fully Yb doped

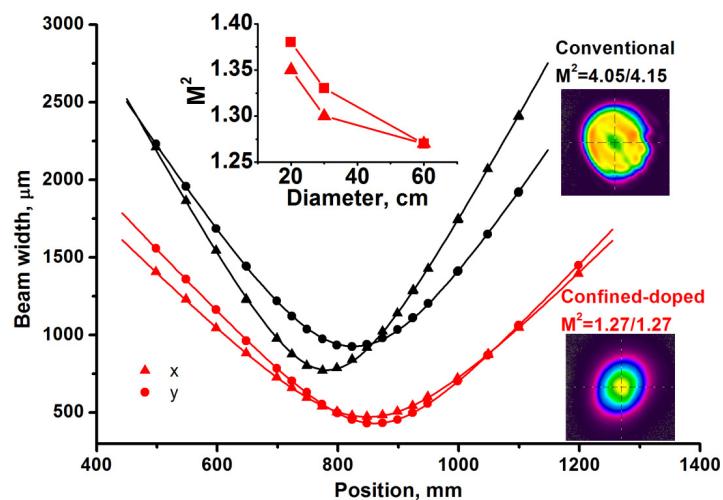
阶跃折射率
局部控制掺杂
Step index
Confined doping

抛物线型边缘折射率
局部控制掺杂
Parabolic edges
Confined doping

新型的特制纤芯光纤（库存现货） - Yb1200-30/40/400DC

New Tailored Core Fiber in stock – Yb1200-30/40/400DC

		Yb1200-30/40/400DC
Optical		
Peak cladding absorption at 920nm	dB/m	1.3 ± 0.4
Core NA		0.07 ± 0.01
Cladding NA		> 0.46
Geometrical and mechanical		
Core diameter	μm	40 ± 4
Doped diameter	μm	30 ± 3
Core concentricity error	%	< 1.5
Cladding diameter flat-to-flat	μm	400 ± 15
Cladding geometry		Octagonal
Coating diameter	μm	500 ± 15
Proof test	kpsi	> 50



Actions
