# LMA ACTIVE FIBRE FOR HIGH POWER LASERS: IMPACT OF APERIODICITY ON MODAL STABILITY AND ADVANCED DESIGNS TO IMPROVE THERMAL RESILIENCE

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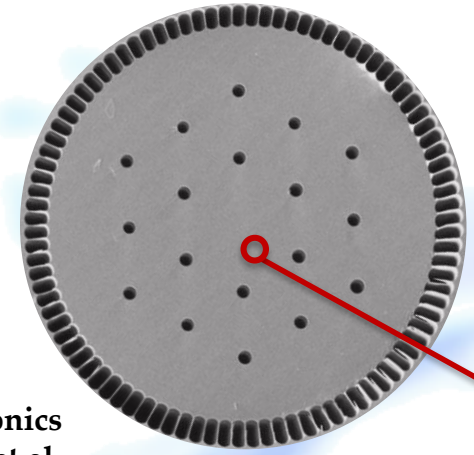
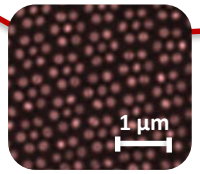
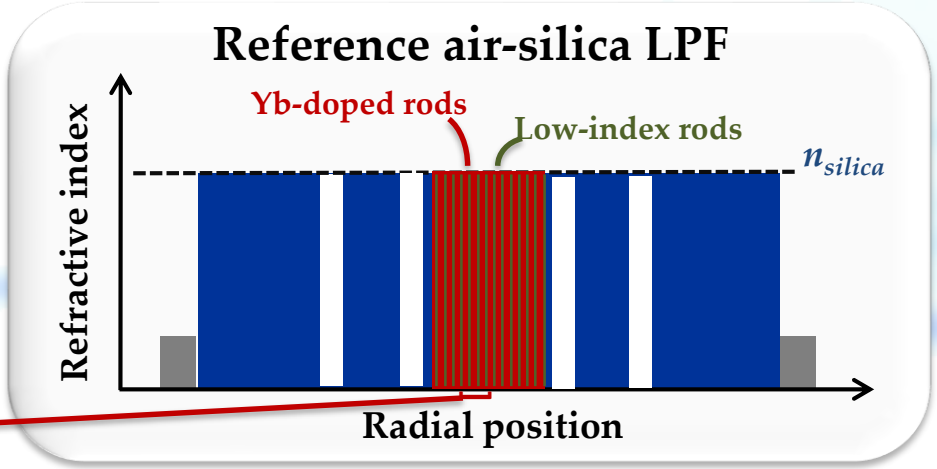
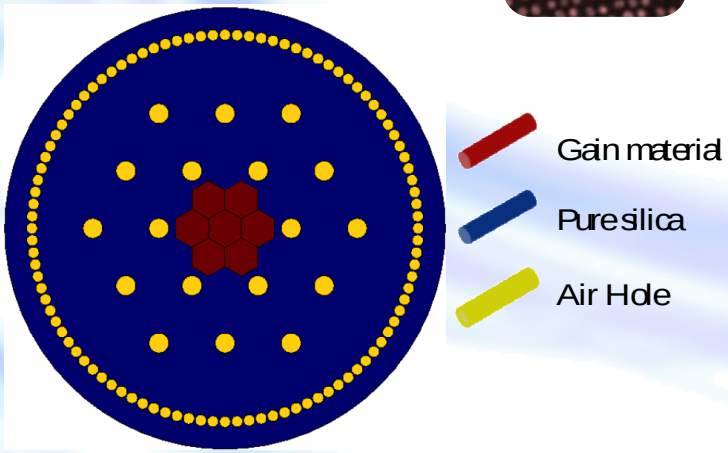
# AIR-SILICA LARGE-PITCH-FIBERS (LPF)

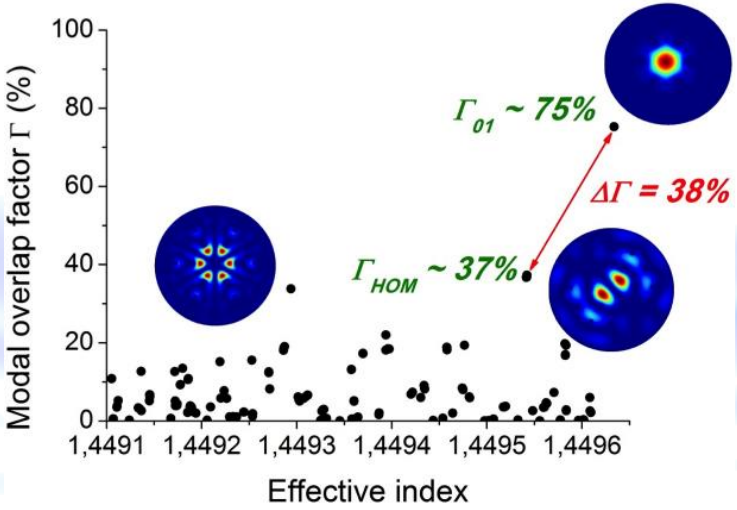


NKT photonics
J. Limpert et al.



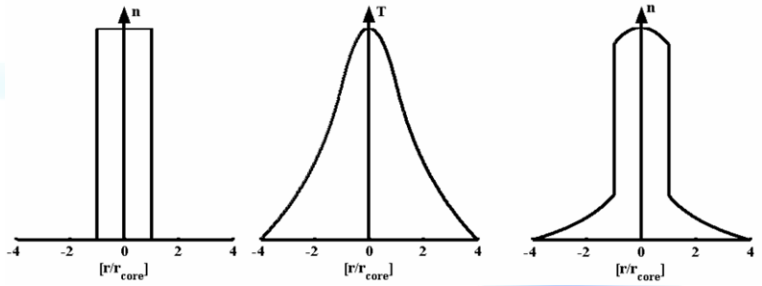



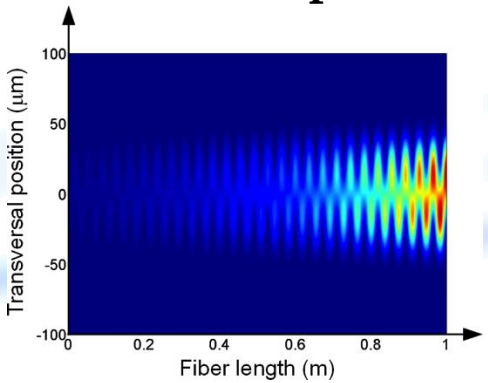

**CRITERION ΔΓ**
**MODAL DISCRIMINATION**

# MODAL INSTABILITIES

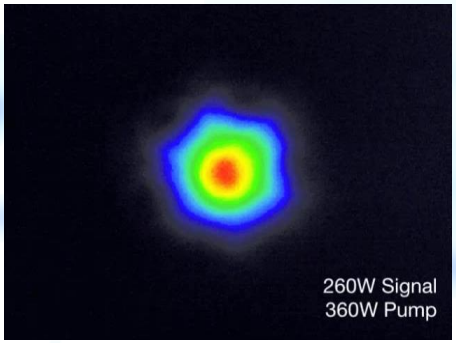
## A thermal-induced process



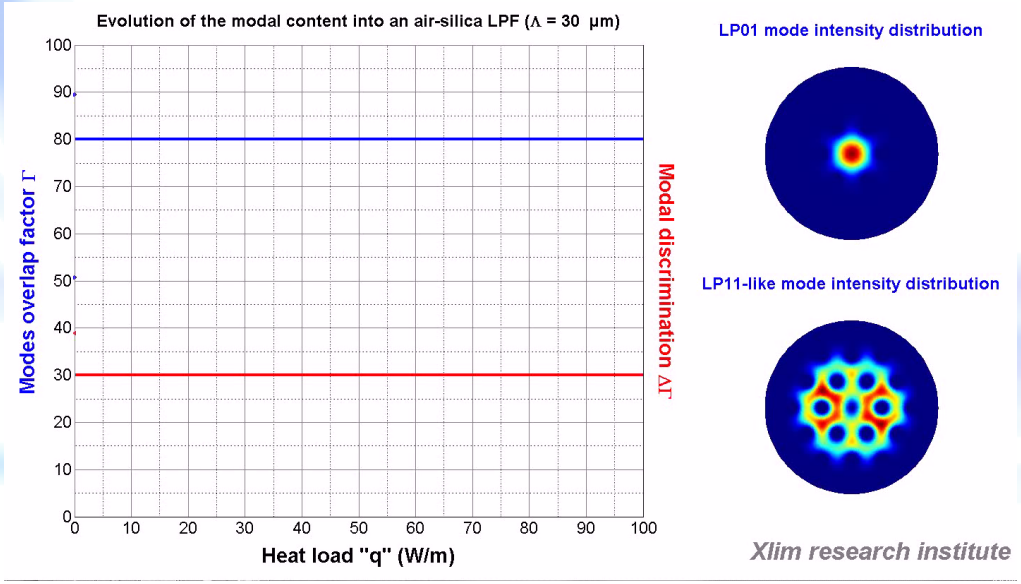

*Hädrich et al. Opt. Exp 14(13) (2006)*




*Jauregui et al. Opt. Exp 20(1) (2011)*

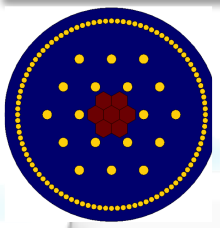


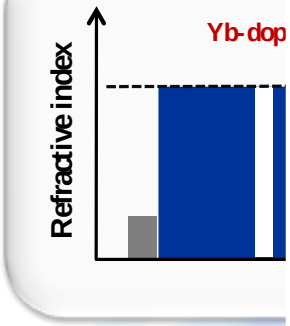

*Eidam et al., Opt. Exp. 19(4) (2011)*

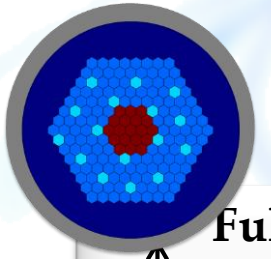


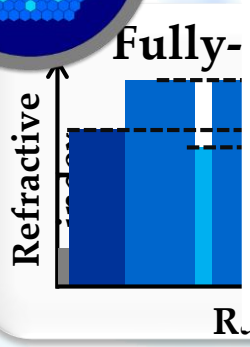

*Xlim research institute*

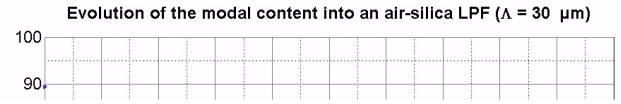
# FULLY-APERIODIC LPF (FA-LPF)

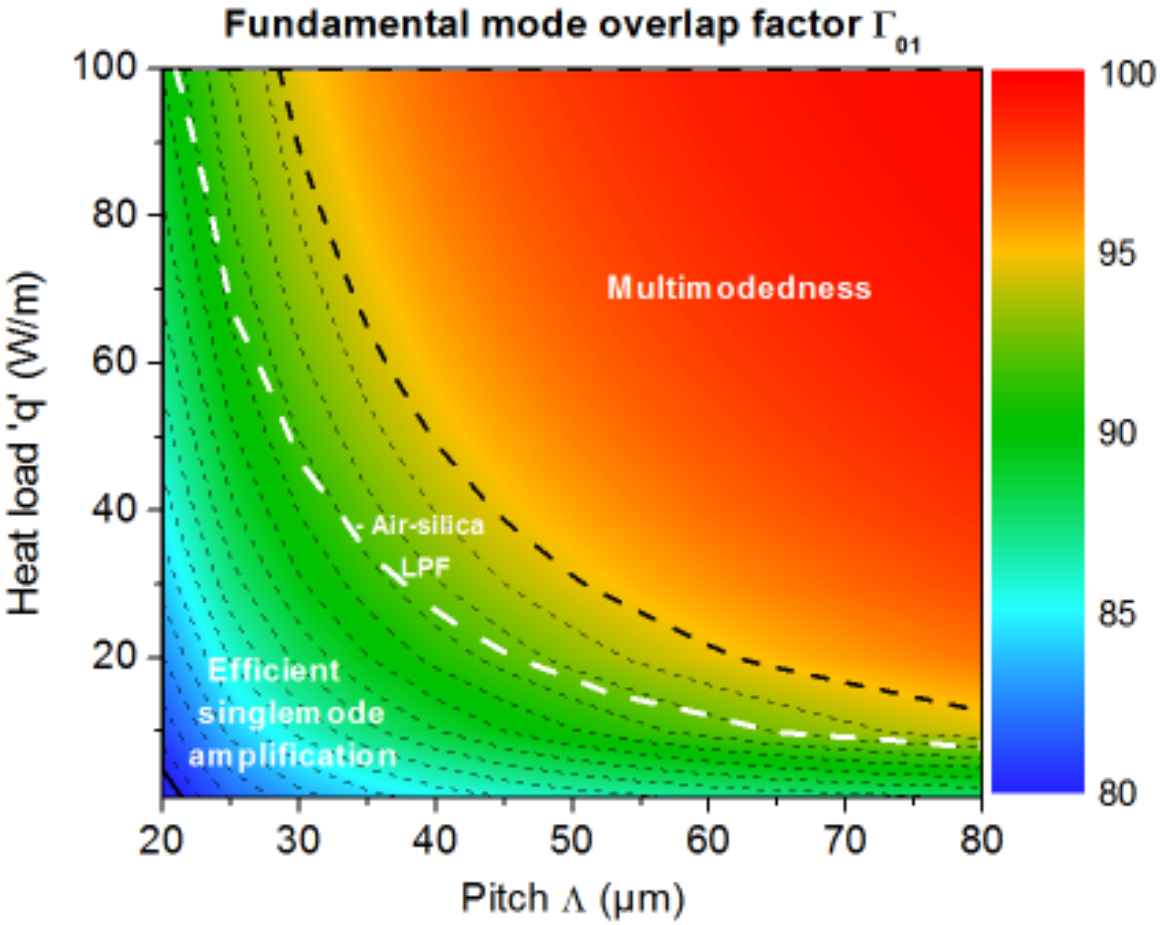


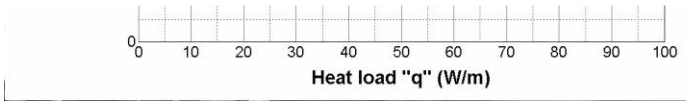


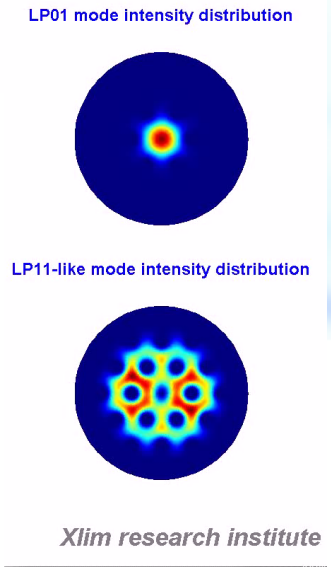



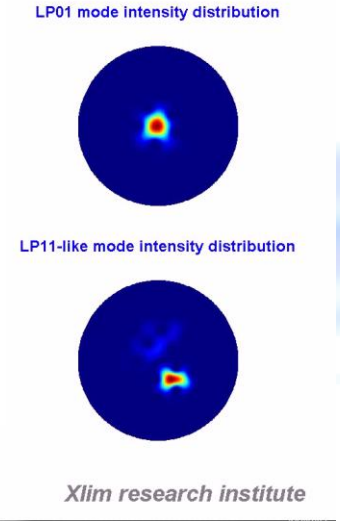


# YB-DOPED FULLY-APERIODIC LPF

## REPUSIL manufacturing process

### Powder sintering and vitrification

*Schuster et al. (2014)*

### Assets

High optical quality
Production of large volume
Unique stack and draw

**Cost effective fabrication process**

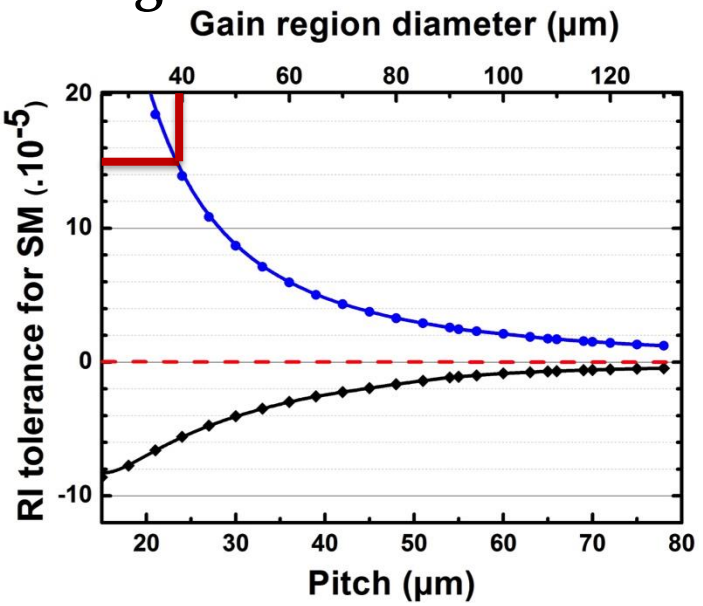
### Control of the index-matching

Yb-doped material

Passively doped glass

Device: Interfiber Analysis IFA-100
Accuracy: ±1.10$^{-4}$

**Small index difference evidenced: ~ 1.5.10$^{-4}$**

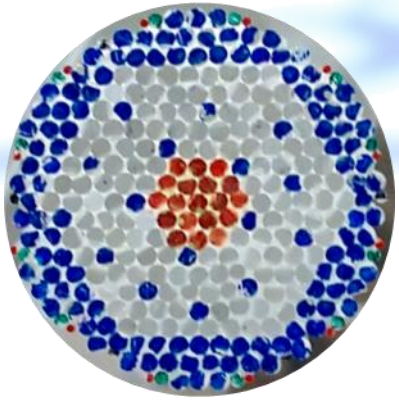


# YB-DOPED FULLY-APERIODIC LPF

Yb-doped material

Passively doped glass

**Stack**

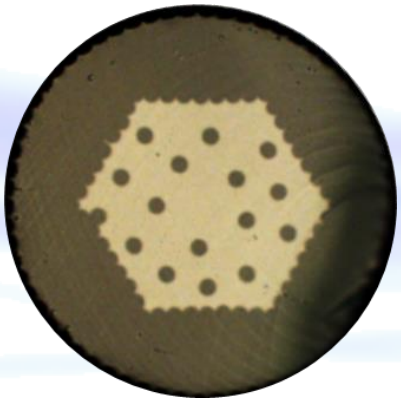


**Core size**
40µ average

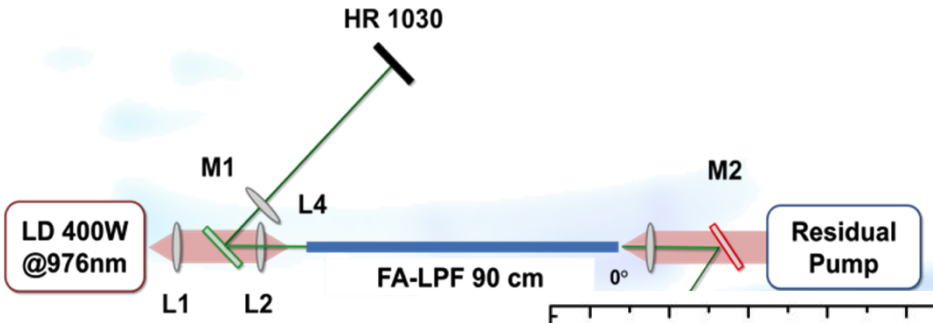
**Air-clad diameter**
210 µm – NA=0.45

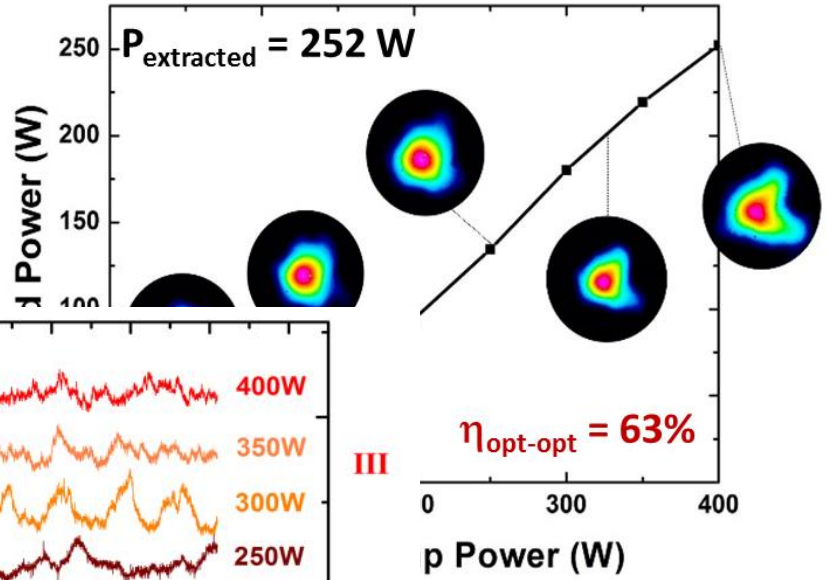
**Rod-type outer diameter**
1.2 mm

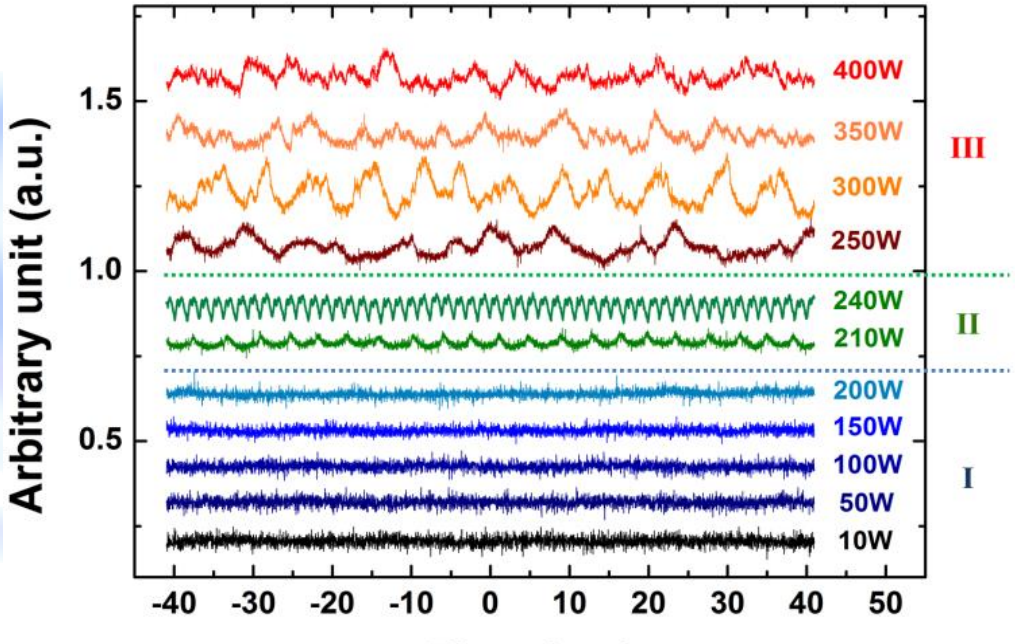
**Yb-doped FA-LPF**

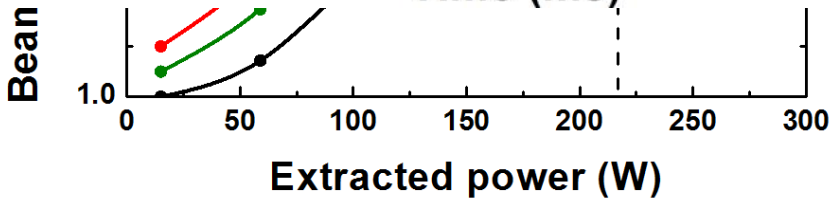


# LASER RESULTS CW

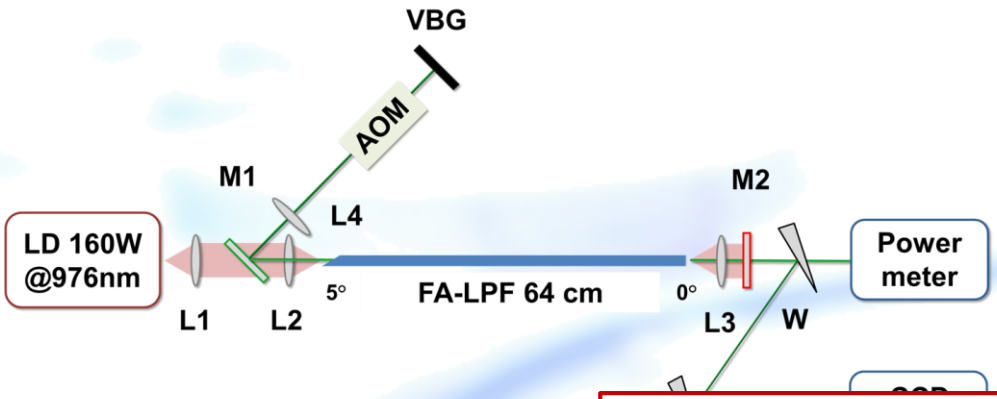


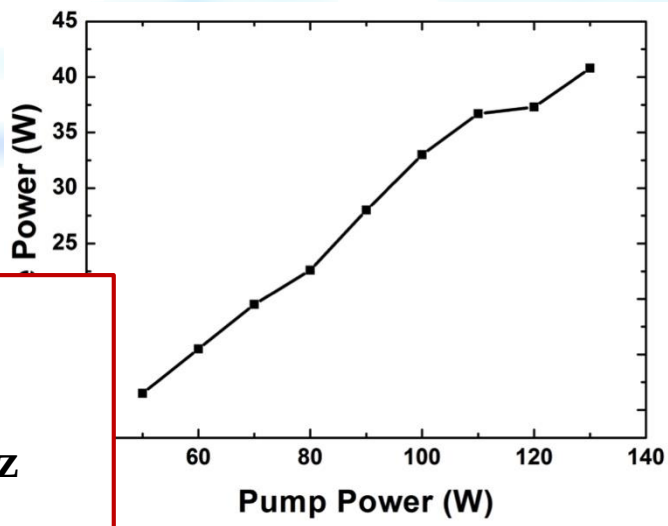



# PRELIMINARY RESULTS Q-SWITCH




**RR = 50 kHz**

*Endcap*

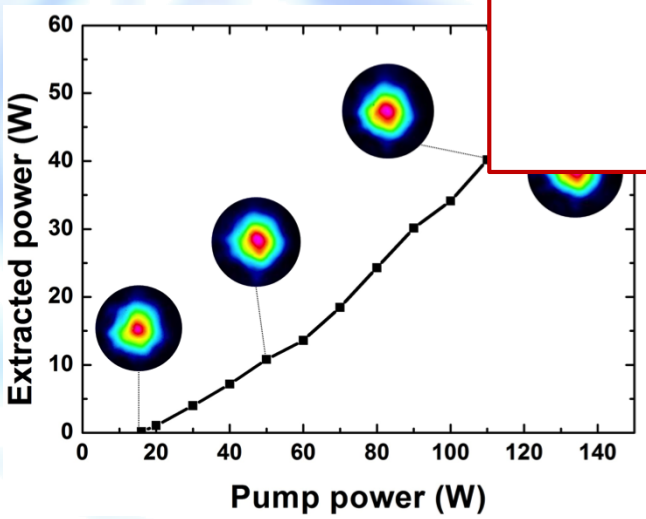


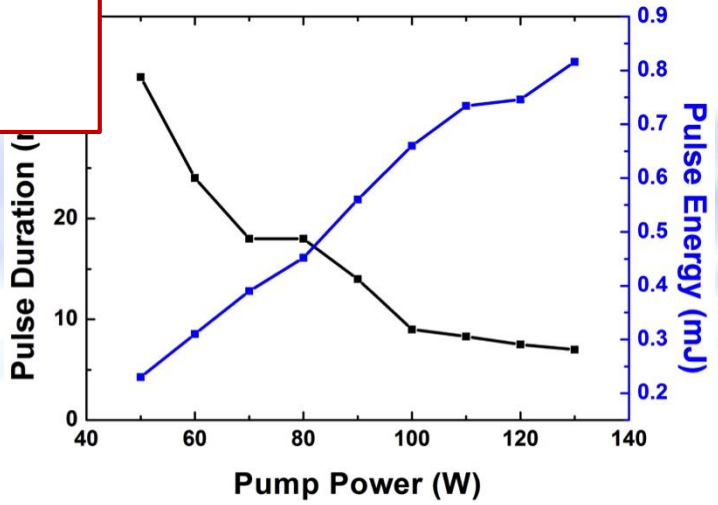

**54W @100kHz**

**41W - 0.82 mJ @50kHz**

**$M^2$~1.4**

**RR = 100 kHz**

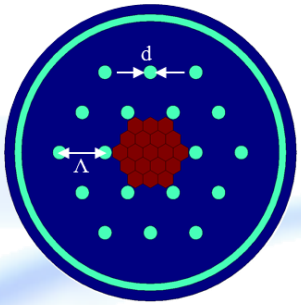


# What about thermal pre-compensation at 2µm?

FA-LPF vs LPF at 2µm

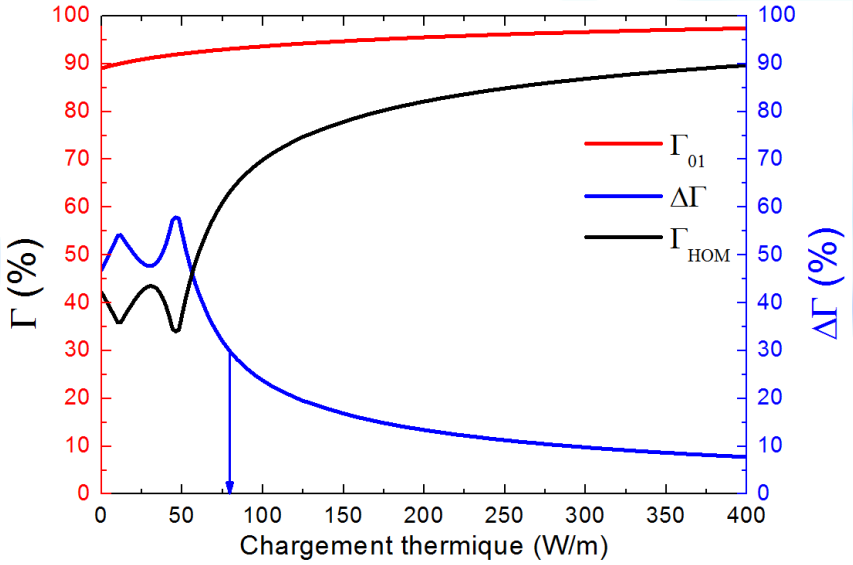
## LPF



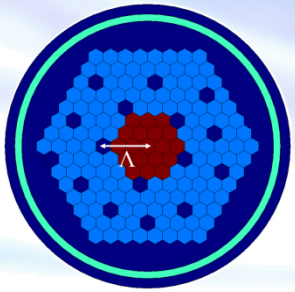

$d/\Lambda = 0{,}3$

$\Lambda = 45\mu m$

$D_{cœur} = 76{,}5\mu m$

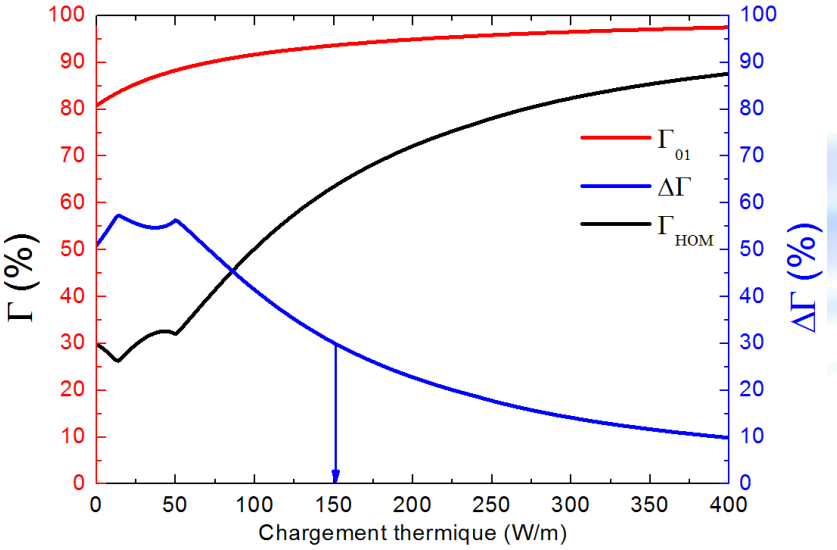



## FA-LPF




$\Lambda = 45\mu m$

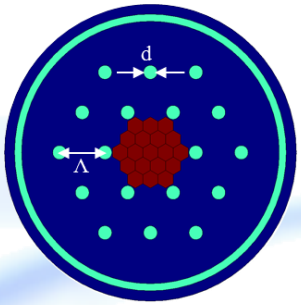
$D_{cœur} = 76{,}5\mu m$



# What about thermal pre-compensation at 2µm?

FA-LPF vs LPF at 2µm

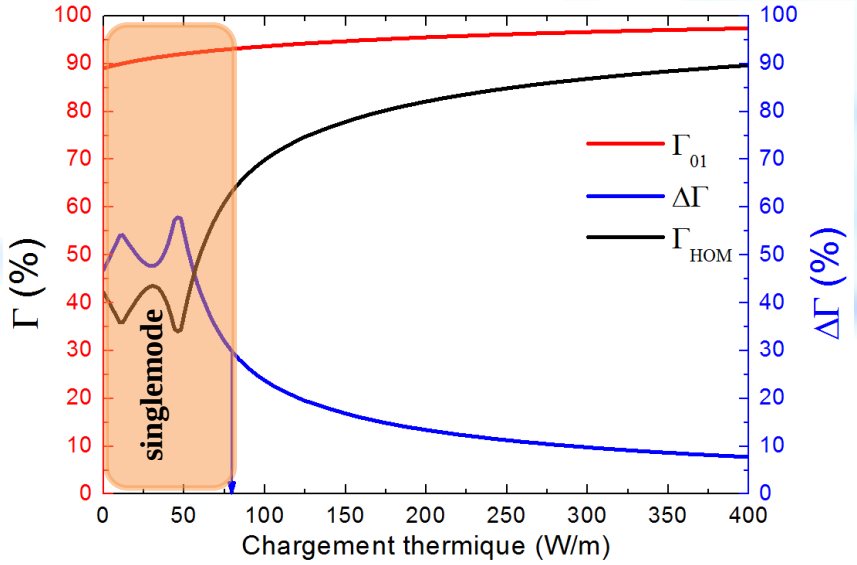
## LPF



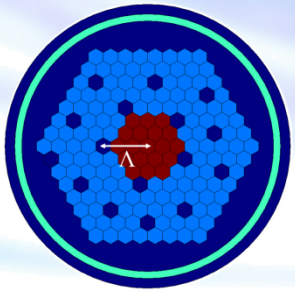

$d/\Lambda = 0,3$

$\Lambda = 45\mu m$

$D_{cœur} = 76,5\mu m$




## FA-LPF

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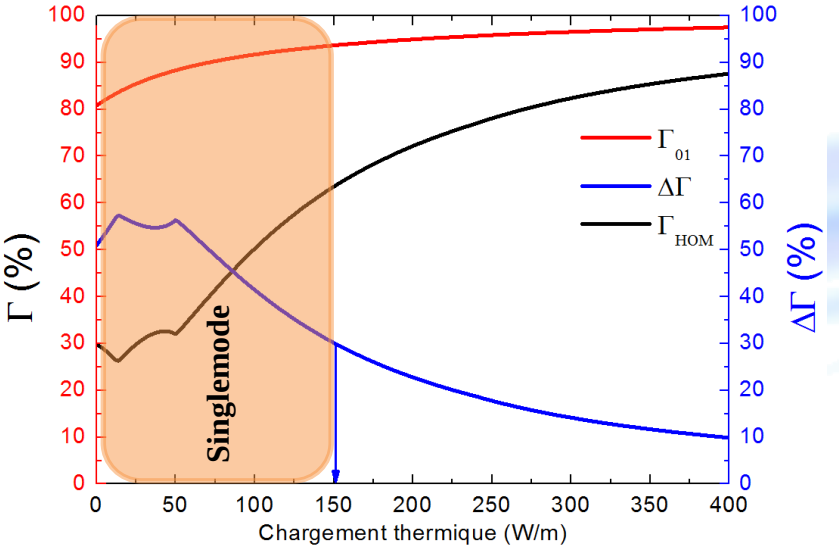
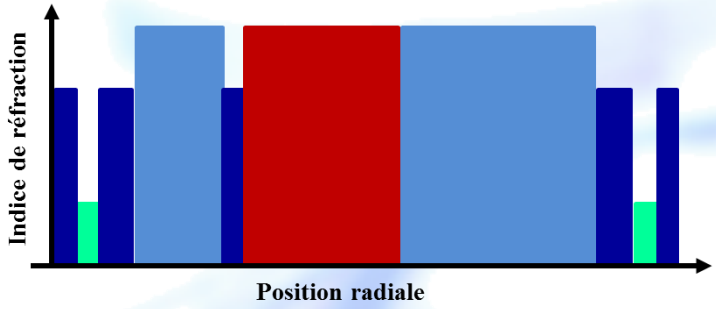
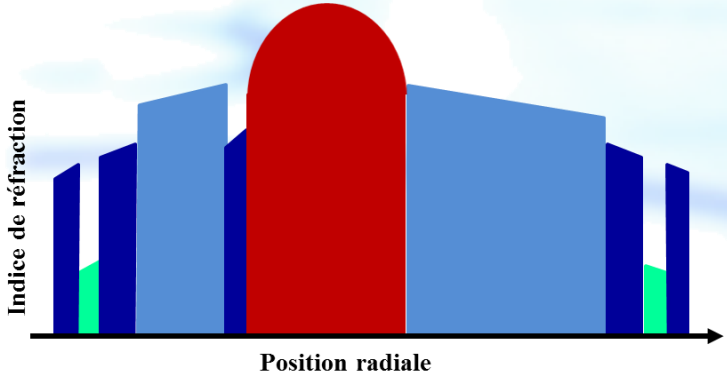


# INITIAL INTUITIVE IDEA

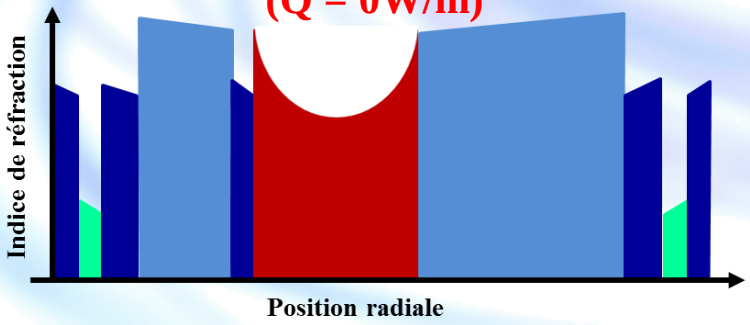
**Transverse RI profile for cold fibre**
**(Q = 0W/m)**



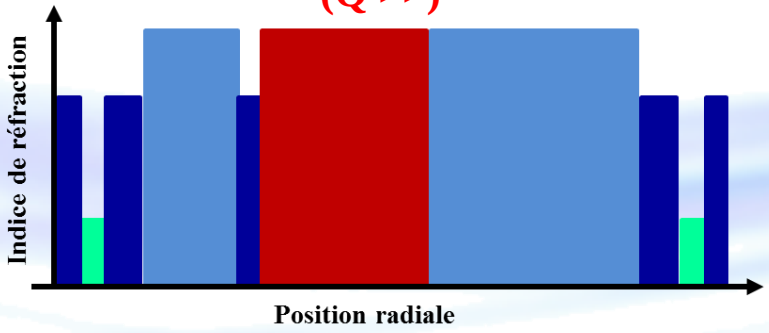

**Transverse RI profile under severe heat load**
**(Q >>)**




**Intuitive pre compensated transverse RI profile for cold fibre**
**(Q = 0W/m)**




**Expected transverse RI profile under severe heat load**
**(Q >>)**



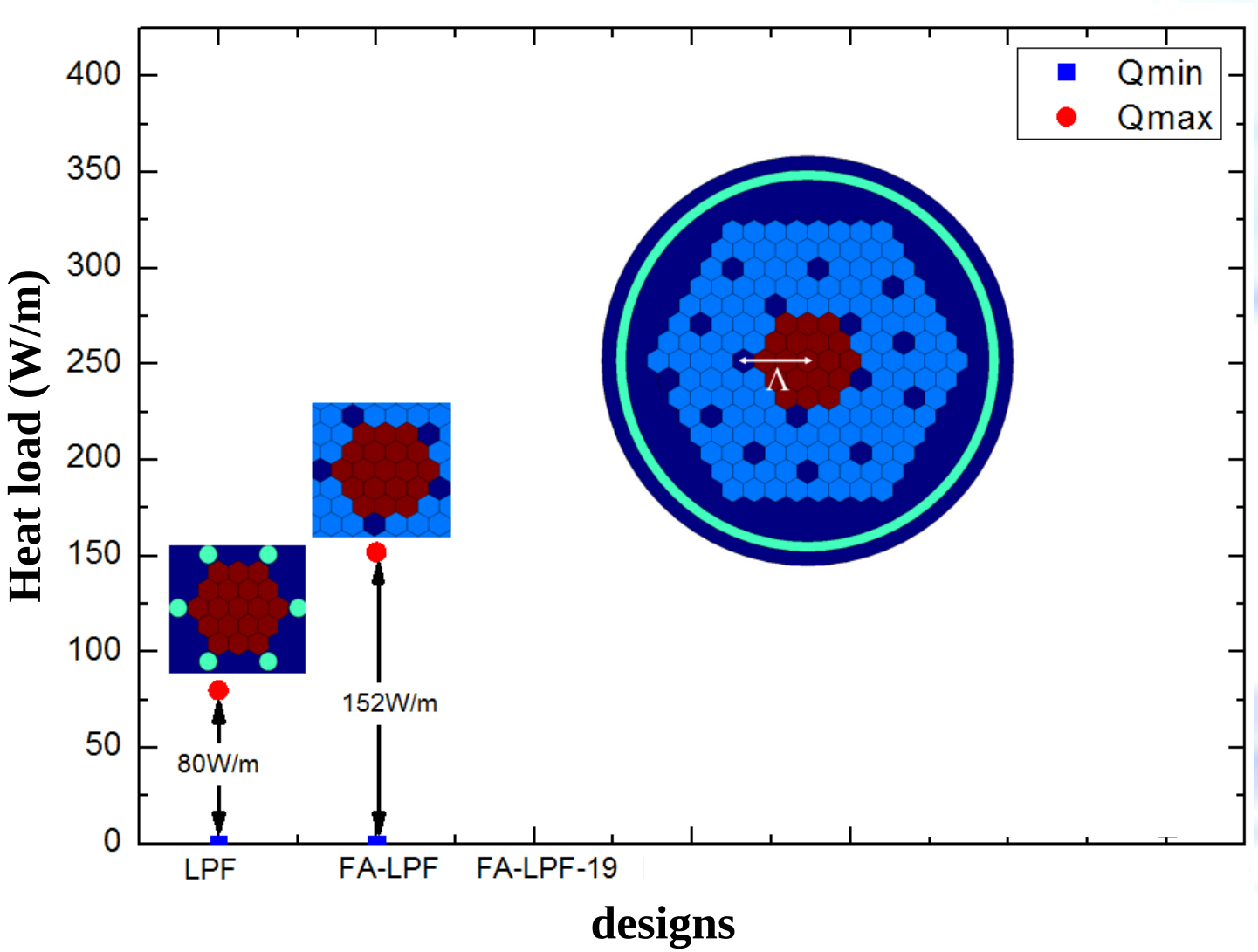

**<u>Two main problems</u>: the fibre doesn't propagate FM when the fibre is cold**
**A $1\times10^{-5}$ accuracy on RI value is required for each material whereas the current technology provide $1\times10^{-4}$ to the very best**

# TOWARD REALISTIC MODELS

**Limits are fixed by**

**Qmin: $\Gamma_{01}$ = 80%**

**Qmax: $\Delta\Gamma$ = 30%**



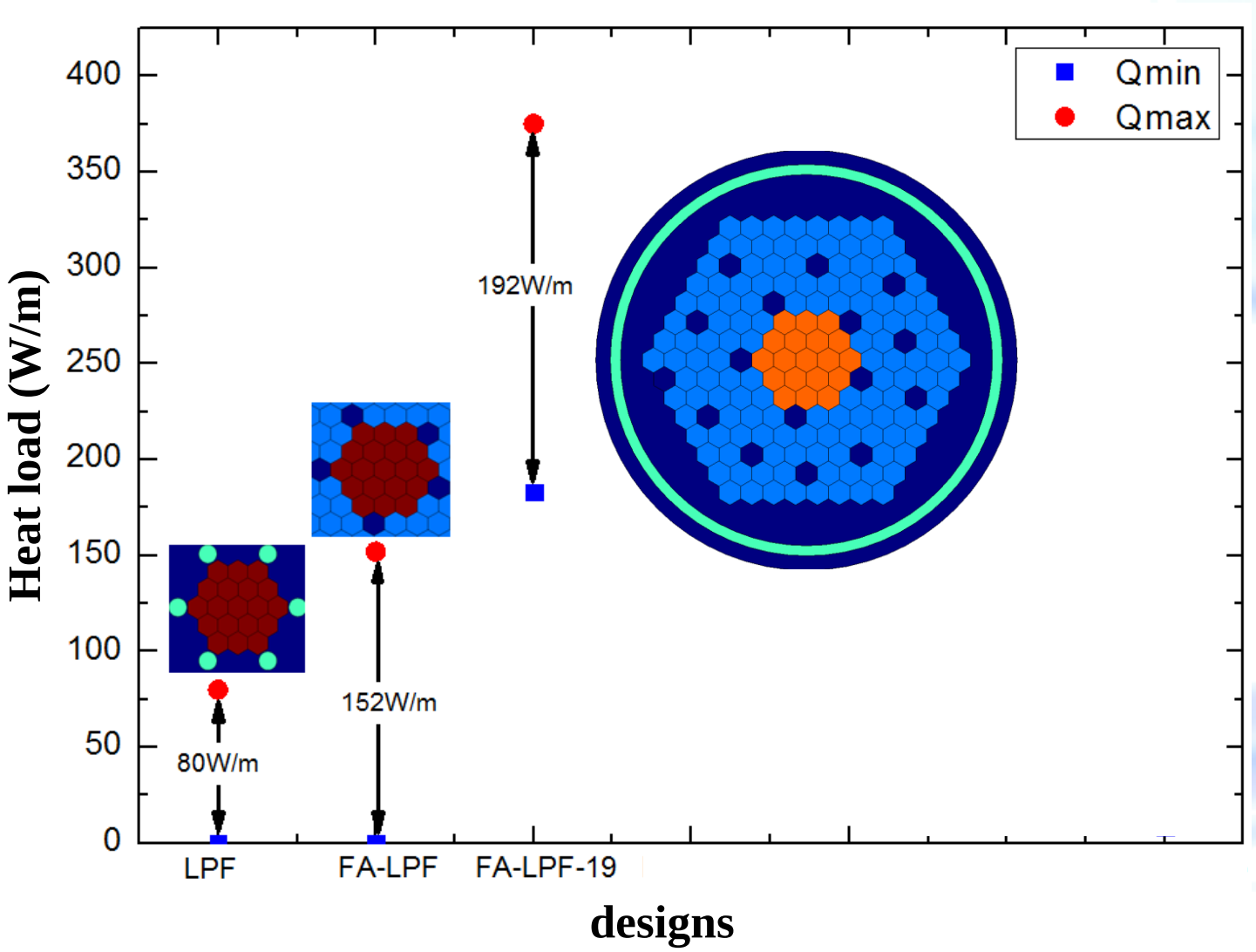
# TOWARD REALISTIC MODELS

**Amplitude of index depression $2 \times 10^{-4}$**

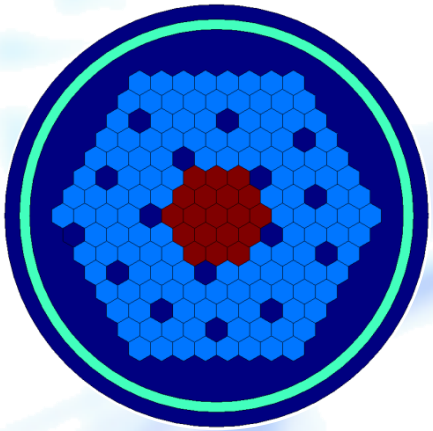
**Limits are fixed by**

**Qmin: $\Gamma_{01} = 80\%$**

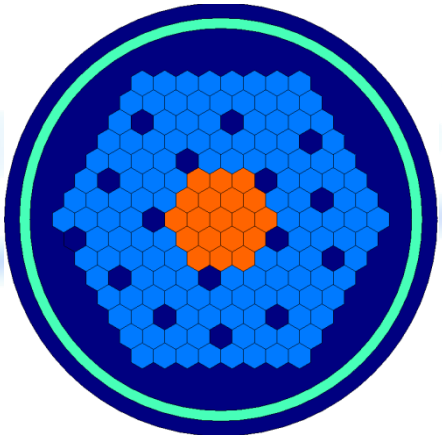
**Qmax: $\Delta\Gamma = 30\%$**



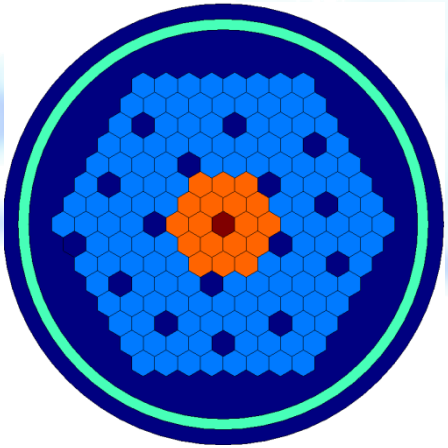
# TOWARD REALISTIC MODELS



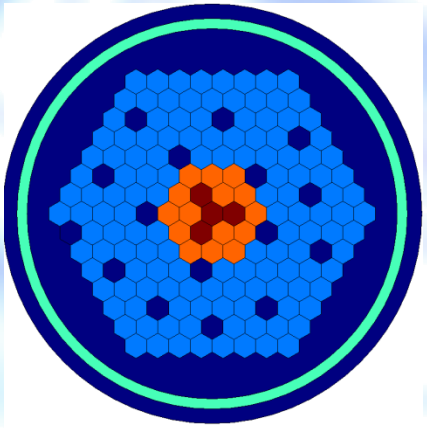
FA-LPF



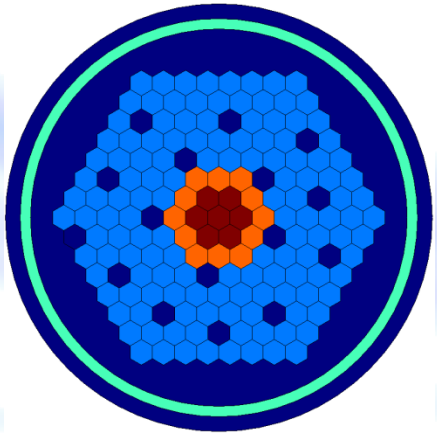
FA-LPF-19



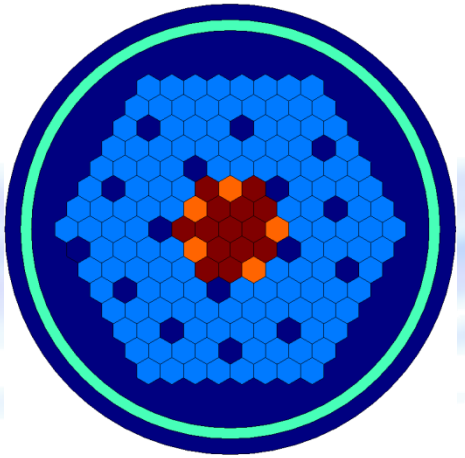
FA-LPF-18



FA-LPF-15



FA-LPF-12



FA-LPF-5

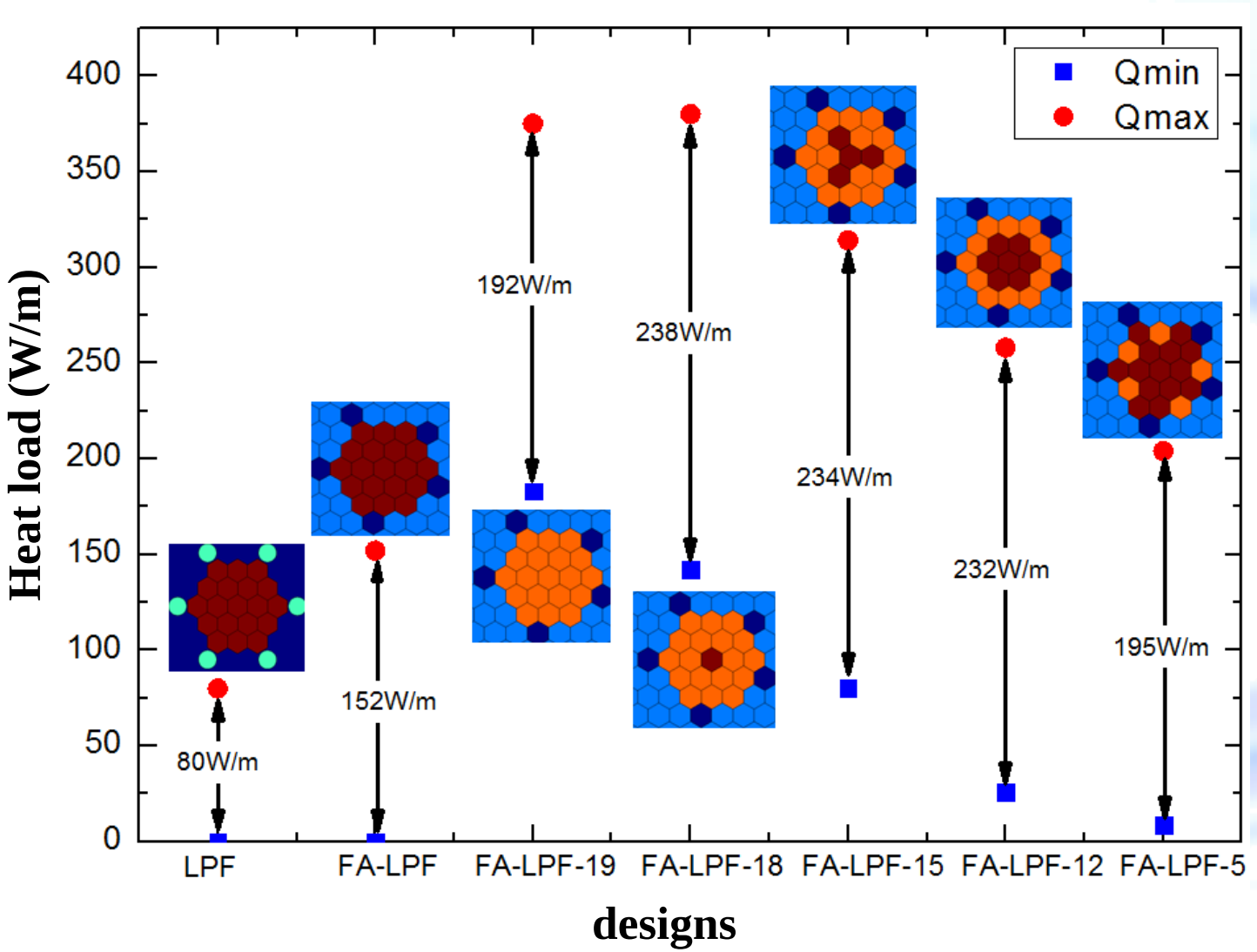
# EFFECTIVE SINGLEMODE BEHAVIOUR

**Dépression de $2x10^{-4}$**

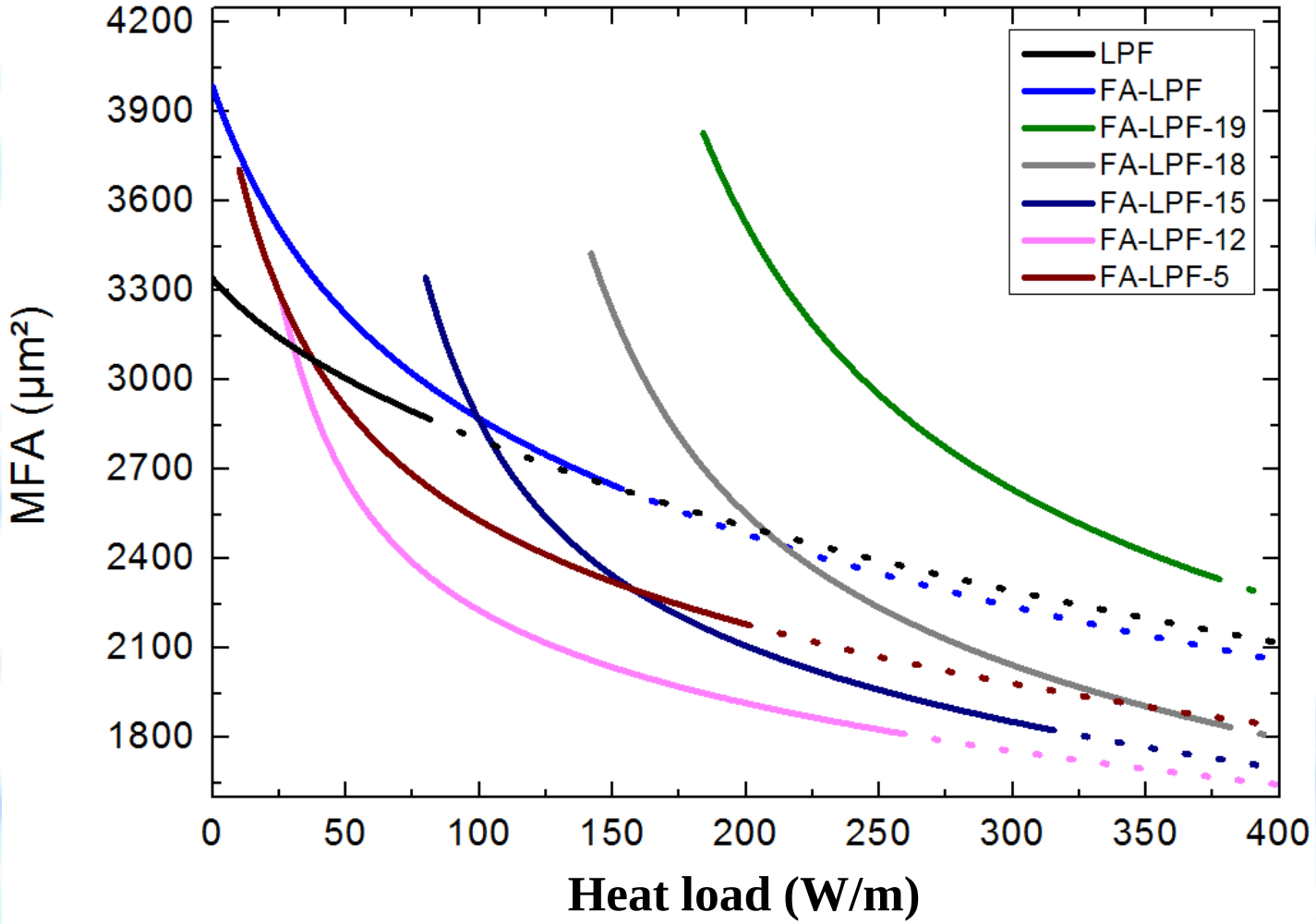
**Limits are fixed by**

**Qmin: $\Gamma_{01}$ = 80%**

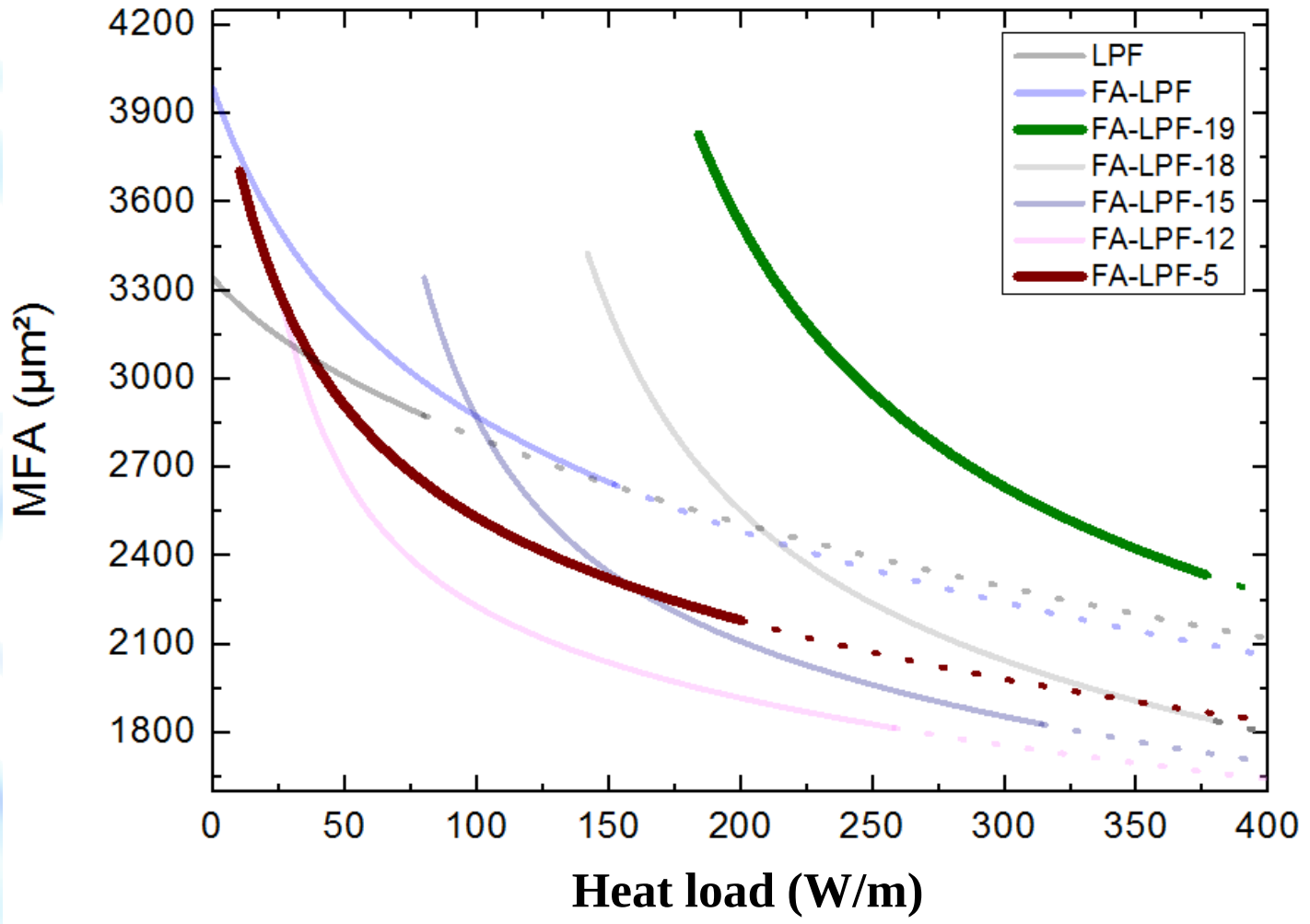
**Qmax: $\Delta\Gamma$ = 30%**



# A STRONG IMPACT ON MFA



# A STRONG IMPACT ON MFA



## CONCLUSION

- ✓ FA-LPF design is intrinsically less sensitive to thermal loading
- ✓ First laser demonstration of non filamented Yb-core FA-LPF
- ✓ CW emission: 252W @$M^2$=1.4 – $\eta_{opt\text{-}opt}$ = 63% (MI threshold at 95W)
- ✓ Q-switch emission – 41W-0.82mJ @50kHz (MI threshold at 70W)
- ✓ Advanced but realistic designs can push away MI threshold provided material RI is accurately controlled

## PROSPECTS

- ✓ Improve of the active/passive materials index
- ✓ Demonstrate Tm-doped FA-LPF and pre-compensated FA-LPF experimentaly

# THANK YOU FOR YOUR ATTENTION

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RESULTS CAN IMMEDIATELY BE TRANSPOSED AT 2Mm, WOULD THERE BE AN ACTION IN THE FRAME OF COST MP1401?