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Focusing Light through Turbid Media by Binary Amplitude Shaping

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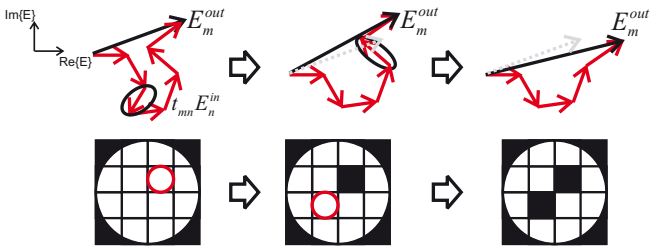
Many materials such as paint, human skin, egg shell and paper are turbid materials which scatter light strongly. If coherent light is transmitted through such materials, a speckle pattern is formed. Here, we demonstrate that light is focused to a bright spot after such a material by selectively blocking parts of the light wave entering the material. By this method, it is possible to utilize fast, MEMS-based binary amplitude modulators for wavefront shaping. This method could prove useful for applications in medical imaging.

THE ALGORITHM



Amplitude map on the SLM before optimization. Segment circled in red will be turned off.

Amplitude map on the SLM as the optimization runs. Black segment is off; segment circled in red will be turned off.

Amplitude map on the SLM when optimization is finished. Segments that lead to destructive interference are off.

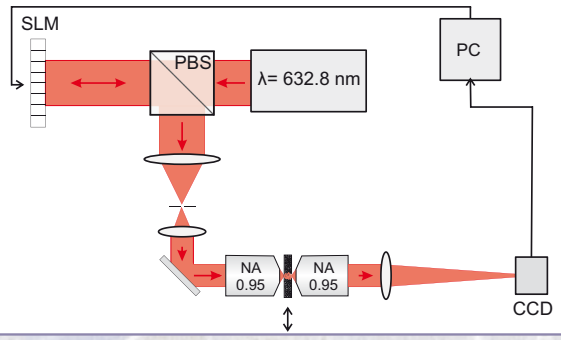
E_m^{out} :Electric field at the output channel "m".

E_n^{in} :Electric field at the input channel "n".

t_{mn} :Transmission matrix element that couples input channel "n" to output channel "m"

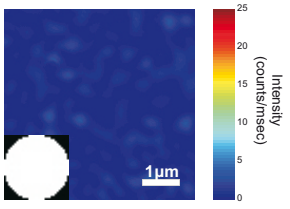
$$E_m^{out} = \sum_n^N t_{mn} E_n^{in}$$

EXPERIMENTAL SETUP

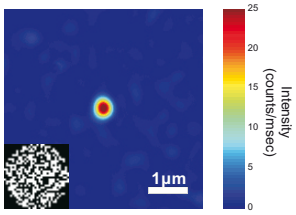


CREATING THE SPOT

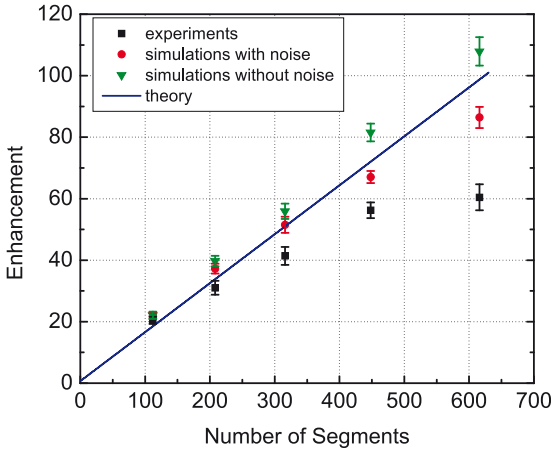
Before Optimization:



After Optimization:



INTENSITY ENHANCEMENT



enhancement for binary amplitude modulation:

$$\eta_{binary} = \frac{< I_{opt} >}{< I_{ref} >} \approx \frac{1}{\pi}\left(\frac{N}{2}\right)$$

enhancement for phase modulation:

$$\eta_{phase} = \frac{< I_{opt} >}{< I_{ref} >} \approx \frac{\pi}{4} N$$

$< I_{opt} >$: Ensemble averaged intensity inside the target area while each time a wavefront optimized for the sample configuration is sent to the sample.

$< I_{ref} >$: Ensemble averaged intensity inside the target area while the wavefront obtained after optimization is sent to changed configuration of the sample.

CONCLUSIONS

We have demonstrated focusing light through a strongly scattering material by blocking part of the light field entering the sample.

The intensity of light at the target position is enhanced by a factor of ~60 when SLM is divided into ~600 segments.

•I.M. Vellekoop and A.P. Mosk, "Focusing coherent light through opaque strongly scattering media" Optics Letters, **32**, 2309-2311 (2007)

•I.M. Vellekoop and A.P. Mosk, "Phase control algorithms for focusing light through turbid media" Optics Communications, **281,** 3071-3080 (2008)