Fiber laser performance and economics – status and trends for low and high power CW, and pulsed lasers

LIEKKI

The Nanoparticle Fiber Company

Laser Marketplace, Laser 2007
Munich, June 20, 2007

Structure of this presentation

Liekki Corporation – brief introduction

Fiber laser market and the laser industry

Performance, economics, products and some key issues

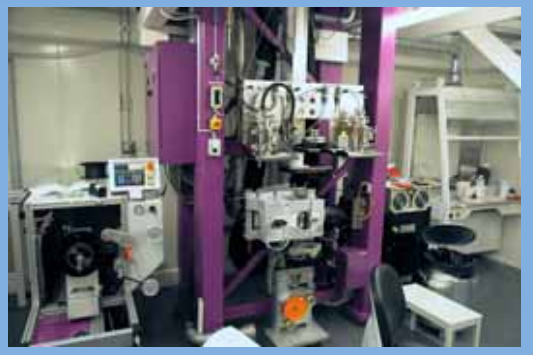
Conclusion

Liekki – the nanoparticle fiber company

Structure
- Liekki Corp. (Helsinki), subsidiary Liekki Inc. USA (Maryland)
- Founded 1999, factory ISO9001:2000 since 2002

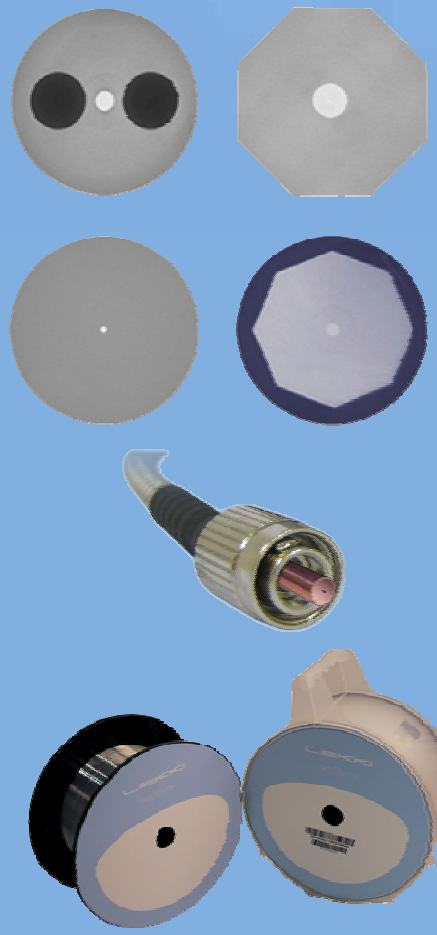
Technology and facilites
- Proprietary fiber manufacturing process – Direct Nanoparticle Deposition (DND)
- 16 patent families consisting of 37 granted patents
- 30+ patent applications and several inventions in process
- Full fiber production, module ass'y/integration and QA process
- Laser laboratory for high power testing

Personnel, customers and network
- Experienced team of 35 employees
- Customers include most fiber laser manufacturers worldwide
- Tight links to leading Finnish research institutes and universities
- Development with leading research labs worldwide, incl. Sandia, Univ. Michigan, Fraunhofer (Jena, Aachen), MIT Lincoln Labs

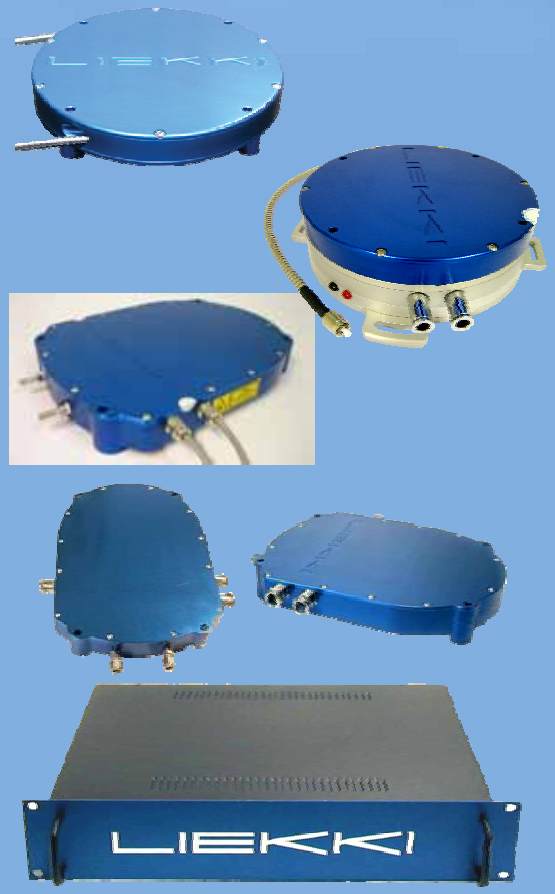


It is not enough to do fibers...

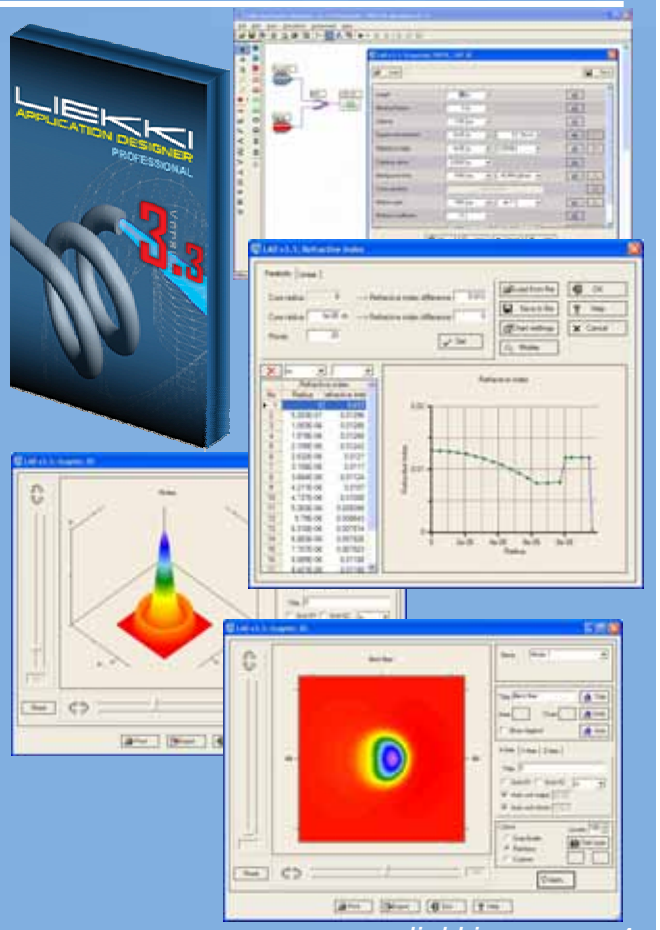
Active and passive fibers, fiber components



Subassemblies and modules



Design software



Structure of this presentation

Liekki Corporation – brief introduction

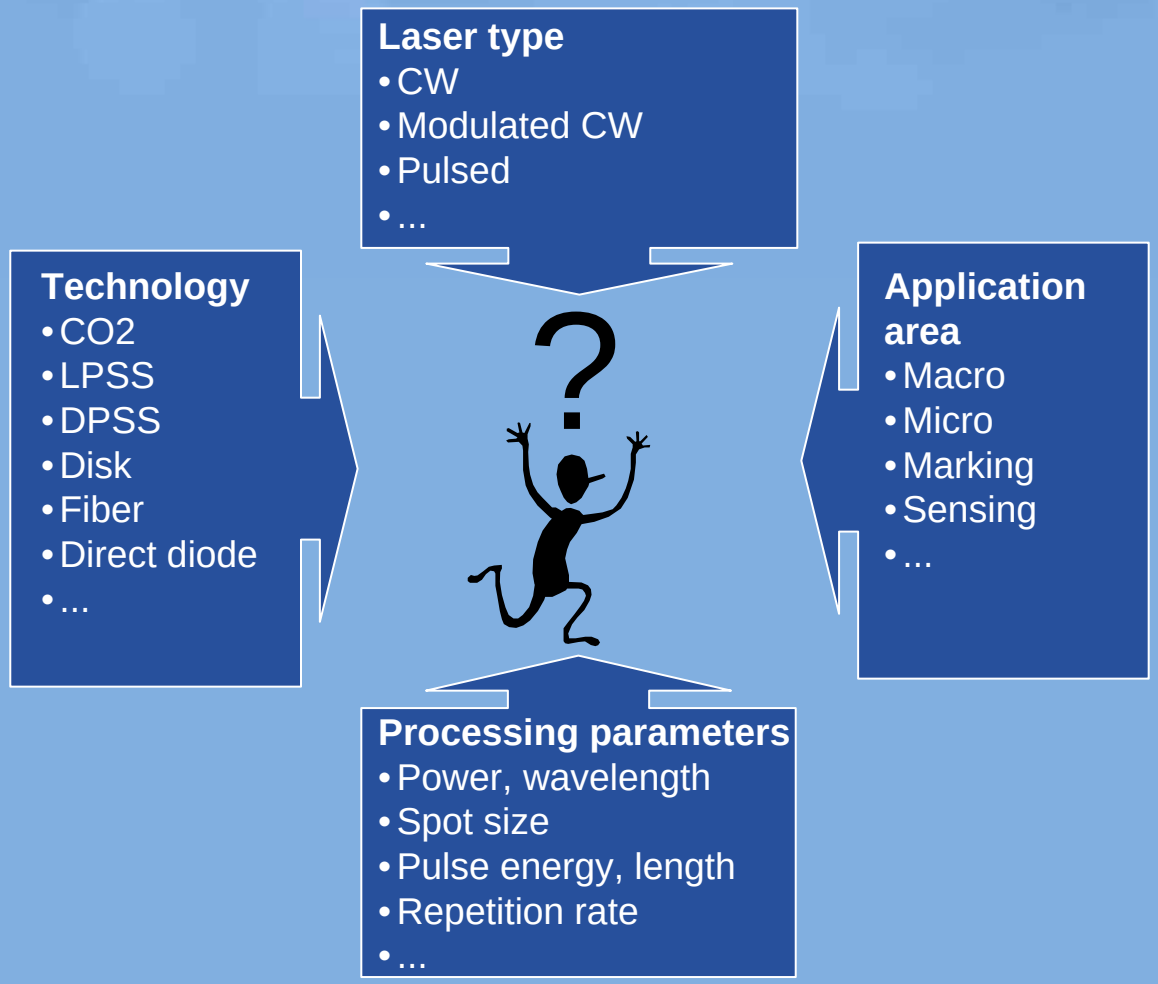
Fiber laser market and the laser industry

Performance, economics, products and some key issues

Conclusion

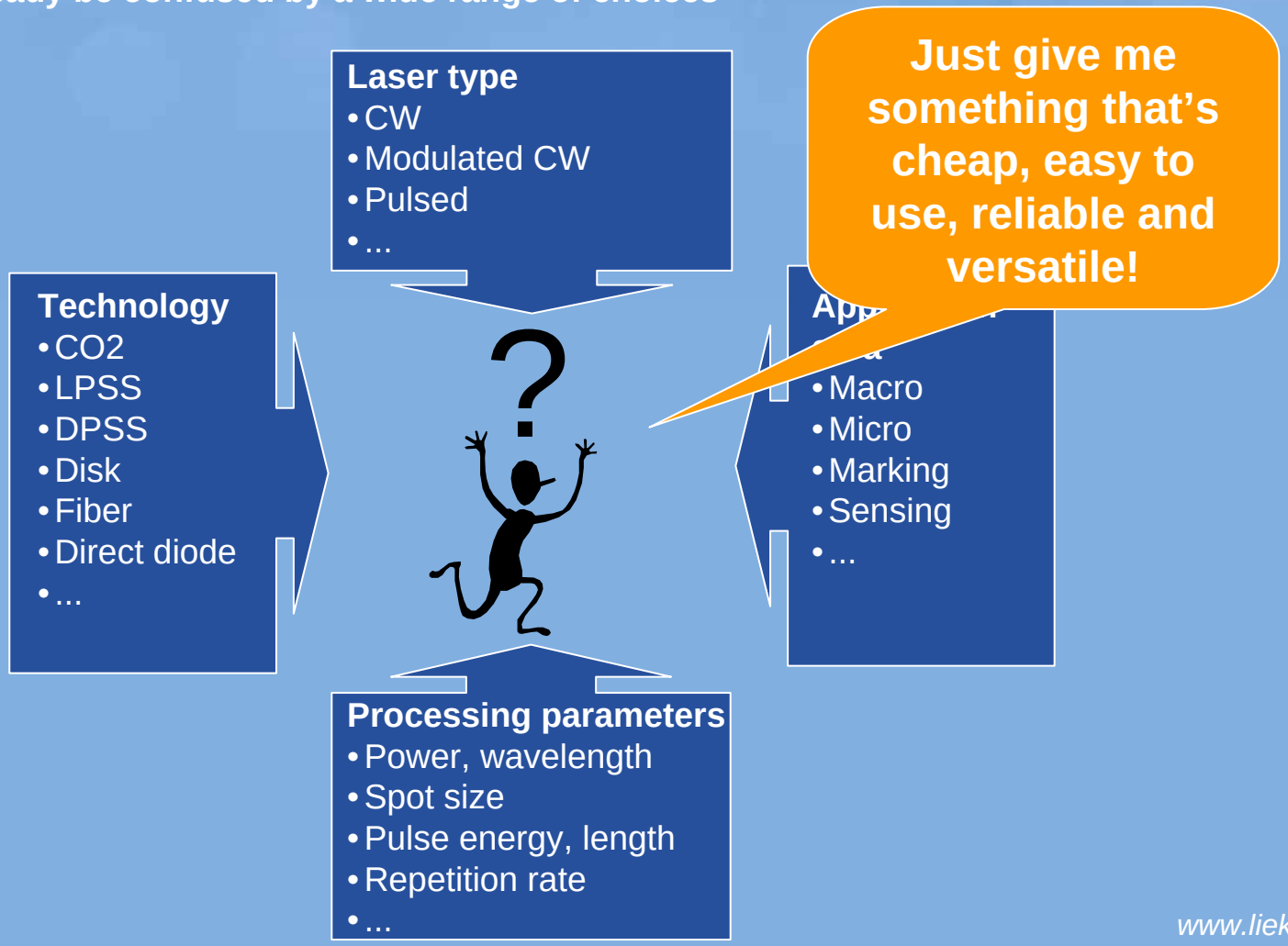
The last thing we need is more laser science...?

Users may already be confused by a wide range of choices



The last thing we need is more laser science...?

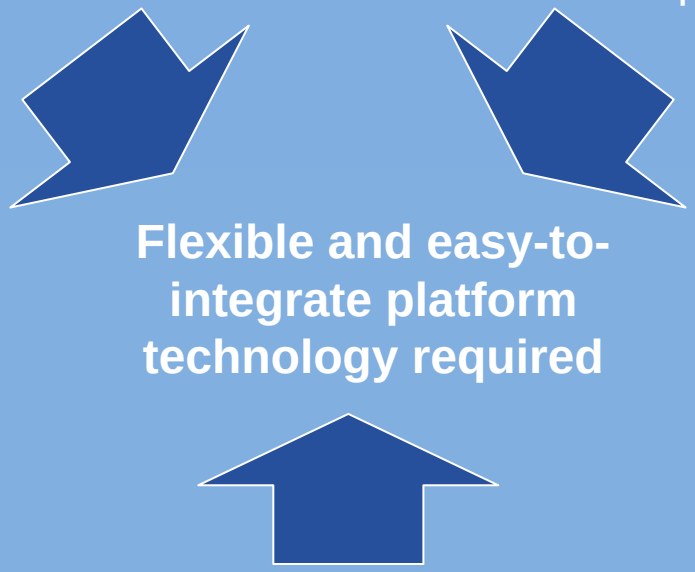
Users may already be confused by a wide range of choices



To drive growth, laser and systems providers must address increasingly demanding customer requirements

Continuous pressure on price pushing cost structure down

Demand for improved quality and reliability



Flexible and easy-to-integrate platform technology required

Continued fast-paced innovation to increase customer adoption

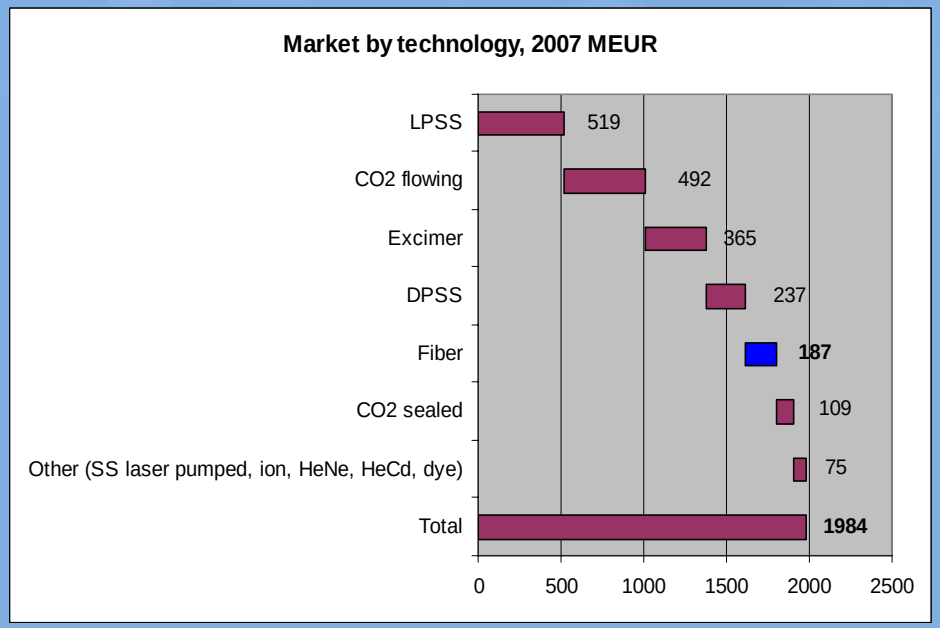
Diode and fiber laser technology with increased integration and ever-more monolithic design may provide solution

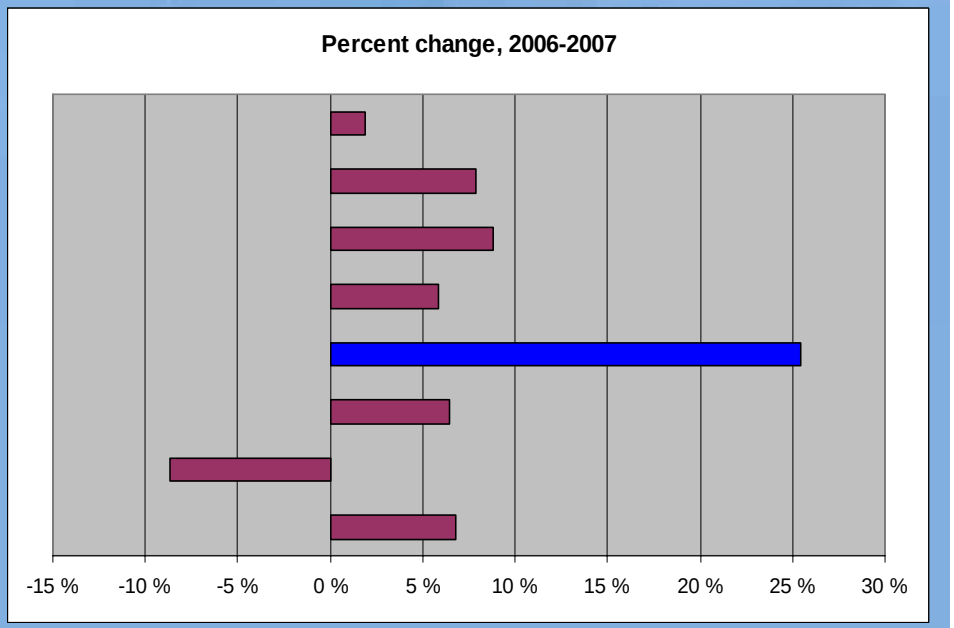
Laser types vs. applications - trend

Application	LPSSL	DPSSL & Fiber	DL	CO2	Excimer
High power cutting		✓		✓	
High power welding, surface treatment		✓	✓	✓	
Precision cutting, drilling, metal welding	✓	✓			
Marking		✓		✓	
Other macro processing	✓	✓	✓	✓	
Micro processing		✓		✓	✓

Source: OPTECH CONSULTING, 8th International Laser Marketplace

Fiber lasers growing fast to become important



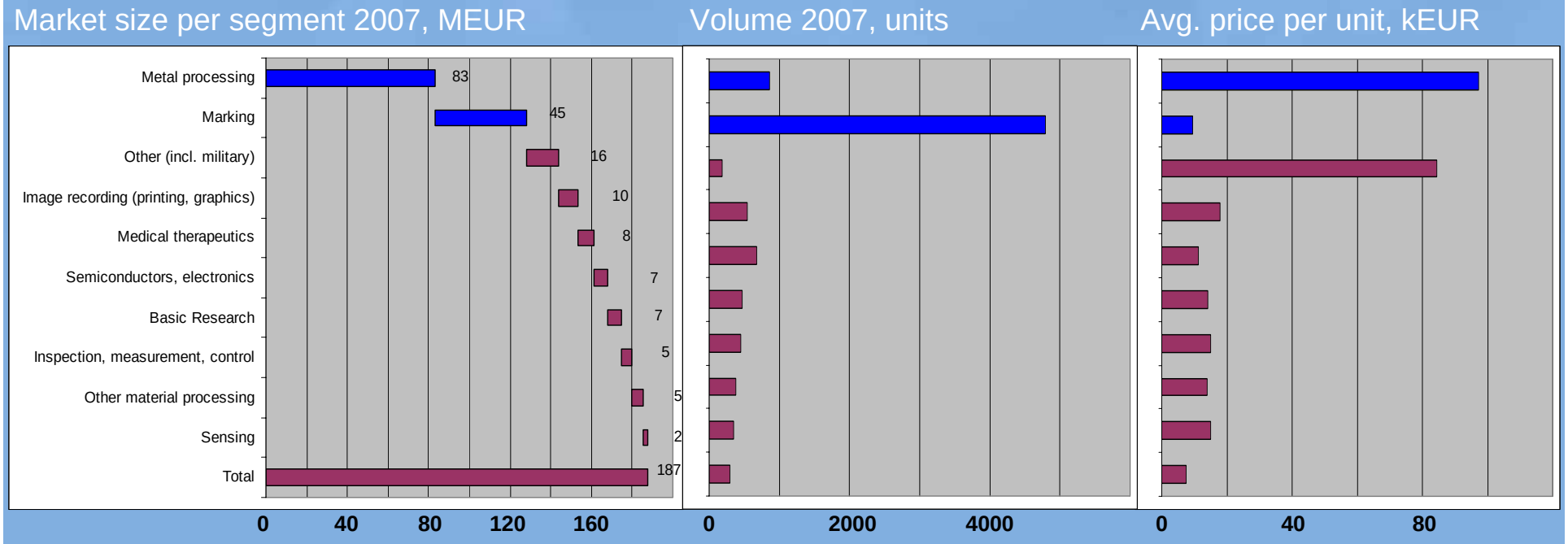


Assuming current growth rates fiber laser sales...

- ... starting from today's #5 position...
- ... pass DPSS in 2009
- ... pass LPSS and excimers in 2012
- ... pass flowing CO2 for #1 position in 2014
- ... exceed 1BEUR in 2015

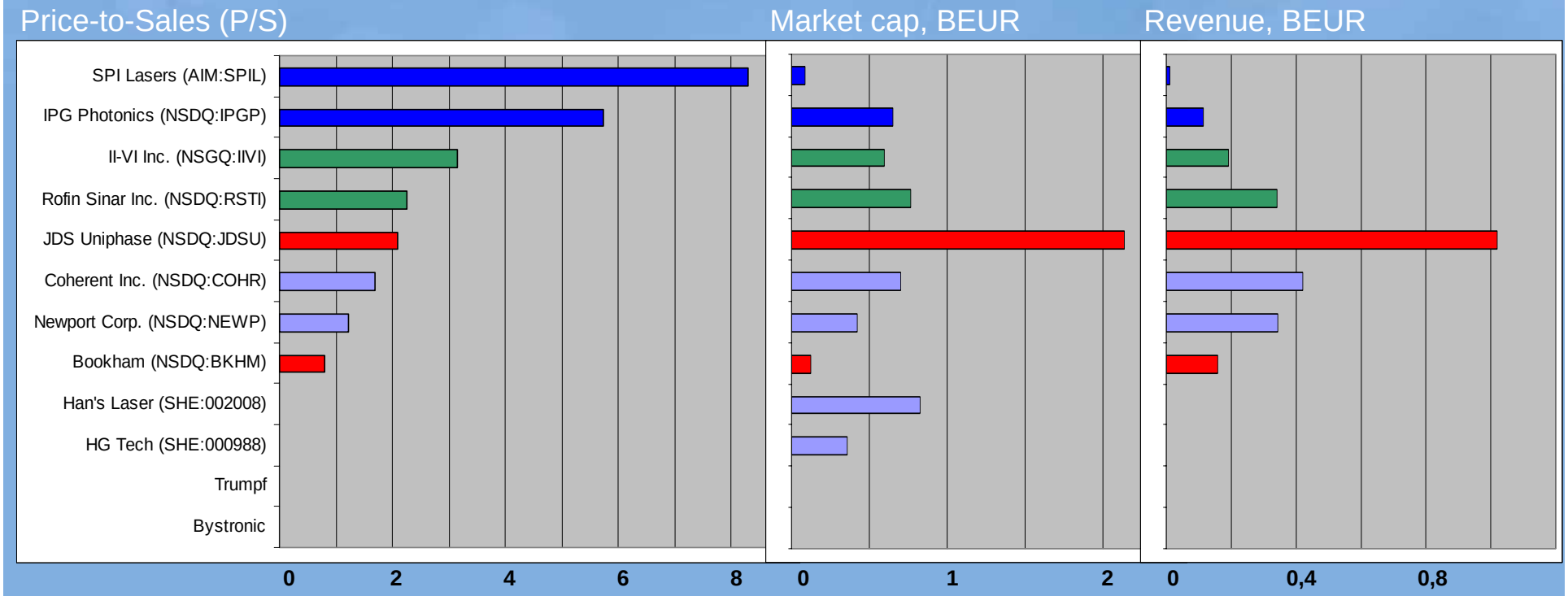
Source: Laser Focus World Marketplace Seminar, PW´07; Optoelectronics Report Jan 1, 2007

Metal processing and marking are the key markets now



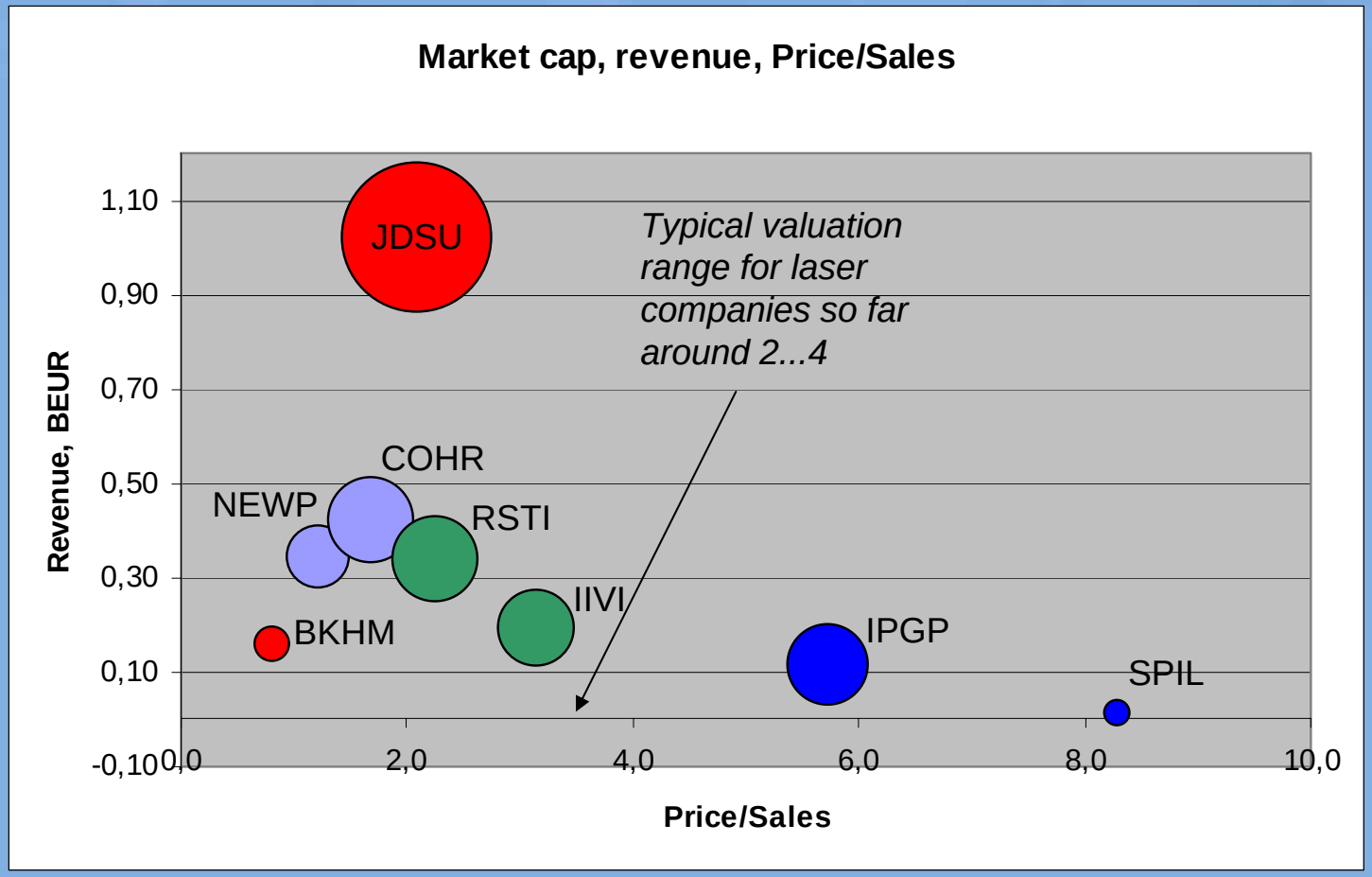
Source: Laser Focus World Marketplace Seminar, PW´07; Optoelectronics Report Jan 1, 2007

Capital markets have noticed fiber laser companies (at least pure plays...)



Addendum: GSI Group (NSDQ:GSIG) P/S 1,4, market cap 0,33BEUR, revenue 0,23BEUR
Addendum: Forward P/E JDSU 29, IPGP 24, IIVI 18, RSTI 17, COHR 16, BKHM N/A
Source: NASDAQ, Shanghai Stock Exchange, London AIM; Yahoo Finance; Google Finance
(NASDAQ sales numbers ttm, others latest available)

The landscape taking shape, but share prices turbulent



Change in share price (last 12 months)

- JDSU, BKHM -30%
- IPGP -20%
- NEWP, COHR -5%
- RSTI +25%
- IIVI +50%
- (Han's Laser +60%)
- (HG Tech +100%)

Note: Market cap depicted as relative area of circle
Source: NASDAQ, Shanghai Stock Exchange, London AIM; Yahoo Finance; Google Finance (NASDAQ sales numbers ttm, others latest available)

Do capital markets know something about technology and business model?

Company	Price-to-Sales	Typical markets	Key technologies	Strategic posture
IPG	5.7	Mat. processing, marking, medical, etc. (broad based offering)	Fiber and direct diode lasers	Tech platform + vertical integration + volume/low price
SPI	8.3	Low-med power mat. processing, marking, medical, military, ...	Fiber lasers	Vertical integration less diodes
Rofin-Sinar	2.3	”Macro, micro, marking”	High power CO2 etc.	Multi-tech
Trumpf	n/a	Material processing	Disk, CO2, diode bars	Tech platform(s) + vertical integration
Bystronic	n/a	High power material processing	High power CO2	Single-tech machinery
JDSU	2.1	Telecom/laser equipment manuf.	Diodes, (fiber)	”in progress”
Bookham	0.8	Telecom/laser equipment manuf.	Diodes	”in progress”
Coherent	1.7	Low-med power mat. processing, scientific, instrumentation, etc.	DPSS, low power CO2	Advanced laser + high margin?
Newport	1.2	Low-med power mat. processing, scientific, instrumentation, etc.	DPSS	Advanced laser + high margin?

Do capital markets know something about technology and busine

Observation 1: Fiber lasers ”pure plays” top the list

Observation 3: Rofin seems to continue with ”multi-tech”

Observation 2: IPG and Trumpf look very similar strategically

Observation 5: Incumbents previously quiet now announcing fiber lasers

Observation 4: ”Diode players” probing fiber lasers as path to enter industrial market

Company	Price/Sale		Key tech	
IPG	5.7	ng, medical, etc. (broad based offering)	Fiber and diode lasers	Vertical integration + volume/low price
SPI	8.3	Low-med power ma	s	Vertical integration less diodes
Rofin-Sinar		r	CO2	Multi-tech
Trumpf		g	Disk, CO2, diode bars	Tech platform(s) + vertical integration
Bystronic	n/a	material processing	High power CO2	Single-tech machinery
JDSU	2.1	Teleco	iodes, (fiber)	”in progress”
Bookham	0.8	Teleco	iodes	”in progress”
Coherent	1.7	Low-m scientif	SS, low power	Advanced laser + high margin?
Newport	1.2	Low-med scientific, instrumentation, etc.	DPSS	Advanced laser + high margin?

Structure of this presentation

Liekki Corporation – brief introduction

Fiber laser market and the laser industry

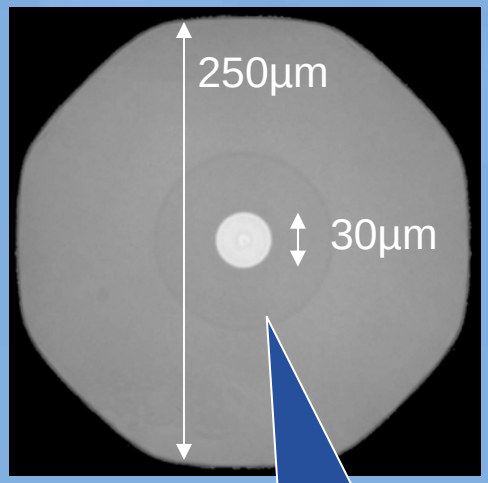
Performance, economics, products and some key issues

Conclusion

Technical perspective: Fiber lasers - breakthrough in brightness and efficiency

Design feature	Driving factors	Implication on laser performance
Gain region built into low loss waveguide	• Fibers with large mode area and single mode operation • Telecom grade silica and good heat conduction paths allow good thermal management	*Superior beamquality (brightness 10^5 that of diodes)!*
Very high gain and efficiency	• Low losses (silica fibers) • Effective gain materials (Yb, Er, Tm) • Efficient pumping – long interaction length • High intensity, low threshold	*Compact and powerful, very little energy wasted!*
Large bandwidth	• Ability to tailor gain profile with co-dopants	*Tunability, short pulse generation and amplification*
Highly confined laser field	• Despite LMA fibers, transverse area still small	*Component quality and managing nonlinearities key!*
Small active region volume	• High gain and avoiding nonlinearities implies short fibers	*Relatively low pulse energies (0.5...10...20mJ)*

DND fibers feature industry's highest pump absorption and excellent power tolerance



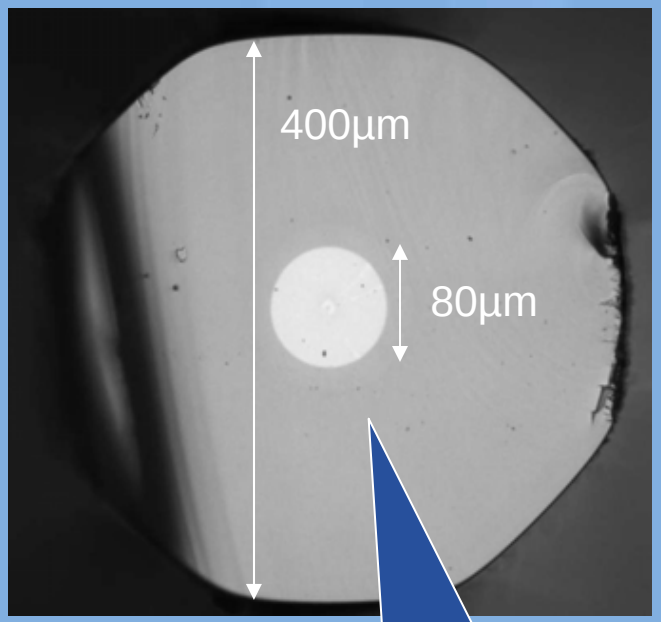
Core material is key to performance!

- Highly-doped Liekki Yb1200-30/250DC
- Pump absorption ~15dB/m at 976nm
- Single-stage amplifier seeded with microchip lasers
- Near diffraction-limited beam profiles (M^2<1.2)
- Peak power >1.2MW achieved with 0.38ns pulses
- Pulse energy >1.1mJ achieved with 2.3ns pulses
- High peak fluence of 410J/cm^2 reached

Authors	d_{core} (µm)	τ (ns)	P_{peak} (MW)	E_{pulse} (mJ)	M^2 (avg x,y)	$\Delta\omega$ (nm)	No. of stages	Peak fluence (J/cm^2)
Di Teodoro and Brooks[1]	40	0.45	1.5	0.7	1.05	0.13	two	160
Brooks and Di Teodoro[2]	40	1.0	1.0	1.0	1.05	0.034	two	230
This work	30	0.42	1.27	0.67	1.17	0.55	one	260
This work	30	4.0	0.35	1.1	1.19	1.0	one	410
Hou *et al.*[3]	80	0.1	6.0 (!)	1.1	1.2	?	three	93
Hou *et al.*[3]	80	3.1	0.5	3.3	1.2	?	three	280

Roger L. Farrow et al., "High-Peak-Power (>1.2MW) Pulsed Fiber Amplifier", Photonics West'06: Fiber laser III, Technology, Systems & Applications (6102), Session 7, paper 6102-22.

Extremely flat refractive index profile and uniform doping push the limits of VLMA fibers



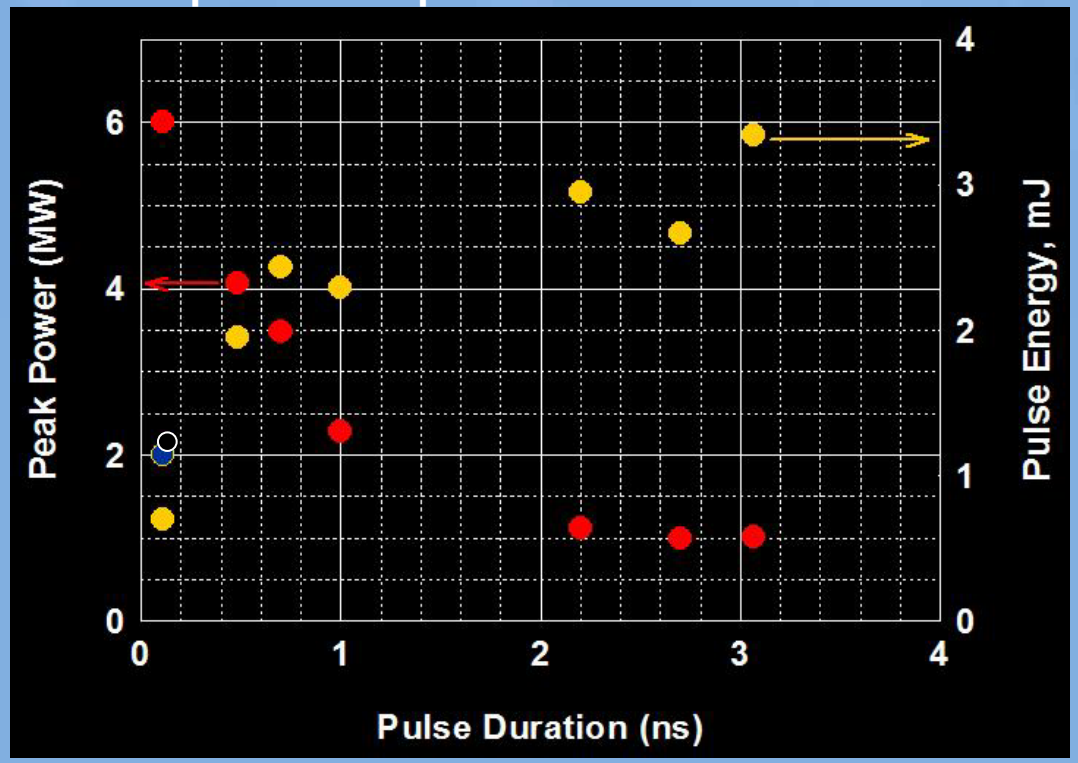
Core material is key to performance!

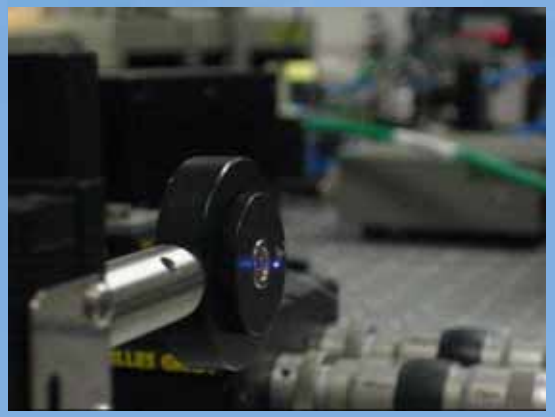
- Liekki Yb-DCF with 80µm core, 400µm clad
- Near diffraction-limited beam (M^2 <1.2) achieved despite very large core
- Largest demonstrated mode area (2750-μm^2) with single-transverse-mode operation
- Very high peak powers (~6MW with sub-ns pulses)
- High average power scaling up to 85W with MW pulses

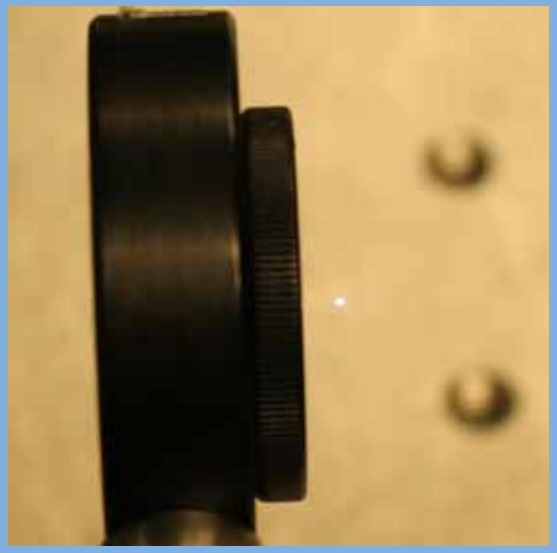
Kai-Chung Hou et al.,"Multi-MW Peak-Power Single-Transverse Mode Pulse Generation with an Yb-doped LMA Fiber Amplifier", Photonics West'06: Fiber laser III, Technology, Systems & Applications (6102), Late breaking development session, paper LBD2

The output was powerful enough to induce air breakdown...

Pulsed operation experiments:





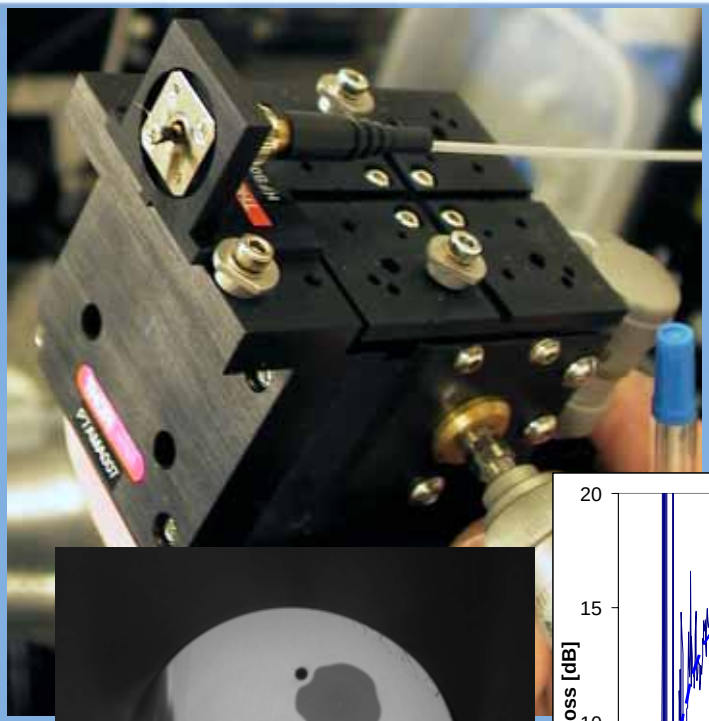


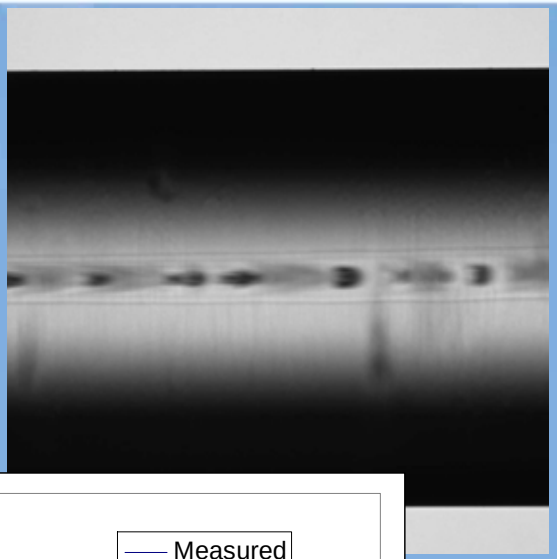
Atmospheric air break-down experiments:

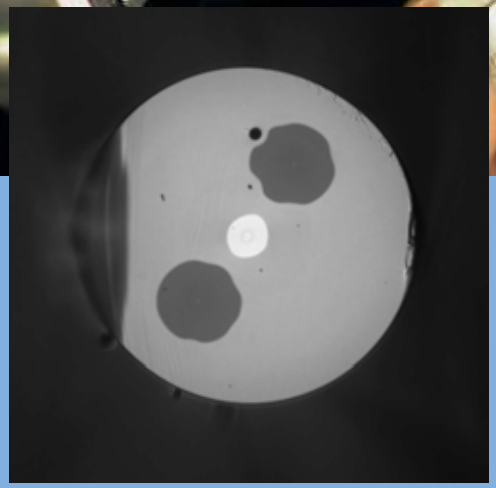
- 510 GW/cm2 for 1-ns
- 2.5 TW/cm2 for 110-ps

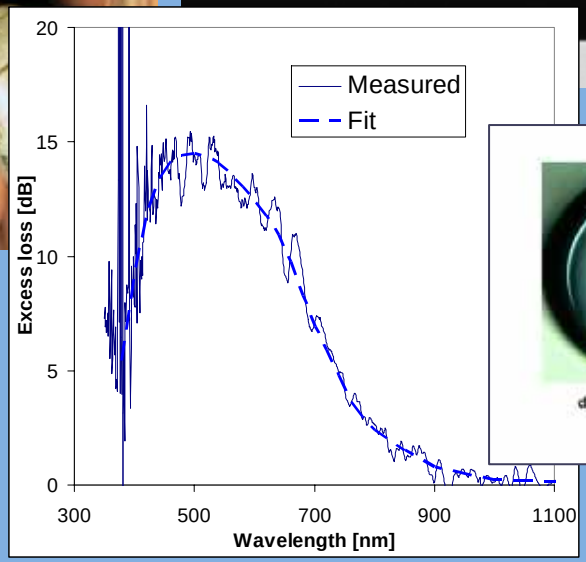
Courtesy Prof. Almantas Galvanauskas, University of Michigan

A lot of things can go wrong when playing with fibers... (particularly due to high gain!)









Shown left:

- Blown out end-facet
- Core blow-out
- Facet damage
- Photodarkening
- Poor process control

Other:

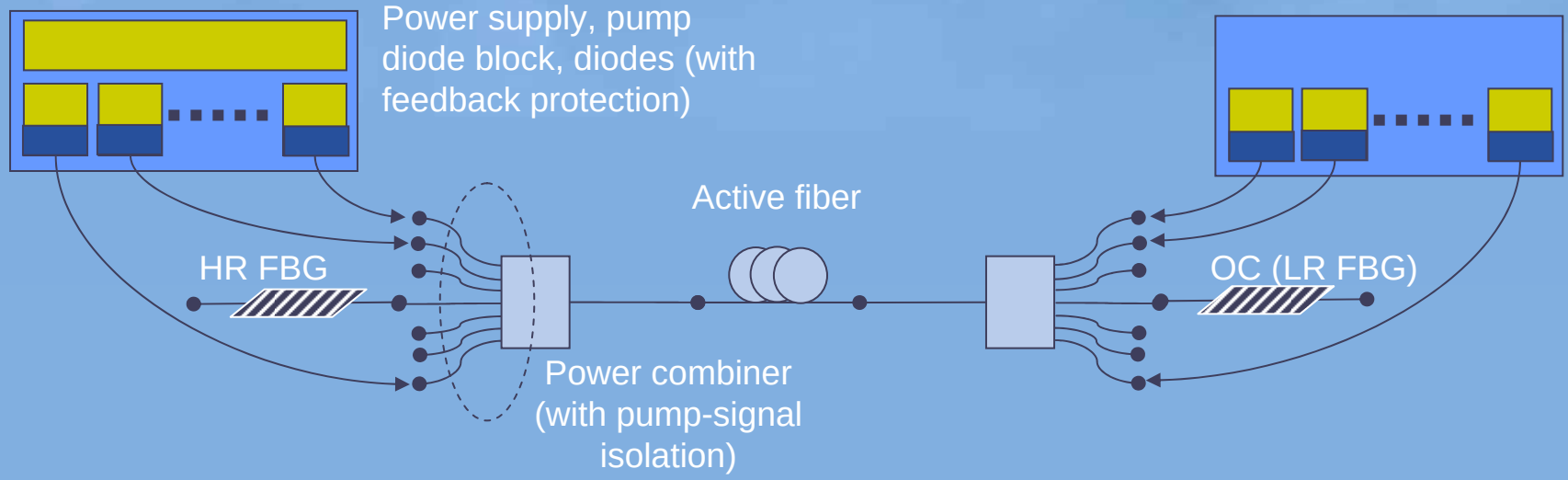
- Pump destruction due to feedback or self-pulsing
- Burned components
- Polymer coating damage
- Splice destruction

Making it right requires experience, precision and skill!

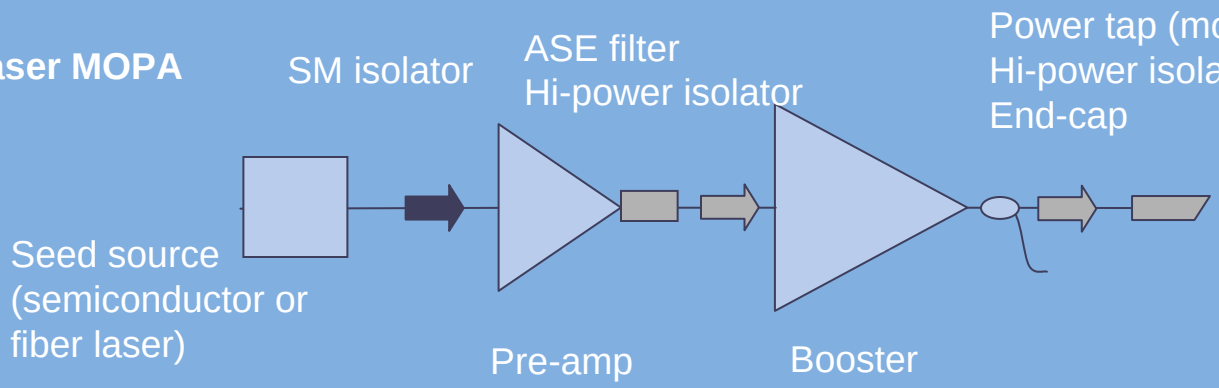
Damaged facet courtesy Soreq

It is all about the components... (and even more so in pulsed!)

Fiber laser (CW or quasi-CW)



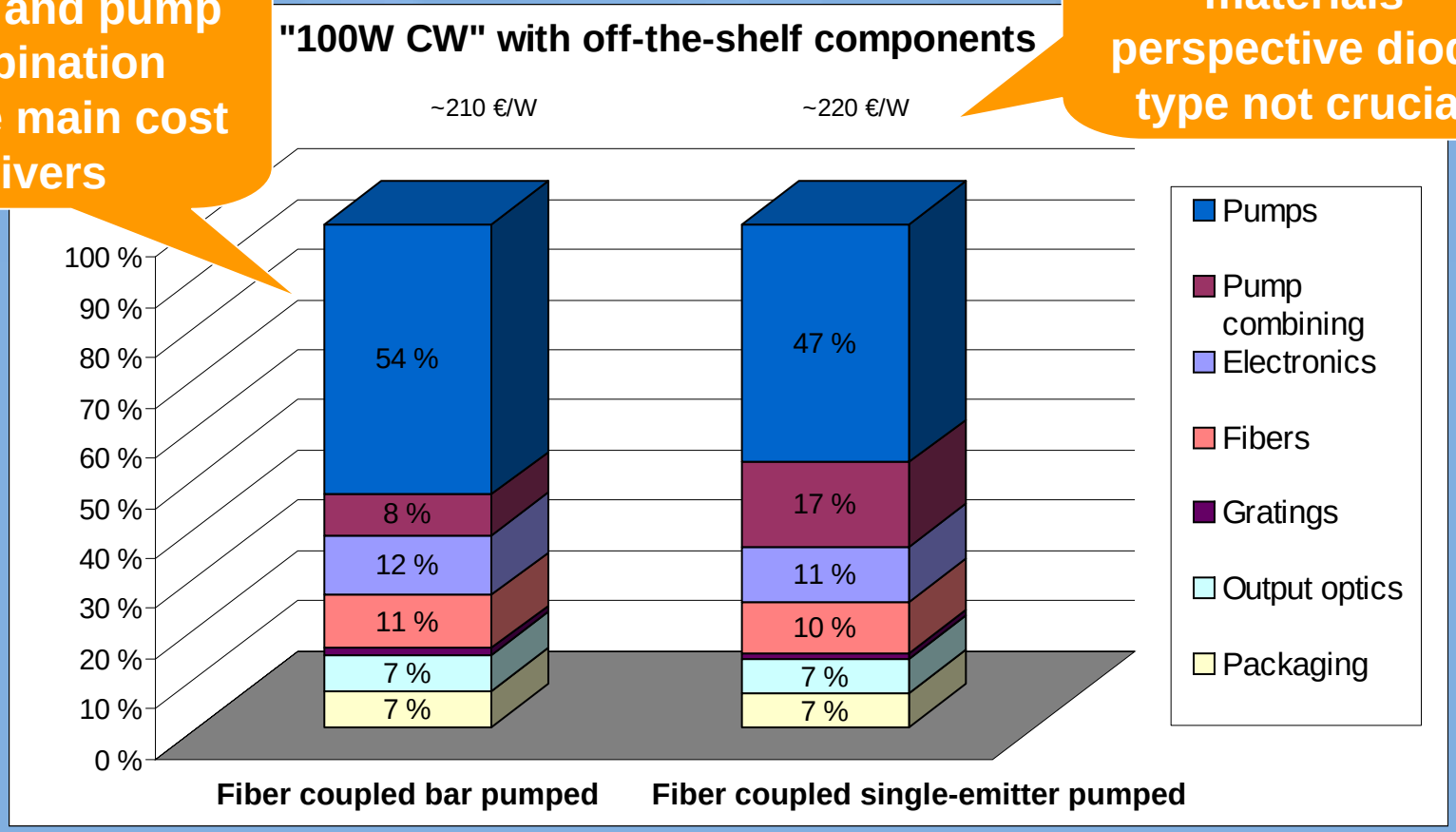
Pulsed fiber laser MOPA



Component pricing drives vertical integration

Diodes and pump combination scheme main cost drivers

From bill-of-materials perspective diode type not crucial



Note: Labor cost not included
Note: At Laser2007 typical 200W complete laser price estimated to hover around 50-70KEUR, ie. 250-350EUR/W

Scarce value chain and ”IPR gridlock” also drive vertical integration and proprietary technology

	Electronics and packaging	Pump diodes	Active and passive fiber	Combiners, FBGs and other fiber components	Isolators and other components	Cabling and output optics	System integration (incl. laser design)
Suppliers	Ample supply of service providers	Several suppliers, scalable processes, plenty of capacity Some product adaptation needed for fiber laser use	**Handful of suppliers, but not many** **Some suppliers moving upstream in value chain**	**Handful of suppliers, high cost, varying quality, manufacture potentially hard to scale up**	**Less than a handful, high cost, varying quality, manufacture potentially hard to scale up**	Several suppliers	Several players
IPR	Not critical, although some IP in place (fiber packaging)	Some IP, does not appear critical	**Lots of IP, some critical, some easily available for licensing**	**Lots of IP, some critical, some easily available for licensing**	Some IP, does not appear critical	Not critical	**Lots of IP for fiber laser/ amp, some critical, some easily available for licensing**

Product proliferation in low power pulsed and CW

Category	Fiber laser manufacturer	Product
Low power CW (<400W) • ”Single mode” (M2 ~ 1.1) • Random polarized • Modulation up to 50kHz, 10us min pulse width • Air cooled (IPG), air/water cooled (SPI)	SPI IPG Miyachi (Spectra-Physics, Trumpf, Nufern, GSI, Apollo Instruments) JDSU, Nufern, Manlight, Lumics, Keopsys, Corelase, etc.	redPOWER 10...350W (400W) YLR-100/200 100/300W (welding system) New 100-300W: TruFiber 300, NuFire, JK50/100/200FL Below 50W: Many diverse products in this category
High power CW SM (400W...1kW...3kW) • As above, but water cooled	IPG (Rofin)	YLR-500...1000...3000-SM
High power CW (over 1kW) • 1...10kW...20kW...(50kW)	IPG	YLR-1000/2000/5000/10000/20000
Pulsed 10-500ns (low peak power) • 0.5...2mJ...(4mJ...10mJ) • Few tens of kW peak power • 10...200kHz (some up to 500kHz)	IPG SPI V-Gen EOLITE Multiwave, Quantel, Manlight, etc.	YLP-series redPOWER 10/12/20/30W VPFL-2000/5000/8000/10000 Corus, Boreas
Pulsed 1-10ns (med/high peak power) • 0.04...1mJ, typically 5...10ns min • Up to 100kW peak power	V-Gen EOLITE	VPFL-SP-2000/5000 Boreas
Pulsed ps and ps (ultrafast)	Clark MXR IMRA Newport Spectra-Physics Fianium, Corelase, Menlo Systems, Toptica, Pritel, Calmar, PolarOnyx, etc.	Impulse Femtolite, uJewel Pantera FM1060, Xlase, etc.

Product prolife…lsed an…

IPG alone in multi kW-class, Rofin introduces 1kW at Laser2007 (and SPI shows 400W ”blade”)

Lots of entrants in 100-300W class at Laser2007

Lots of players in below 50W CW category

Lots of players in basic pulsed, IPG presses prices down

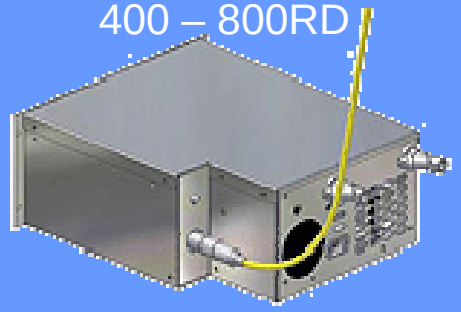
MW-class peak power pulsed not there yet (Spectra Pantera and EOLITE Boreas close though...)

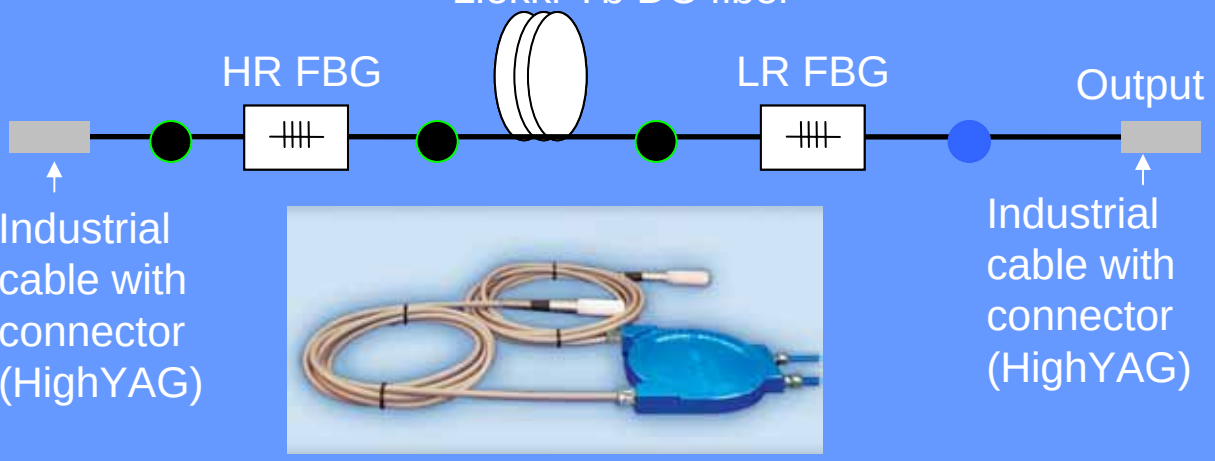
Several players in ultrafast category

Category	Fiber la…acturer	Pro…
Low power CW (<400W)	SPI IPG Miyachi (Spectr…ysics, Rofin, Trumpf, Nufern, …l, Apollo Instruments) JDSU, …fern, Manlight, Lumics, Keopsy…, Corelase, etc.	…dPOWER 10...350W (400W) YLR-100/200 100/300W (welding system) New 100-300W: TruFiber 300, NuFire, JK50/100/200FL Below 50W: Many diverse products in this category
• …10us min pulse width …ooled (SPI)		
High power CW SM (400W...1kW...3kW) • As above, but water cooled	IPG (Rofin)	…-500...1000...3000-SM
High power CW (over 1kW) • 1...10kW...20kW...(50kW)	IPG	…-1000/2000/5000/10000/…00
Pulsed 10-500ns (low peak power) • 0.5...2mJ...(4mJ...10mJ) • Few tens of kW peak power • 10...200kHz (some up to 500kHz)	… SPI V-Gen EOLITE Multiwave, Quantel…	…-series …dPOWER 10/12/20/30W VPFL-2000/5000/8000/10000
Pulsed 1-10ns (med/high peak power) • 0.04...1mJ, typically 5...10ns min • Up to 100kW peak power	V-Gen EOLITE	
Pulsed ps and ps (ultrafast)	Clark MXR IMRA Newport Spectra-Physics Fianium, Corelase, Menlo Systems, Toptica, Pritel, Calmar, PolarOnyx, etc.	Impulse Femtolite, uJewel Pantera FM1060, Xlase, etc.

Simple end-pumped architecture – ”multi-laser”

Laserline LDM
400 – 800RD





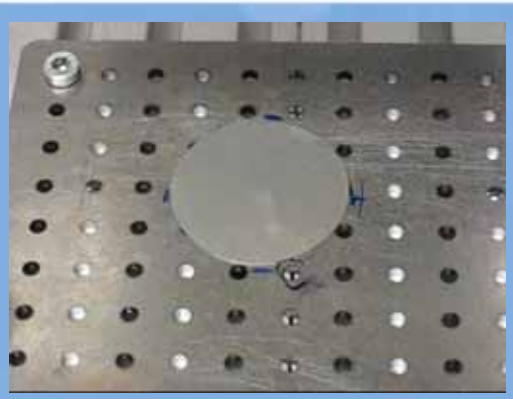
- Laserline – reliable hipower pump source (upto 750W)
- All controlling done through Laserline interface (only one system to learn)
- Plug-and-play compatibility
- Rack-mounted
- Fiber unit very simple and low cost!
- Versatile – two qualities of beam at the price of one

Liekki OE-Yb-RML-400 Optical Engine
”Beam converter”

- Current units reach from 10 up to150W
- Demonstrated powers up to 365W

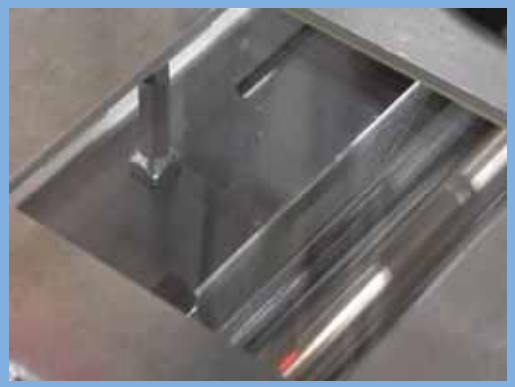
Plastic, marking, engraving, cutting – one system, many beams...

Liekki OE-Yb-RML-400 *"Beam converter"* system with Laserline diodelaser and chiller



Marking: Fiber laser 25W, 80um

Marking: Fiber laser 25...50W, 80um

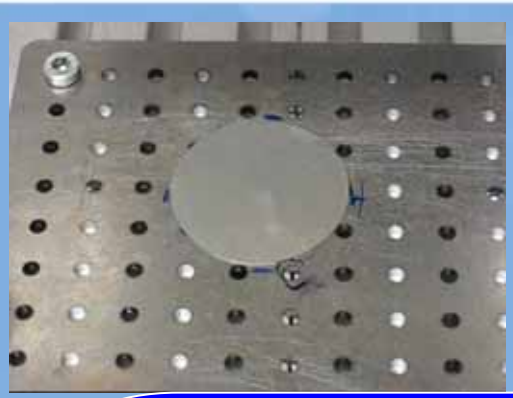


Plastic welding: Diode laser 200W, 1.2mm

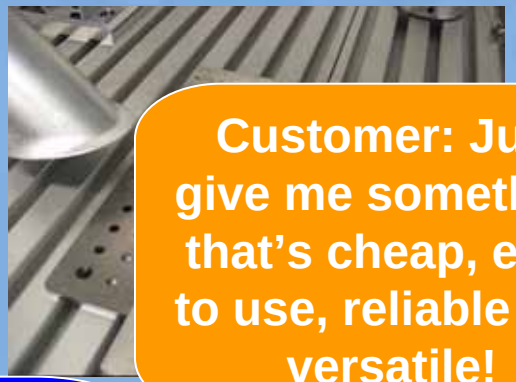
Thin stainless cutting: Fiber laser 90W, 40um

Plastic, marking, engraving, cutting – one system, many beams...

Liekki OE-Yb-RML-400 *"Beam converter"* system with Laserline diodelaser and chiller



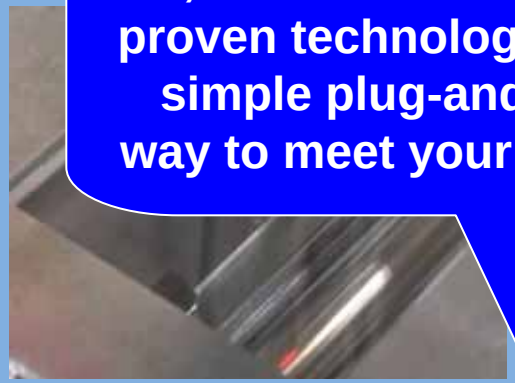
Mar



Fiber laser 2

Customer: Just give me something that's cheap, easy to use, reliable and versatile!

Ok, so let's combine two proven technologies in a simple plug-and-play way to meet your needs!



Plastic welding: Diode laser 200W, 1.2mm

Thin stainless cutting: Fiber laser 90W, 40um

Structure of this presentation

Liekki Corporation – brief introduction

Fiber laser market and the laser industry

Performance, economics, products and some key issues

Conclusion

Conclusion

- Fiber laser market is growing and becoming important, driven by a few big attackers and a large number of smaller players – and now – incumbents joining
- The first major “beach heads” are metal and fine materials processing and marking, with medical, semiconductor processing, printing and military following
  - Several players now entering 50-300W “single mode” arena
  - Rofin alone sofar in joining IPG for the kW-class combat
  - SPI “blade” path to OEM?
- Fiber and diode technology may induce a strategic paradigm shift in the laser industry – all players will need to decide their stance
  - Will markets reward others than first-movers/pure-plays (IPG)
  - Business model – vertical integration or not?, OEMs?, component suppliers?
  - Price/volume dynamics, and who will survive, who will be good enough to capture high margin markets
- However, value chain scarcity, component pricing and “IPR gridlock” remain serious issues, potentially only solved by vertical integration and proprietary solutions
- Nevertheless, interesting product introductions continue unabated, signalling that the train is moving and continues to accelerate

Questions and comments welcome. Thank you!

LIEKKI

The Nanoparticle Fiber Company

Per Stenius (per.stenius@liekki.com)
More information at: www.liekki.com