

# 基于COMSOL六边形光子晶体 光纤色散特性研究

COMSOL  
CONFERENCE  
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光纤技术经过  
40多年的发展

光纤通信  
成为主流

人们生活水平的  
不断提高，通信  
量日益增加

掺铒光纤放大器技术的发现，  
三个低损耗窗口的发现

衰减  
色散

波分复用技术向密集型  
波分复用技术发展

人们从三个方面控制色散

➤从材料方面



寻找负色散材料来抵消色散材料产生的色散

➤从光纤结构上



采用微结构有空气孔的光纤，即光子晶体光纤，通过改变截面空气孔的大小与分布，控制色散

➤从传输光的方式上



人们借助于水孤立波的特性，能长时间保持不变的形状与速度，传输很长的距离，采用光孤子在光纤中传输

## 研究方案

采用理论分析、数值模拟，并与 COMSOL 软件仿真相结合的研究方法，分析光子晶体光纤结构对色散特性的影响。

(1) 从麦克斯韦方程组出发，推导光纤中光传输方程，从而得到光纤中色散特性。

(2) 采用多极法和有限元法，分析光子晶体光纤光传输的特性，进而分析光子晶体光纤结构对光子晶体光纤色散特性的影响，从而使用更短的光子晶体光纤对更长的光纤色散进行补偿。

(3) 利用 COMSOL 软件进行模拟仿真，结合理论分析，对结构进行优化。

## 材料色散

由于采用的是纯石英材料，所以对于不同结构的光子晶体光纤而言，材料色散都相同。

材料色散通过劳伦特级数公式 (laurent series equation) 计算。

$$\eta^2 = A_0 + A_1\lambda^2 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} + \frac{A_4}{\lambda^6} + \frac{A_5}{\lambda^8}$$

# 材料色散

laurent series 公式中系数:

$$A0 = 2.35728$$

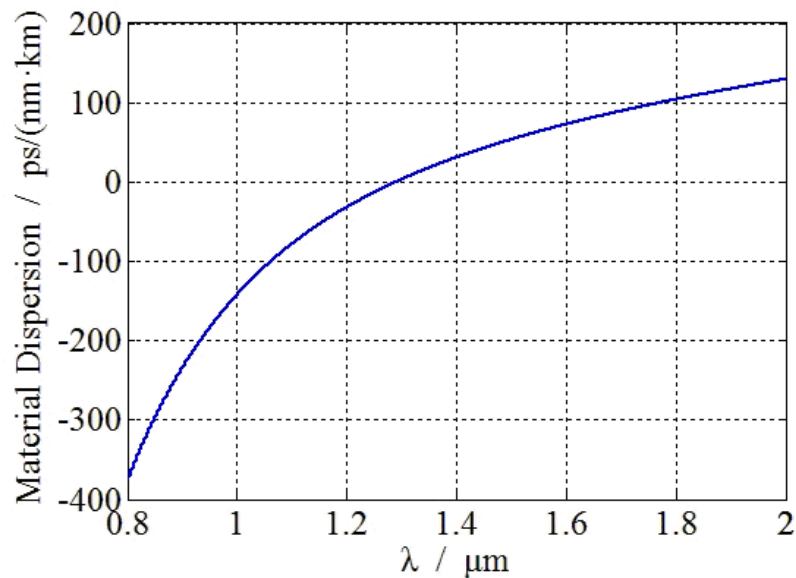
$$A1 = -0.0117$$

$$A2 = 0.01054$$

$$A3 = 0.000134143$$

$$A4 = -0.000000445368$$

$$A5 = -0.0000000592362$$



石英材料的色散曲线

## 波导色散

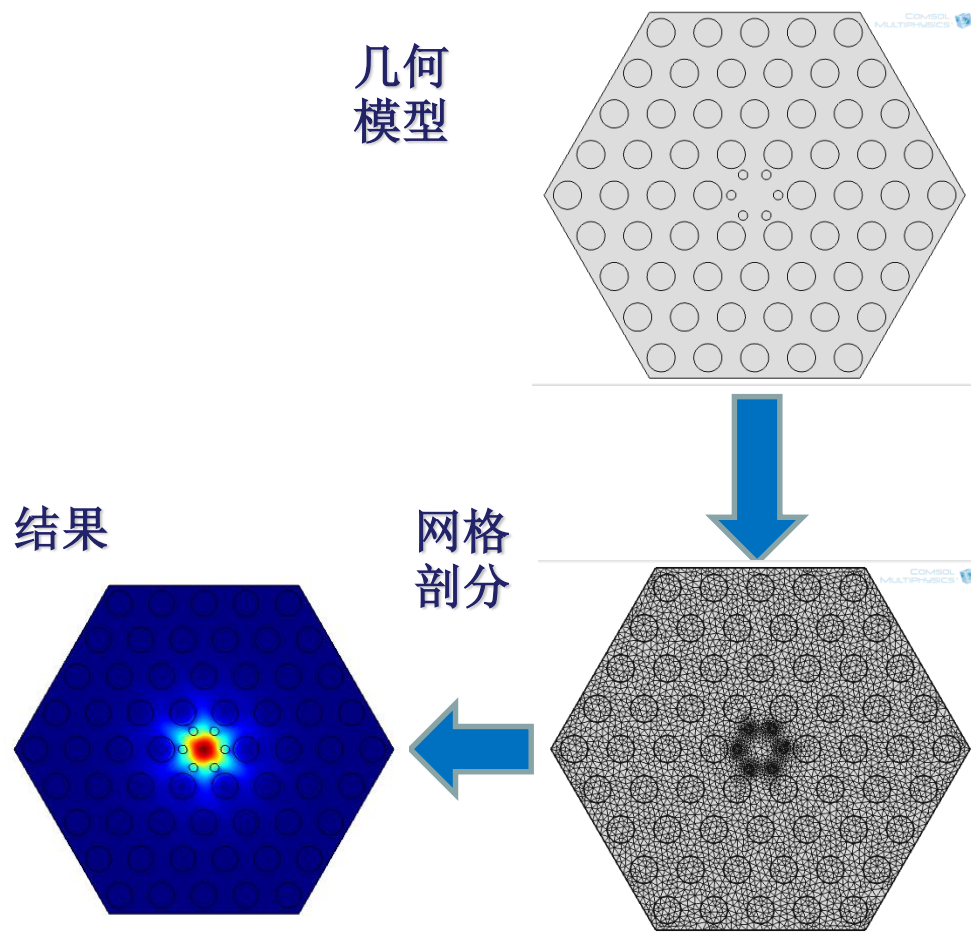
光子晶体光纤的波导色散与光子晶体光纤的结构有着密切的联系，改变光子晶体光纤的结构，我们可以得到不同的波导色散，波导色散我们可以通过以下公式求得：

$$D_w = -\frac{\lambda}{c} \frac{d^2 n_{\text{eff}}}{d\lambda^2}$$

其中  $n_{\text{eff}}$  为有效折射率， $\lambda$  为传输波长。为了求得波导色散，应首先求出有效折射率与波长的关系。利用 COMSOL Multiphysics，获得光子晶体光纤在不同波长时不同模式的有效折射率。在  $0.2\sim 2\mu\text{m}$  之间，波长变化间隔  $0.01\mu\text{m}$ ，对不同空气孔直径进行数值模拟。

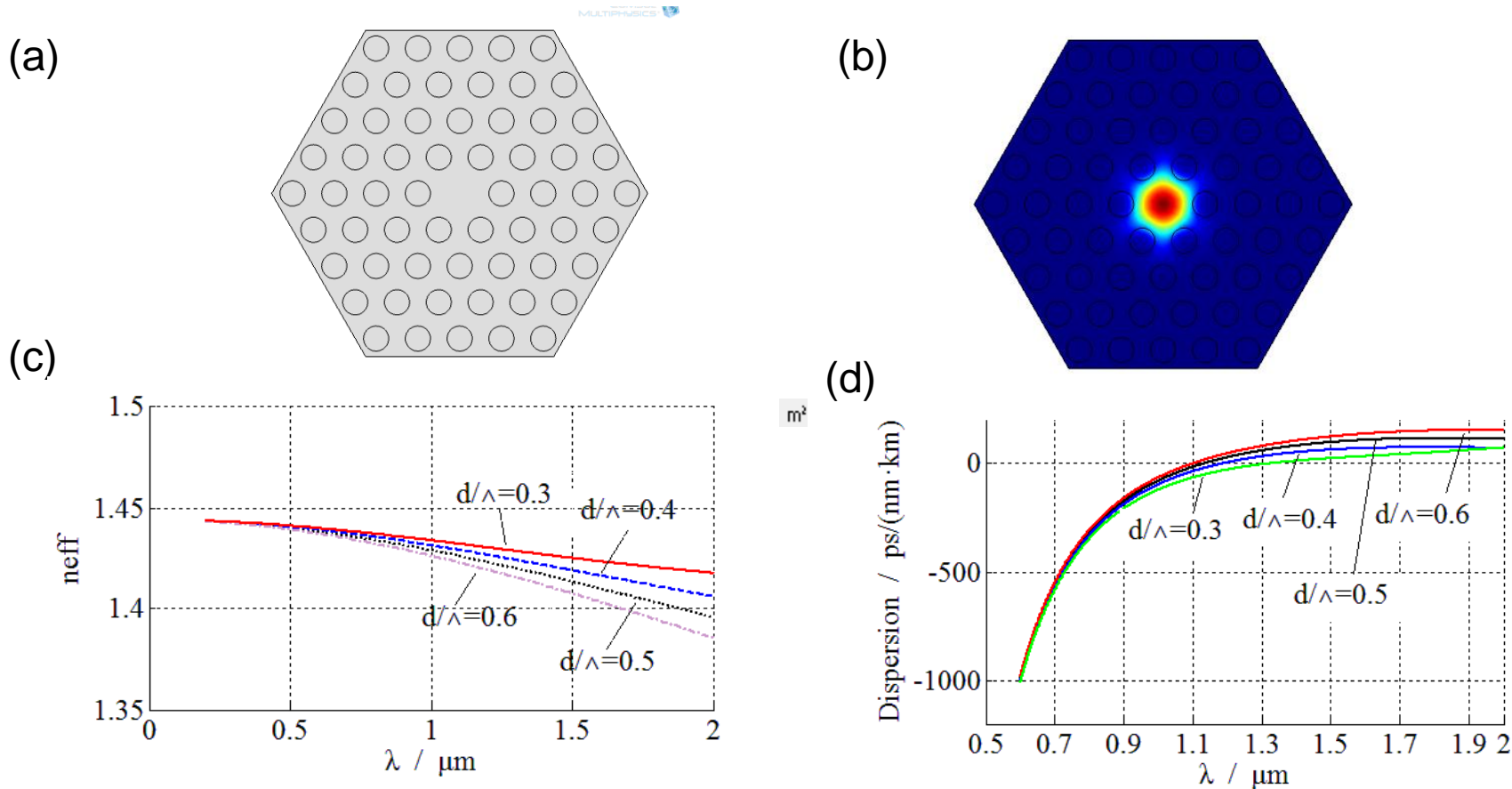
# COMSOL Multiphysics的模拟过程

- 选择电磁波方程
- 选择模式分析求解器
- 创建几何模型
- 设定材料属性
- 设定边界条件
- 生成网格
- 求解
- 后处理





# 中间不含小圆孔的光子晶体光纤



(a) 模型图 (b) 二维电场图 (c) 有效折射率 (d) 色散

## 中间不含小圆孔的光子晶体光纤

$d/\Lambda=0.3$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44 0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}=[$  1.44349953 1.44344942 1.44339704 1.44334241 1.44328553 1.44322643 1.44316512 1.44310162 1.44303595  
1.44296812 1.44289815 1.44282605 1.44275184 1.44267555 1.44259718 1.44251675 1.44243427 1.44234978 1.44226328  
1.44217479 1.44208433 1.44199191 1.44189756 1.44180129 1.44170313 1.44160307 1.44150116 1.44139740 1.44129181  
1.44118442 1.44107524 1.44096429 1.44085158 1.44073715 1.44062101 1.44050317 1.44038366 1.44026251 1.44013972  
1.44001532 1.43988933 1.43976178 1.43963267 1.43950204 1.43936991 1.43923629 1.43910122 1.43896470 1.43882677  
1.43868744 1.43854675 1.43840470 1.43826133 1.43811666 1.43797071 1.43782350 1.43767506 1.43752542 1.43737459  
1.43722260 1.43706948 1.43691525 1.43675993 1.43660356 1.43644614 1.43628772 1.43612832 1.43596795 1.43580665  
1.43564445 1.43548136 1.43531742 1.43515264 1.43498707 1.43482071 1.43465361 1.43448578 1.43431726 1.43414806  
1.43397823 1.43380777 1.43363672 1.43346511 1.43329297 1.43312031 1.43294718 1.43277359 1.43259957 1.43242541  
1.43225035 1.43207521 1.43189974 1.43172399 1.43154796 1.43137170 1.43119523 1.43101857 1.43084175 1.43066479  
1.43048773 1.43031059 1.43013340 1.42995618 1.42977895 1.42960175 1.42942460 1.42924752 1.42907054 1.42889369  
1.42871698 1.42854045 1.42836412 1.42818801 1.42801214 1.42783655 1.42766124 1.42748625 1.42731160 1.42713731  
1.42696341 1.42678990 1.42661682 1.42644419 1.42627202 1.42610034 1.42592916 1.42575851 1.42558841 1.42541887  
1.42524991 1.42508154 1.42491380 1.42474668 1.42458022 1.42441441 1.42424929 1.42408486 1.42392114 1.42375814  
1.42359588 1.42343437 1.42327361 1.42311363 1.42295444 1.42279603 1.42263843 1.42248164 1.42232568 1.42217055  
1.42201626 1.42186281 1.42171022 1.42155848 1.42140762 1.42125763 1.42110851 1.42096027 1.42081292 1.42066646  
1.42052089 1.42037622 1.42023244 1.42008956 1.41994758 1.41980650 1.41966632 1.41952705 1.41938867 1.41925120  
1.41911462 1.41897894 1.41884415 1.41871026 1.41857726 1.41844515 1.41831393 1.41818358 1.41805411 1.41792552  
1.41779780 1.41767095 ];

## 中间不含小圆孔的光子晶体光纤

$d/\Lambda=0.4$

Lambda=[ 0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42  
0.43 0.44 0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67  
0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92  
0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17  
1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42  
1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67  
1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92  
1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00];

$n_{\text{eff}}$ =[1.44340462 1.44334488 1.44328240 1.44321722 1.44314934 1.44307878 1.44300556 1.44292970 1.44285120  
1.44277009 1.44268639 1.44260011 1.44251126 1.44241986 1.44232594 1.44222950 1.44213056 1.44202914 1.44192526  
1.44181893 1.44171016 1.44159898 1.44148541 1.44136945 1.44125112 1.44113045 1.44100745 1.44088213 1.44075451  
1.44062460 1.44049244 1.44035802 1.44022137 1.44008251 1.43994145 1.43979821 1.43965280 1.43950525 1.43935556  
1.43920377 1.43904987 1.43889390 1.43873587 1.43857579 1.43841369 1.43824957 1.43808347 1.43791538 1.43774535  
1.43757337 1.43739947 1.43722367 1.43704599 1.43686643 1.43668503 1.43650180 1.43631675 1.43612991 1.43594129  
1.43575092 1.43555881 1.43536497 1.43516944 1.43497222 1.43477334 1.43457282 1.43437067 1.43416691 1.43396157  
1.43375466 1.43354621 1.43333623 1.43312474 1.43291176 1.43269732 1.43248142 1.43226411 1.43204538 1.43182527  
1.43160379 1.43138097 1.43115683 1.43093138 1.43070465 1.43047666 1.43024743 1.43001698 1.42978533 1.42955251  
1.42931854 1.42908344 1.42884722 1.42860992 1.42837155 1.42813214 1.42789171 1.42765028 1.42740787 1.42716451  
1.42692022 1.42667502 1.42642894 1.42618199 1.42593421 1.42568561 1.42543621 1.42518605 1.42493514 1.42468351  
1.42443118 1.42417817 1.42392451 1.42367022 1.42341533 1.42315986 1.42290383 1.42264726 1.42239019 1.42213263  
1.42187461 1.42161616 1.42135729 1.42109803 1.42083841 1.42057844 1.42031816 1.42005759 1.41979675 1.41953566  
1.41927436 1.41901286 1.41875118 1.41848936 1.41822742 1.41796538 1.41770326 1.41744109 1.41717889 1.41691669  
1.41665451 1.41639237 1.41613030 1.41586832 1.41560646 1.41534473 1.41508317 1.41482179 1.41456062 1.41429968  
1.41403899 1.41377859 1.41351848 1.41325869 1.41299925 1.41274018 1.41248150 1.41222323 1.41196539 1.41170801  
1.41145110 1.41119469 1.41093881 1.41068346 1.41042867 1.41017447 1.40992087 1.40966789 1.40941555 1.40916387  
1.40891288 1.40866259 1.40841302 1.40816418 1.40791610 1.40766880 1.40742229 1.40717660 1.40693173 1.40668770  
1.40644454 1.40620226];

## 中间不含小圆孔的光子晶体光纤

$d/\Lambda=0.5$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42  
0.43 0.44 0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67  
0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92  
0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17  
1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42  
1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67  
1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92  
1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}=[1.44329812 1.44322763 1.44315393 1.44307702 1.44299692 1.44291365 1.44282724 1.44273769 1.44264504$   
1.44254928 1.44245045 1.44234857 1.44224364 1.44213569 1.44202474 1.44191080 1.44179389 1.44167403 1.44155124  
1.44142553 1.44129693 1.44116545 1.44103110 1.44089391 1.44075390 1.44061107 1.44046546 1.44031707 1.44016592  
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1.43832639 1.43814352 1.43795813 1.43777022 1.43757982 1.43738693 1.43719159 1.43699380 1.43679358 1.43659095  
1.43638593 1.43617853 1.43596878 1.43575668 1.43554226 1.43532553 1.43510651 1.43488522 1.43466167 1.43443588  
1.43420787 1.43397766 1.43374526 1.43351069 1.43327397 1.43303511 1.43279414 1.43255106 1.43230591 1.43205868  
1.43180941 1.43155810 1.43130479 1.43104947 1.43079218 1.43053292 1.43027173 1.43000860 1.42974357 1.42947665  
1.42920785 1.42893720 1.42866472 1.42839041 1.42811430 1.42783641 1.42755675 1.42727535 1.42699222 1.42670737  
1.42642083 1.42613262 1.42584275 1.42555125 1.42525812 1.42496340 1.42466709 1.42436922 1.42406980 1.42376886  
1.42346642 1.42316248 1.42285708 1.42255022 1.42224194 1.42193224 1.42162115 1.42130869 1.42099487 1.42067973  
1.42036326 1.42004551 1.41972647 1.41940619 1.41908467 1.41876193 1.41843800 1.41811289 1.41778663 1.41745924  
1.41713073 1.41680113 1.41647045 1.41613873 1.41580597 1.41547220 1.41513744 1.41480171 1.41446504 1.41412744  
1.41378893 1.41344953 1.41310928 1.41276818 1.41242626 1.41208354 1.41174004 1.41139579 1.41105080 1.41070510  
1.41035871 1.41001165 1.40966394 1.40931561 1.40896667 1.40861715 1.40826708 1.40791647 1.40756534 1.40721372  
1.40686163 1.40650909 1.40615613 1.40580276 1.40544901 1.40509491 1.40474047 1.40438571 1.40403067 1.40367536  
1.40331980 1.40296402 1.40260804 1.40225189 1.40189557 1.40153913 1.40118258 1.40082594 1.40046923 1.40011249  
1.39975573 1.39939897 1.39904224 1.39868555 1.39832894 1.39797242 1.39761602 1.39725976 1.39690366 1.39654775  
1.39619204 1.39583656 ];

## 中间不含小圆孔的光子晶体光纤

$d/\Lambda=0.6$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42  
0.43 0.44 0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67  
0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92  
0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17  
1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42  
1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67  
1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92  
1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}=[$  1.44317342 1.44309040 1.44300358 1.44291298 1.44281864 1.44272057 1.44261879 1.44251332 1.44240420  
1.44229142 1.44217503 1.44205504 1.44193146 1.44180433 1.44167366 1.44153947 1.44140179 1.44126062 1.44111600  
1.44096795 1.44081648 1.44066161 1.44050336 1.44034176 1.44017683 1.44000857 1.43983702 1.43966219 1.43948411  
1.43930279 1.43911825 1.43893051 1.43873959 1.43854551 1.43834829 1.43814795 1.43794450 1.43773798 1.43752838  
1.43731575 1.43710008 1.43688141 1.43665976 1.43643513 1.43620755 1.43597704 1.43574361 1.43550730 1.43526810  
1.43502605 1.43478116 1.43453344 1.43428293 1.43402963 1.43377357 1.43351476 1.43325322 1.43298897 1.43272203  
1.43245241 1.43218013 1.43190522 1.43162769 1.43134756 1.43106484 1.43077956 1.43049173 1.43020136 1.42990849  
1.42961312 1.42931528 1.42901497 1.42871223 1.42840706 1.42809948 1.42778952 1.42747719 1.42716251 1.42684549  
1.42652616 1.42620452 1.42588061 1.42555443 1.42522600 1.42489535 1.42456248 1.42422743 1.42389019 1.42355080  
1.42320927 1.42286562 1.42251986 1.42217201 1.42182210 1.42147013 1.42111613 1.42076012 1.42040210 1.42004211  
1.41968015 1.41931625 1.41895041 1.41858267 1.41821304 1.41784154 1.41746818 1.41709298 1.41671596  
1.41633714 1.41595653 1.41557416 1.41519004 1.41480419 1.41441664 1.41402738 1.41363646 1.41324387 1.41284965  
1.41245381 1.41205636 1.41165734 1.41125675 1.41085461 1.41045095 1.41004577 1.40963911 1.40923097 1.40882139  
1.40841037 1.40799793 1.40758410 1.40716889 1.40675233 1.40633442 1.40591520 1.40549468 1.40507287 1.40464981  
1.40422550 1.40379997 1.40337324 1.40294532 1.40251624 1.40208602 1.40165467 1.40122222 1.40078869 1.40035409  
1.39991844 1.39948177 1.39904410 1.39860544 1.39816582 1.39772526 1.39728378 1.39684139 1.39639812 1.39595399  
1.39550902 1.39506322 1.39461663 1.39416927 1.39372114 1.39327228 1.39282270 1.39237243 1.39192149 1.39146989  
1.39101767 1.39056483 1.39011141 1.38965742 1.38920288 1.38874782 1.38829226 1.38783622 1.38737972 1.38692279  
1.38646543 1.38600769 1.38554957 ];

## 中间不含小圆孔的光子晶体光纤

$$\begin{aligned} n_{\text{eff}}(d/\Lambda=0.3) = & - 1.4653\text{e-}05*\lambda^{\{10\}} + 0.00018003*\lambda^{\{9\}} \\ & - 0.00088708*\lambda^{\{8\}} + 0.0024024*\lambda^{\{7\}} - \\ & 0.0043079*\lambda^{\{6\}} + 0.0054511*\lambda^{\{5\}} - \\ & 0.0040297*\lambda^{\{4\}} + 0.004478*\lambda^{\{3\}} - \\ & 0.013533*\lambda^{\{2\}} + 7.3037\text{e-}05*\lambda + 1.444 \end{aligned}$$

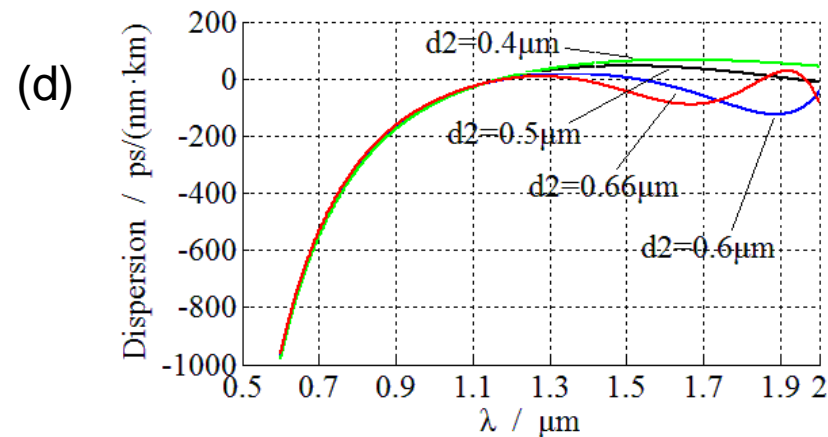
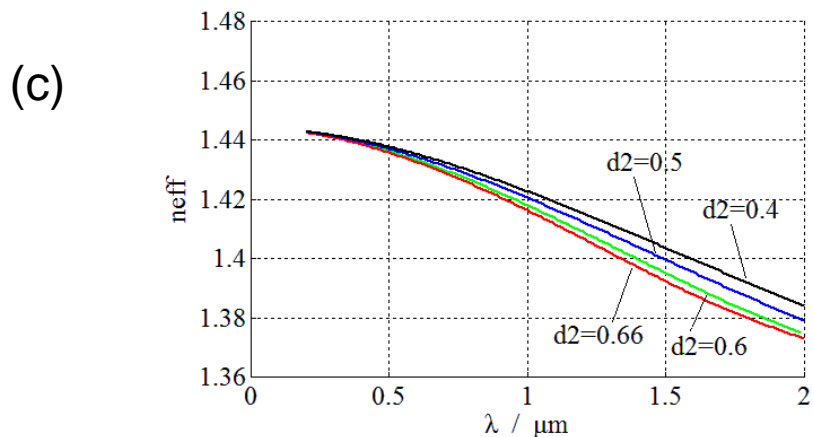
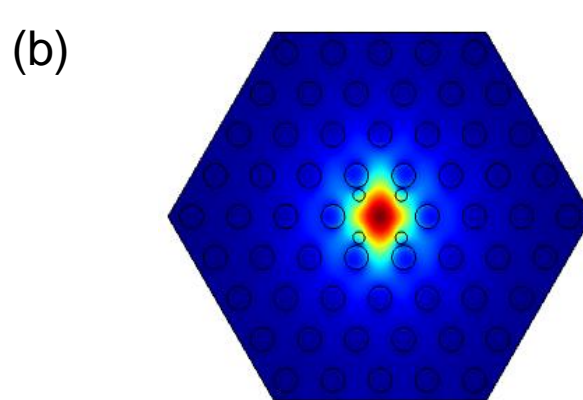
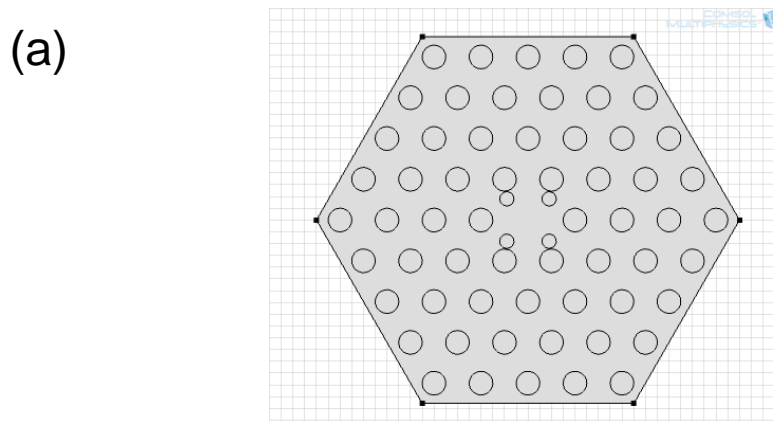
$$\begin{aligned} n_{\text{eff}}(d/\Lambda=0.4) = & - 2.8231\text{e-}07*\lambda^{\{10\}} + 4.4165\text{e-}07*\lambda^{\{9\}} \\ & + 2.4347\text{e-}05*\lambda^{\{8\}} - 0.00019105*\lambda^{\{7\}} \\ & + 0.00054614*\lambda^{\{6\}} - 0.00062818*\lambda^{\{5\}} \\ & + 0.00039187*\lambda^{\{4\}} + 0.002593*\lambda^{\{3\}} - \\ & 0.015333*\lambda^{\{2\}} - 2.4033\text{e-}05*\lambda + 1.444 \end{aligned}$$

## 中间不含小圆孔的光子晶体光纤

$$\begin{aligned} n_{\text{eff}}(d/\Lambda=0.5) = & - 2.1745\text{e-}06*\lambda^{\{10\}} + 2.7382\text{e-}05*\lambda^{\{9\}} \\ & - 0.00014466*\lambda^{\{8\}} + 0.00039938*\lambda^{\{7\}} - \\ & 0.00061824*\lambda^{\{6\}} + 0.00064796*\lambda^{\{5\}} - \\ & 0.00061534*\lambda^{\{4\}} + 0.0034057*\lambda^{\{3\}} - \\ & 0.018142*\lambda^{\{2\}} - 2.3251\text{e-}05*\lambda + 1.444 \end{aligned}$$

$$\begin{aligned} n_{\text{eff}}(d/\Lambda=0.6) = & - 2.6402\text{e-}06*\lambda^{\{10\}} + 3.3709\text{e-}05*\lambda^{\{9\}} \\ & - 0.00018945*\lambda^{\{8\}} + 0.00059934*\lambda^{\{7\}} - \\ & 0.0011535*\lambda^{\{6\}} + 0.0014792*\lambda^{\{5\}} - \\ & 0.0015309*\lambda^{\{4\}} + 0.0044643*\lambda^{\{3\}} - \\ & 0.021481*\lambda^{\{2\}} - 1.6741\text{e-}05*\lambda + 1.444 \end{aligned}$$

# 中间含四个小圆孔的光子晶体光纤



(a) 模型图 (b) 二维电场图 (c) 有效折射率 (d) 色散



## 中间含四个小圆孔的光子晶体光纤

$$d_2/\Lambda_2=0.4$$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44 0.45  
0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73  
0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01  
1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29  
1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57  
1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85  
1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[1.442918 1.442811 1.442699 1.442582 1.442460 1.442334 1.442203 1.442068 1.441929 1.441784 1.441636 1.441483 1.441326  
1.441164 1.440999 1.440829 1.440655 1.440477 1.440295 1.440109 1.439919 1.439725 1.439527 1.439325 1.439120 1.438911 1.438698  
1.438482 1.438261 1.438038 1.437811 1.437580 1.437346 1.437108 1.436867 1.436623 1.436376 1.436125 1.435871 1.435614 1.435354  
1.435091 1.434825 1.434556 1.434283 1.434008 1.433731 1.433450 1.433166 1.432880 1.432591 1.432300 1.432006 1.431709 1.431410  
1.431108 1.430803 1.430497 1.430188 1.429876 1.429562 1.429246 1.428928 1.428607 1.428285 1.427960 1.427633 1.427304 1.426973  
1.426639 1.426304 1.425967 1.425628 1.425288 1.424945 1.424601 1.424255 1.423907 1.423557 1.423206 1.422853 1.422498 1.422142  
1.421784 1.421425 1.421064 1.420702 1.420339 1.419974 1.419607 1.419240 1.418871 1.418501 1.418129 1.417756 1.417383 1.417007  
1.416631 1.416254 1.415876 1.415496 1.415116 1.414734 1.414352 1.413969 1.413585 1.413199 1.412814 1.412427 1.412039 1.411651  
1.411262 1.410872 1.410482 1.410091 1.409699 1.409307 1.408914 1.408521 1.408127 1.407733 1.407338 1.406943 1.406547 1.406151  
1.405755 1.405358 1.404962 1.404564 1.404167 1.403770 1.403372 1.402974 1.402576 1.402178 1.401780 1.401382 1.400984 1.400586  
1.400188 1.399790 1.399392 1.398994 1.398597 1.398200 1.397803 1.397406 1.397010 1.396614 1.396218 1.395823 1.395428 1.395033  
1.394639 1.394246 1.393853 1.393460 1.393068 1.392677 1.392287 1.391897 1.391508 1.391119 1.390732 1.390345 1.389959 1.389574  
1.389189 1.388806 1.388424 1.388042 1.387662 1.387283 1.386904 1.386527 1.386151 1.385776 1.385402 1.385030 1.384658  
1.384288 ];

## 中间含四个小圆孔的光子晶体光纤

$$d_2/\Lambda_2=0.5$$

Lambda=[ 0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44  
0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72  
0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00  
1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28  
1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56  
1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84  
1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[1.442805 1.442687 1.442563 1.442434 1.442300 1.442161 1.442017 1.441868 1.441714 1.441555 1.441391 1.441223 1.441050  
1.440872 1.440689 1.440502 1.440310 1.440114 1.439914 1.439709 1.439499 1.439285 1.439068 1.438845 1.438619 1.438389 1.438154  
1.437915 1.437673 1.437426 1.437176 1.436922 1.436664 1.436402 1.436136 1.435867 1.435594 1.435318 1.435038 1.434755 1.434468  
1.434178 1.433884 1.433587 1.433287 1.432984 1.432677 1.432367 1.432055 1.431739 1.431420 1.431098 1.430773 1.430446 1.430115  
1.429782 1.429446 1.429107 1.428766 1.428422 1.428075 1.427726 1.427375 1.427021 1.426664 1.426305 1.425944 1.425581 1.425215  
1.424847 1.424477 1.424105 1.423730 1.423354 1.422976 1.422595 1.422213 1.421829 1.421443 1.421055 1.420665 1.420274 1.419881  
1.419486 1.419090 1.418692 1.418292 1.417891 1.417489 1.417085 1.416680 1.416273 1.415865 1.415456 1.415046 1.414634 1.414221  
1.413807 1.413392 1.412976 1.412559 1.412141 1.411722 1.411303 1.410882 1.410460 1.410038 1.409615 1.409191 1.408767 1.408342  
1.407916 1.407490 1.407063 1.406636 1.406208 1.405780 1.405352 1.404923 1.404494 1.404065 1.403635 1.403205 1.402775 1.402346  
1.401916 1.401486 1.401056 1.400626 1.400196 1.399766 1.399337 1.398907 1.398478 1.398049 1.397621 1.397193 1.396765 1.396338  
1.395911 1.395485 1.395060 1.394635 1.394210 1.393787 1.393364 1.392942 1.392521 1.392100 1.391681 1.391262 1.390845 1.390428  
1.390013 1.389598 1.389185 1.388773 1.388362 1.387953 1.387545 1.387138 1.386733 1.386329 1.385926 1.385525 1.385126 1.384728  
1.384332 1.383938 1.383545 1.383154 1.382765 1.382377 1.381992 1.381608 1.381227 1.380847 1.380469 1.380094 1.379720  
1.379349 ];

## 中间含四个小圆孔的光子晶体光纤

$$d_2/A_2=0.6$$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44 0.45  
0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73  
0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01  
1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29  
1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57  
1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85  
1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[ 1.442669 1.442537 1.442399 1.442256 1.442107 1.441952 1.441792 1.441626 1.441455 1.441278 1.441096 1.440909 1.440717  
1.440519 1.440316 1.440109 1.439896 1.439678 1.439455 1.439228 1.438995 1.438758 1.438517 1.438270 1.438019 1.437763 1.437503  
1.437239 1.436970 1.436696 1.436419 1.436137 1.435851 1.435561 1.435267 1.434968 1.434666 1.434360 1.434050 1.433736 1.433418  
1.433097 1.432771 1.432442 1.432110 1.431774 1.431435 1.431092 1.430745 1.430396 1.430042 1.429686 1.429327 1.428964 1.428598  
1.428229 1.427857 1.427483 1.427105 1.426724 1.426341 1.425954 1.425565 1.425174 1.424779 1.424382 1.423983 1.423581 1.423176  
1.422769 1.422360 1.421948 1.421534 1.421118 1.420700 1.420279 1.419857 1.419432 1.419006 1.418577 1.418147 1.417714 1.417280  
1.416845 1.416407 1.415968 1.415527 1.415085 1.414641 1.414195 1.413748 1.413300 1.412851 1.412400 1.411948 1.411495 1.411040  
1.410585 1.410128 1.409671 1.409212 1.408753 1.408293 1.407832 1.407370 1.406908 1.406445 1.405982 1.405518 1.405053 1.404588  
1.404123 1.403657 1.403191 1.402725 1.402259 1.401793 1.401326 1.400860 1.400394 1.399928 1.399462 1.398997 1.398531 1.398067  
1.397602 1.397138 1.396675 1.396213 1.395751 1.395290 1.394829 1.394370 1.393912 1.393454 1.392998 1.392543 1.392089 1.391637  
1.391186 1.390737 1.390289 1.389842 1.389398 1.388955 1.388514 1.388075 1.387638 1.387203 1.386770 1.386340 1.385912 1.385486  
1.385063 1.384642 1.384224 1.383808 1.383395 1.382985 1.382578 1.382174 1.381773 1.381374 1.380979 1.380587 1.380198 1.379812  
1.379050 1.378674 1.378301 1.377931 1.377565 1.377202 1.376842 1.376486 1.376132 1.375782 1.375435 1.375092 ];

## 中间含四个小圆孔的光子晶体光纤

$$d_2/\Lambda_2=0.66$$

Lambda=[ 0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44  
0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72  
0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00  
1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28  
1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56  
1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84  
1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[ 1.44257310 1.44243188 1.44228448 1.44213097 1.44197140 1.44180584 1.44163435 1.44145698 1.44127381 1.44108488  
1.44089026 1.44069001 1.44048418 1.44027284 1.44005605 1.43983385 1.43960631 1.43937350 1.43913545 1.43889224 1.43864392  
1.43839055 1.43813218 1.43786886 1.43760066 1.43732764 1.43704984 1.43676732 1.43648014 1.43618836 1.43589202 1.43559118  
1.43528590 1.43497623 1.43466222 1.43434393 1.43402142 1.43369473 1.43336392 1.43302904 1.43269015 1.43234730 1.43200053  
1.43164991 1.43129549 1.43093731 1.43057543 1.43020991 1.42984079 1.42946813 1.42909197 1.42871238 1.42832939 1.42794307  
1.42755346 1.42716062 1.42676459 1.42636543 1.42596319 1.42555792 1.42514968 1.42473850 1.42432445 1.42390758 1.42348793  
1.42306556 1.42264052 1.42221286 1.42178264 1.42134989 1.42091469 1.42047707 1.42003709 1.41959480 1.41915026 1.41870351  
1.41825461 1.41780362 1.41735058 1.41689555 1.41643858 1.41597972 1.41551904 1.41505658 1.41459241 1.41412657 1.41365912  
1.41319012 1.41271962 1.41224769 1.41177438 1.41129975 1.41082385 1.41034675 1.40986851 1.40938920 1.40890886 1.40842757  
1.40794538 1.40746238 1.40697861 1.40649415 1.40600906 1.40552342 1.40503729 1.40455076 1.40406388 1.40357675 1.40308942  
1.40260199 1.40211454 1.40162714 1.40113989 1.40065286 1.40016615 1.39967986 1.39919407 1.39870888 1.39822439 1.39774072  
1.39725795 1.39677621 1.39629559 1.39581623 1.39533823 1.39486173 1.39438683 1.39391367 1.39344238 1.39297308 1.39250591  
1.39204101 1.39157849 1.39111850 1.39066116 1.39020659 1.38975493 1.38930628 1.38886076 1.38841846 1.38797949 1.38754391  
1.38711182 1.38668327 1.38625830 1.38583697 1.38541929 1.38500528 1.38459495 1.38418829 1.38378528 1.38338591 1.38299015  
1.38259795 1.38220929 1.38182410 1.38144235 1.38106399 1.38068896 1.38031721 1.37994868 1.37958333 1.37922110 1.37886194  
1.37850580 1.37815264 1.37780239 1.37745502 ];

## 中间含四个小圆孔的光子晶体光纤

$$\begin{aligned} n_{\text{eff}}(d_2/\Lambda_2=0.4) = & -9.8688\text{e-}06*\lambda^{\{10\}} + \\ & 0.00014295*\lambda^{\{9\}} - 0.00085998*\lambda^{\{8\}} + \\ & 0.0027034*\lambda^{\{7\}} - 0.0045684*\lambda^{\{6\}} + \\ & 0.0037189*\lambda^{\{5\}} - 0.0012603*\lambda^{\{4\}} + \\ & 0.0071762*\lambda^{\{3\}} - 0.02808*\lambda^{\{2\}} - 0.00011885*\lambda \\ & + 1.444 \end{aligned}$$

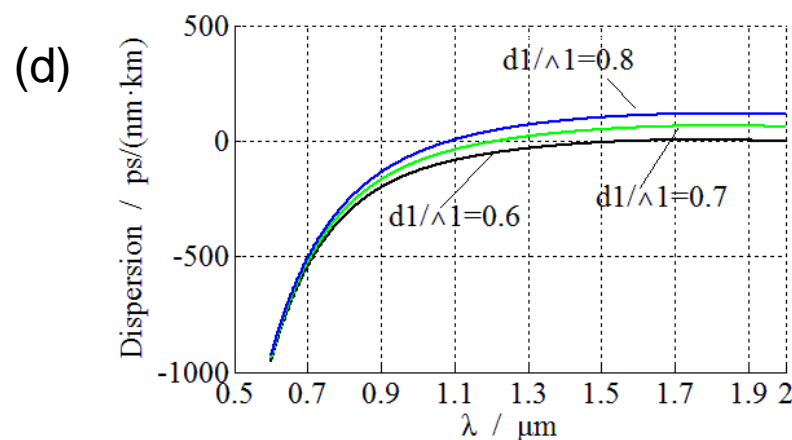
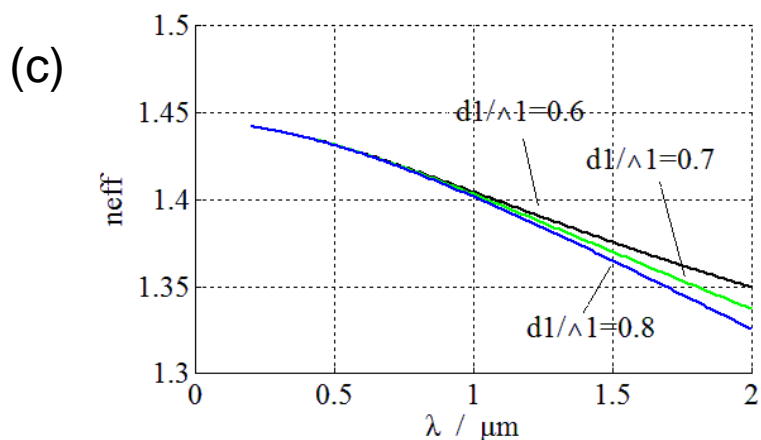
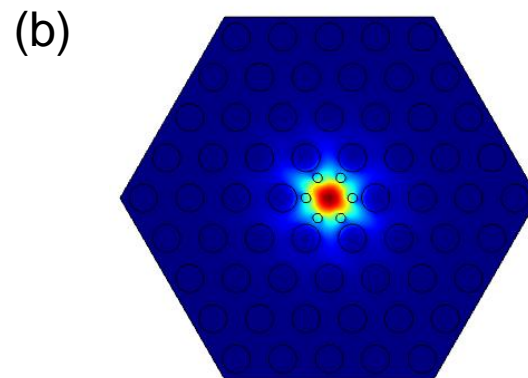
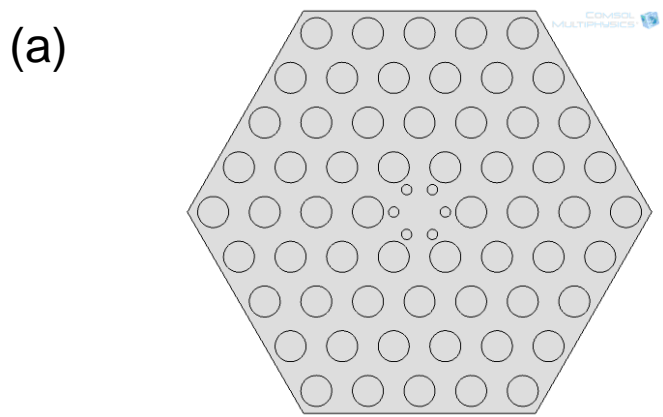
$$\begin{aligned} n_{\text{eff}}(d_2/\Lambda_2=0.5) = & 3.4381\text{e-}05*\lambda^{\{10\}} - 0.00041548*\lambda^{\{9\}} \\ & + 0.0020673*\lambda^{\{8\}} - 0.0056403*\lambda^{\{7\}} + \\ & 0.009509*\lambda^{\{6\}} - 0.010477*\lambda^{\{5\}} + \\ & 0.0071274*\lambda^{\{4\}} + 0.0050016*\lambda^{\{3\}} - \\ & 0.030342*\lambda^{\{2\}} - 0.00021338*\lambda + 1.444 \end{aligned}$$

## 中间含四个小圆孔的光子晶体光纤

$$n_{\text{eff}}(d_2/\Lambda_2=0.6) = -0.0016942*\lambda^{10} + 0.01741*\lambda^9 - 0.07786*\lambda^8 + 0.1987*\lambda^7 - 0.31861*\lambda^6 + 0.33364*\lambda^5 - 0.23038*\lambda^4 + 0.11177*\lambda^3 - 0.062612*\lambda^2 + 0.0040456*\lambda + 1.4437$$

$$n_{\text{eff}}(d_2/\Lambda_2=0.66) = 0.0082071*\lambda^{10} - 0.084619*\lambda^9 + 0.37506*\lambda^8 - 0.93873*\lambda^7 + 1.4654*\lambda^6 - 1.4855*\lambda^5 + 0.98536*\lambda^4 - 0.41069*\lambda^3 + 0.073075*\lambda^2 - 0.0161*\lambda + 1.445$$

# 中间含六个小圆孔的光子晶体光纤



(a) 模型图 (b) 二维电场图 (c) 有效折射率 (d) 色散

## 中间含六个小圆孔的光子晶体光纤

$$d_1/\Lambda_1=0.6$$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44 0.45  
0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73  
0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01  
1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29  
1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57  
1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85  
1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[1.44211383 1.44188940 1.44165545 1.44141210 1.44115949 1.44089775 1.44062700 1.44034737 1.44005899 1.43976200  
1.43945653 1.43914269 1.43882063 1.43849048 1.43815236 1.43780641 1.43745276 1.43709153 1.43672287 1.43634689 1.43596375  
1.43557355 1.43517645 1.43477257 1.43436204 1.43394500 1.43352158 1.43309191 1.43265613 1.43221437 1.43176677 1.43131344  
1.43085454 1.43039019 1.42992053 1.42944568 1.42896578 1.42848096 1.42799136 1.42749709 1.42699830 1.42649512 1.42598766  
1.42547607 1.42496046 1.42444096 1.42391771 1.42339081 1.42286041 1.42232661 1.42178954 1.42124932 1.42070607 1.42015990  
1.41961093 1.41905927 1.41850503 1.41794834 1.41738928 1.41682798 1.41626453 1.41569905 1.41513162 1.41456236 1.41399136  
1.41341871 1.41284451 1.41226885 1.41169183 1.41111352 1.41053402 1.40995341 1.40937177 1.40878919 1.40820573 1.40762149  
1.40703652 1.40645090 1.40586471 1.40527801 1.40469087 1.40410334 1.40351551 1.40292741 1.40233913 1.40175070 1.40116219  
1.40057365 1.39998514 1.39939670 1.39880838 1.39822022 1.39763229 1.39704461 1.39645724 1.39587021 1.39528357 1.39469735  
1.39411159 1.39352632 1.39294159 1.39235743 1.39177386 1.39119093 1.39060866 1.39002708 1.38944623 1.38886612 1.38828680  
1.38770827 1.38713058 1.38655375 1.38597779 1.38540274 1.38482862 1.38425544 1.38368324 1.38311204 1.38254185 1.38197269  
1.38140460 1.38083758 1.38027166 1.37970685 1.37914319 1.37858067 1.37801933 1.37745919 1.37690025 1.37634255 1.37578609  
1.37523089 1.37467698 1.37412438 1.37357309 1.37302313 1.37247453 1.37192731 1.37138147 1.37083704 1.37029404 1.36975248  
1.36921239 1.36867377 1.36813665 1.36760104 1.36706697 1.36653445 1.36600350 1.36547414 1.36494639 1.36442027 1.36389579  
1.36337297 1.36285184 1.36233241 1.36181471 1.36129875 1.36078455 1.36027213 1.35976151 1.35925271 1.35874576 1.35824066  
1.35773745 1.35723615 1.35673676 1.35623932 1.35574385 1.35525036 1.35475888 1.35426942 1.35378202 1.35329668 1.35281343  
1.35233230 1.35185330 1.35137645 1.35090177 1.35042930 1.34995903];



## 中间含六个小圆孔的光子晶体光纤

$$d_1/A_1=0.7$$

Lambda=[ 0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44  
0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72  
0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00  
1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28  
1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56  
1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84  
1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[1.44210495 1.44187938 1.44164419 1.44139951 1.44114545 1.44088215 1.44060972 1.44032829 1.44003798 1.43973892  
1.43943123 1.43911502 1.43879043 1.43845757 1.43811657 1.43776754 1.43741061 1.43704590 1.43667353 1.43629362 1.43590629  
1.43551166 1.43510984 1.43470097 1.43428515 1.43386251 1.43343316 1.43299723 1.43255482 1.43210606 1.43165106 1.43118994  
1.43072281 1.43024980 1.42977100 1.42928654 1.42879653 1.42830109 1.42780031 1.42729433 1.42678323 1.42626714 1.42574617  
1.42522041 1.42468998 1.42415498 1.42361552 1.42307169 1.42252361 1.42197138 1.42141509 1.42085484 1.42029074 1.41972287  
1.41915134 1.41857623 1.41799765 1.41741568 1.41683041 1.41624193 1.41565033 1.41505570 1.41445812 1.41385767 1.41325444  
1.41264851 1.41203995 1.41142884 1.41081527 1.41019930 1.40958100 1.40896046 1.40833774 1.40771291 1.40708603 1.40645718  
1.40582642 1.40519381 1.40455942 1.40392330 1.40328552 1.40264612 1.40200518 1.40136275 1.40071887 1.40007360 1.39942700  
1.39877911 1.39812999 1.39747968 1.39682822 1.39617567 1.39552207 1.39486746 1.39421189 1.39355539 1.39289801 1.39223978  
1.39158075 1.39092095 1.39026042 1.38959919 1.38893730 1.38827478 1.38761167 1.38694800 1.38628380 1.38561909 1.38495392  
1.38428831 1.38362228 1.38295587 1.38228911 1.38162202 1.38095462 1.38028695 1.37961902 1.37895087 1.37828251 1.37761398  
1.37694529 1.37627646 1.37560753 1.37493851 1.37426942 1.37360028 1.37293112 1.37226196 1.37159281 1.37092370 1.37025465  
1.36958568 1.36891680 1.36824803 1.36757941 1.36691093 1.36624263 1.36557452 1.36490662 1.36423895 1.36357152 1.36290436  
1.36223748 1.36157091 1.36090465 1.36023873 1.35957316 1.35890797 1.35824317 1.35757878 1.35691482 1.35625130 1.35558824  
1.35492566 1.35426359 1.35360203 1.35294101 1.35228054 1.35162064 1.35096133 1.35030263 1.34964456 1.34898714 1.34833038  
1.34767430 1.34701892 1.34636427 1.34571036 1.34505721 1.34440484 1.34375326 1.34310251 1.34245259 1.34180354 1.34115536  
1.34050807 1.33986171 1.33921629 1.33857183 1.33792834 1.33728586 ];

## 中间含六个小圆孔的光子晶体光纤

$$d_1/A_1=0.8$$

Lambda=[0.20 0.21 0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31 0.32 0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40 0.41 0.42 0.43 0.44 0.45 0.46 0.47 0.48 0.49 0.50 0.51 0.52 0.53 0.54 0.55 0.56 0.57 0.58 0.59 0.60 0.61 0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29 1.30 1.31 1.32 1.33 1.34 1.35 1.36 1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76 1.77 1.78 1.79 1.80 1.81 1.82 1.83 1.84 1.85 1.86 1.87 1.88 1.89 1.90 1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 ];

$n_{\text{eff}}$ =[1.44209539 1.44186862 1.44163212 1.44138603 1.44113047 1.44086554 1.44059137 1.44030808 1.44001578 1.43971460 1.43940464 1.43908603 1.43875887 1.43842328 1.43807938 1.43772728 1.43736709 1.43699892 1.43662288 1.43623909 1.43584765 1.43544867 1.43504226 1.43462853 1.43420759 1.43377953 1.43334447 1.43290251 1.43245375 1.43199830 1.43153626 1.43106772 1.43059279 1.43011157 1.42962415 1.42913064 1.42863113 1.42812571 1.42761447 1.42709752 1.42657495 1.42604684 1.42551328 1.42497437 1.42443019 1.42388084 1.42332639 1.42276693 1.42220255 1.42163332 1.42105934 1.42048068 1.41989742 1.41930964 1.41871742 1.41812083 1.41751995 1.41691486 1.41630562 1.41569231 1.41507501 1.41445377 1.41382867 1.41319979 1.41256717 1.41193090 1.41129104 1.41064764 1.41000078 1.40935051 1.40869689 1.40804000 1.40737987 1.40671658 1.40605018 1.40538073 1.40470827 1.40403288 1.40335459 1.40267346 1.40198955 1.40130290 1.40061356 1.39992159 1.39922703 1.39852993 1.39783034 1.39712830 1.39642385 1.39571705 1.39500794 1.39429655 1.39358294 1.39286714 1.39214920 1.39142915 1.39070703 1.38998290 1.38925677 1.38852869 1.38779871 1.38706685 1.38633315 1.38559765 1.38486038 1.38412138 1.38338068 1.38263832 1.38189433 1.38114874 1.38040159 1.37965290 1.37890271 1.37815105 1.37739796 1.37664345 1.37588757 1.37513033 1.37437178 1.37361194 1.37285083 1.37208850 1.37132495 1.37056023 1.36979437 1.36902738 1.36825929 1.36749014 1.36671994 1.36594874 1.36517654 1.36440338 1.36362928 1.36285427 1.36207838 1.36130163 1.36052404 1.35974563 1.35896645 1.35818650 1.35740582 1.35662442 1.35584233 1.35505959 1.35427620 1.35349219 1.35270760 1.35192243 1.35113673 1.35035050 1.34956377 1.34877657 1.34798892 1.34720084 1.34641236 1.34562350 1.34483429 1.34404474 1.34325488 1.34246473 1.34167432 1.34088367 1.34009281 1.33930175 1.33851052 1.33771914 1.33692764 1.33613604 1.33534436 1.33455263 1.33376087 1.33296910 1.33217735 1.33138564 1.33059400 1.32980244 1.32901099 1.32821968 1.32742852 1.32663755 1.32584679 ];

## 中间含六个小圆孔的光子晶体光纤

$$\begin{aligned} n_{\text{eff}}(d_1/\Lambda_1=0.6) = & - 0.00020203*\lambda^{\{ 10\}} + 0.002852*\lambda^{\{ 9\}} \\ & - 0.017093*\lambda^{\{ 8\}} + 0.056355*\lambda^{\{ 7\}} - \\ & 0.11026*\lambda^{\{ 6\}} + 0.12891*\lambda^{\{ 5\}} - 0.091279*\lambda^{\{ 4\}} \\ & + 0.0612*\lambda^{\{ 3\}} - 0.071506*\lambda^{\{ 2\}} + 0.0013947*\lambda + \\ & 1.4443 \end{aligned}$$

$$\begin{aligned} n_{\text{eff}}(d_1/\Lambda_1=0.7) = & - 0.00010976*\lambda^{\{ 10\}} + \\ & 0.0014727*\lambda^{\{ 9\}} - 0.0084776*\lambda^{\{ 8\}} + \\ & 0.027015*\lambda^{\{ 7\}} - 0.051032*\lambda^{\{ 6\}} + \\ & 0.05705*\lambda^{\{ 5\}} - 0.039878*\lambda^{\{ 4\}} + \\ & 0.037913*\lambda^{\{ 3\}} - 0.06555*\lambda^{\{ 2\}} + 0.00051209*\lambda \\ & + 1.4444 \end{aligned}$$

## 中间含六个小圆孔的光子晶体光纤

$$\begin{aligned} n_{\text{eff}}(d_1/\Lambda_1=0.8) = & - 5.6466\text{e-}05*\lambda^{\{10\}} + \\ & 0.00067138*\lambda^{\{9\}} - 0.003403*\lambda^{\{8\}} + \\ & 0.0093967*\lambda^{\{7\}} - 0.014772*\lambda^{\{6\}} + \\ & 0.012675*\lambda^{\{5\}} - 0.0086977*\lambda^{\{4\}} + \\ & 0.023947*\lambda^{\{3\}} - 0.062185*\lambda^{\{2\}} + 1.3856\text{e-}05*\lambda \\ & + 1.4444 \end{aligned}$$

## 结论

当空气孔直径相同时，空气孔直径与孔间距之比  $d/\Lambda$  增大，有效折射率减少，而色散系数增大。当中心附近有小空气孔时，小空气孔直径  $d_2$  越小有效折射率越大，色散系数越大；在小空气孔直径不变时，大空气孔直径与其孔间距之比  $d_1/\Lambda_1$  增大，则色散系数增大，当  $d_1/\Lambda_1=0.6$  时，发现中间带六小圆孔的光子晶体光纤具有更好的负色散特性。

谢谢