中国科学院大学物理科学学院

奖学金申请表

学科专业	理论物理	学生姓名	徐立桐
导师姓名	奚婷婷	本人联系方式	13051097007
就读年级	硕博连读第五年		
研究方向	超快光学	攻读学位	理学博士

在学期间学习成绩、科研工作及取得的成果介绍（须附原件或复印件。对于每项科研工作，要求写清楚申请人的科学贡献与价值。）

成绩：

1. 在学期间学习成绩优异，GPA 3.78/4。
2. 英文水平良好，四级 644，六级 589，研一即通过硕士及博士英语免修考试。
3. 熟练掌握 C，Python 等编程语言，自学并行计算原理并灵活运用。

科研工作：

研一时独立开发了课题组数值模拟程序的并行计算版本，使得运行速度提高 20 倍（使用 GPU 可达 60 倍），并可进行数据的自动化处理。

参加 The 13th International Conference on Information Optics and Photonics，作口头报告 “Supercontiuum vortices generation in thin plates: towards few-cycle vortex beams”

参加第十八届全国激光技术与光电子学术会议（LTO 2023），作口头报告“高功率中红外少周期涡旋光的产生”

以第一作者发表三篇学术论文:

1. **Litong Xu**, Dongwei Li, Junwei Chang, Tingting Xi, Zuoqiang Hao, *Helical filaments array generated by femtosecond vortex beams with lens array in air*, Results in Physics, **26** (2021) 104334.
2. **Litong Xu**, Dongwei Li, Junwei Chang, Deming Li, Tingting Xi, Zuoqiang Hao, *Powerful supercontinuum vortices generated by femtosecond vortex beams with thin plates*, Photonics Research, **10** (2022) 802-809.
3. **Litong Xu**, Dongwei Li, Junwei Chang, Tingting Xi, Zuoqiang Hao, *Few-cycle vortex beam generated from self-compression of mid-infrared femtosecond vortices in thin plates,* submitted to Physical Review A, **106** (2022) 053516

（1）第一篇论文 *Helical filaments array generated by femtosecond vortex beams with lens array in air* 发表于 Results in Physics。

高功率飞秒涡旋光在大气中的远距离传输具有激光诱导击穿光谱、激光诱导闪电和微波传导等重要应用前景。但初始噪声的存在使得涡旋飞秒激光远距离传输的成丝模式极为不稳定。为了满足激光远距离传输的应用需求，我们需要控制成丝模式。在此项工作中，我们利用透镜阵列对飞秒涡旋光进行周期相位调制，产生了稳定的环形多丝分布模式，这种周期相位调制的方法能够有效抑制初始噪声的影响，更有利于飞秒激光的远距离应用。并且，我们对涡旋光产生的多丝旋

转传输进行了深入研究，揭示了其与涡旋光携带的轨道角动量之间的物理联系，丰富了非线性光学的物理内容。在这项工作中我独立完成了全文的数值计算工作和论文初稿，并与导师一起完成论文的修改稿。

（2）第二篇论文 *Powerful supercontinuum vortices generated by femtosecond vortex beams with thin plates* 发表于 Photonics Research（中科院一区 Top 期刊）。

飞秒激光成丝过程中产生的超连续辐射对白光 LIDAR、产生周期量级脉冲等应用有着重要意义。然而在飞秒涡旋光成丝过程中，由于多丝之间的破坏性干涉，超连续辐射将丢失泵浦光的涡旋相位结构。为了解决这一问题，我们提出使用多玻片装置来来产生超连续涡旋光。我们首先进行理论分析和数值模拟，对方案的可行性进行验证，并预测实验所需的条件，接着由合作课题组对该方案进行实验验证。我们的方案使得飞秒涡旋光能够在保持环形强度分布的条件下获得光谱展宽，从而得到有着超宽光谱的飞秒涡旋光。其他文献报道产生的超连续涡旋光的功率都在阈值功率附近，而通过我们方案产生的功率已经达到了阈值功率的几百倍，并且还可以通过扩束等方法进一步提高。在这项工作中我独立完成了全文的数值计算工作和论文初稿，并参与部分实验工作。

（3）第三篇论文 *Few-cycle vortex beam generated from self-compression of mid-infrared femtosecond vortices in thin plates,* 发表于 Physical Review A。

这项工作是上一工作的延续，致力于产生少周期涡旋光，来推动孤立阿秒脉冲的产生。我们从理论上分析了使用薄片法产生少周期涡旋光所需要的条件，并基于光谱展宽、多丝抑制及脉冲压缩三项要求推导出该方案对激光波长及薄片参数的要求。接下来我们用数值模拟验证了理论的正确性，展示高功率少周期涡旋

光(1.5 个光周期)的产生，并对中红外飞秒涡旋的自压缩过程进行了详细的研究。该工作对未来的实验有重要指导意义，高功率少周期涡旋光的产生将对超快科学的发展有很大的推动作用。在这项工作中我独立完成了理论分析与推导、数值模拟以及论文的撰写。

书籍著作：

无

专利：

无

在学期间获奖情况（须附原件或复印件）

国科大优秀学生荣誉称号：

1. 2021 年三好学生

其他获奖情况：

无

在学期间参加公共服务情况

2020, 2021 年高等激光物理学课程助教

2020 年粒子探测技术期末考试监考

推荐意见（推荐人原则上应为申请人导师，并佐证申请人对学术成果的科学贡献与价值）：

该申请人是一位非常优秀的博士生。

在研一期间不仅高质量地修完了所学课程，还独立完成了课题组模拟程序并行计算代码的编写，为课题的顺利开展打好了基础。

在研二一年的时间里，独立完成了两篇论文的数值计算工作，在两篇文章的物理结果讨论中都起到了关键的作用，论文初稿也均由该申请人独立完成。

转博后，科研工作做得更加深入，除上面的三篇文章外，还已做出两项更好的理论成果正在投稿，以及一项与实验组合作的工作正在整理成论文。

申请人的各项素质很高，表现出很强的科研潜力，因此，我强烈推荐申请人申请国家奖学金，以鼓励他继续努力取得更好的成绩。

推荐人签名： 姜婷婷

日期：2023 年 9 月 25 日

学生郑重承诺以上陈述及提交的全部书面材料真实有效。

学生签字：徐立桐 日期：2023 年 9 月 25 日

注意事项：

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University of Chinese Academy of Sciences

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三好学生

荣 誉 称 号

（2020-2021学年）

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Helical filaments array generated by femtosecond vortex beams with lens array in air

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ABSTRACT

When the peak power exceeds many times the critical power of self-focusing, femtosecond vortex beams will break up into multiple filaments with random distribution because of the initial random noise, which is adverse to the applications. By numerical simulation we demonstrate that the use of the lens array can resist the influence of initial noise, leading to a regular distribution of multiple filaments. During the propagation, the filaments are symmetrically distributed on a ring and rotate around the beam center, thus forming helical filaments array. Besides, the rotation rate of the filaments can be controlled by changing the vortex radius, topological charge, and focusing condition.

Introduction

Filamentation induced by intense laser pulses in air has aroused great attention since its first experimental observation by Braun et al. [1]. This process, resulting from the dynamic competition between self-focusing, diffraction and plasma defocusing, leads to the formation of an intense ~ 100 μm filament core with a surrounding energy reservoir [2]. During filamentation several nonlinear phenomena arise, such as supercontinuum generation [3], intensity clamping [4], long plasma channel generation [2,5], and conical third-harmonic emission [6]. Due to these distinctive features of filamentation, various potential applications have been proposed, such as remote sensing [7], broadband microwave emission [8], THz generation [9] and wave guiding [10,11]. For the applications, it is important to control the filamentation dynamics, including filamentation onset and length, as well as filaments distribution. To control the filamentation process, the propagation of femtosecond laser pulses with different spatial distributions has been investigated, such as annular Gaussian beam [5], Bessel beam [12], and vortex beams [13–15]. The vortex beams are of particular interest owing to its ability to resist atmosphere turbulence [16,17]. Besides, the femtosecond vortex beam, which has a higher critical power for self-focusing than that of a femtosecond Gaussian beam [14,18], can propagate over much longer distance before filamentation, which is beneficial to remote applications.

It has been shown that the femtosecond vortex beam will break up into multiple filaments with random distribution due to initial noise [14,19,20]. It is important to control the filaments distribution of femtosecond vortex beams. The filaments distribution of a Gaussian beam has been controlled by using amplitude masks [21], beam astigmatism [22], phase plates [23], and microlens array (MLA) [24] to resist the influence of the initial noise. In particular, MLA or lens array (LA) has shown its superiority in that it can control both the number and positions of the generated filaments [25,26]. For a vortex beam, the filaments distribution is more complex, because it is dependent on not only the initial noise, but also the evolution of the vortex ring and distribution of the spiral phase [14]. However, whether the methods mentioned above can be used to control the filaments distribution of a vortex beam is still unclear. The control of filaments distribution of femtosecond vortex beams will be beneficial not only to wave guiding, but also to the protection against lightning strikes by virtue of the curved plasma channel resulting from the spiral wavefront [27]. What is more, the enhancement of localization and repeatability of the intensity distribution can be extremely beneficial for laser induced breakdown spectroscopy (LIBS) of remote regions of interest [28]. To our best knowledge, the regulation of filaments distribution of a femtosecond vortex beam has not been realized.

In this paper, we simulate the multi-filamentation of a femtosecond vortex beam focused by a LA in air. We show that with the phase modulation of LA, the filamentation pattern is stable against initial perturbations in the beam profile. What is more, the filaments are symmetrically distributed on a ring, and keep rotating around the beam center. The rotation rate of filaments can be controlled by changing the vortex radius, topological charge and focusing condition.

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PHOTONICS Research

Powerful supercontinuum vortices generated by femtosecond vortex beams with thin plates

Litong Xu,[1,2,†] Dongwei Li,[1,†] Junwei Chang,[1] Deming Li,[1] Tingting Xi,[2,3] and Zuoqiang Hao[1,4]

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We demonstrate numerically and experimentally the generation of powerful supercontinuum vortices from femtosecond vortex beams by using multiple thin fused silica plates. The supercontinuum vortices are shown to preserve the vortex phase profile of the initial beam for spectral components ranging from 500 nm to 1200 nm. The transfer of the vortex phase profile results from the inhibition of multiple filamentation and the preservation of the vortex ring with relatively uniform intensity distribution by means of the thin-plate scheme, where the supercontinuum is mainly generated from the self-phase modulation and self-steepening effects. Our scheme works for vortex beams with different topological charges, which provides a simple and effective method to generate supercontinuum vortices with high power. © 2022 Chinese Laser Press

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1. INTRODUCTION

Vortex beams, characterized with ring shaped intensity distribution and helical wavefront with a phase singularity in the beam center [1], have attracted great attention since Allen *et al.* proposed their well-defined orbital angular momentum [2]. The orbital angular momentum that each photon of the vortex beam carries is proportional to the topological charge and can be transferred between an object and the light field [3]. Based on the distinctive characteristics, vortex beams have found many important applications in various areas, such as optical tweezers [4], microscopy [5], and optical communications [6]. On the other hand, the ultrashort pulse with spiral wavefront provides opportunities for new applications in high field physics, such as vortex THz generation [7], electron vortices generation [8], and proton acceleration [9]. Femtosecond vortex beams can be generated from a femtosecond Gaussian beam with phase encoding elements, such as a spatial light modulator (SLM) [10], spiral phase plate [11], and q-plate [12]. However, few-cycle or attosecond vortex beams are hard to realize by the above-mentioned methods due to chromatic aberrations. Supercontinuum vortices generated by nonlinear propagation of femtosecond vortex beams should be a good choice to generate few-cycle vortex beams.

The supercontinuum vortices have been reported to be generated by the four-wave frequency mixing approach [13,14], or introducing vortex phase to a Gaussian supercontinuum by using a broadband SLM [1]. However, these methods cannot be used to generate high power supercontinuum vortices. When intense femtosecond laser pulses propagate in Kerr medium, supercontinuum emission is mainly generated by self-phase modulation (SPM) [15] and self-steepening effects [16]. When filamentation occurs, ionization also plays an important role in the blueshift of spectrum broadening [17]. However, the supercontinuum will lose the vortex phase profile if multiple filaments are generated [10,18]. In this case, the multiple filaments that result from the initial perturbation are incoherent, and the phase of filaments accumulated from SPM effect destroys the regular distribution of the vortex phase profile. Consequently, the vortex phase profile cannot be transferred to the newly generated spectral components [10,18]. Only low power supercontinuum vortices are reported to be generated in air when the peak power of laser pulse is close to the critical power for self-focusing [19]. Up to date, it has not been reported that high power supercontinuum vortices can be generated by SPM during the nonlinear propagation of femtosecond vortex beams with peak power many times the critical power for self-focusing.

In this paper, for the first time to our best knowledge, we demonstrate the generation of supercontinuum vortices from intense femtosecond vortex beams by using several thin fused silica plates. The thin-plate scheme has been successfully used to generate supercontinuum from femtosecond Gaussian beams [20–23]. Here we use the thin-plate setup to inhibit the breakup of the intense femtosecond vortex beams. Before the

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Few-cycle vortex beam generated from self-compression of midinfrared femtosecond vortices in thin plates

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We demonstrate theoretically that a few-cycle vortex beam with high peak power can be generated by self-compression of a midinfrared femtosecond vortex beam in thin fused silica plates. We first investigate the requirements of solitonlike pulse self-compression of the vortex beam on a laser wavelength and parameters of the thin plates based on three preconditions of sufficient spectral broadening, appropriate dispersion compensation, and inhibition of multiple filamentation. Our simulations confirm the existence of the solitonlike pulse self-compression regime of the vortex beam and demonstrate that the 3-μm femtosecond vortex beam with an input duration of 90 fs can be compressed to 15.1 fs with the vortex characteristics preserved. The conversion efficiency is as high as 91.5%, and the peak power reaches 0.18 TW. Our work is instructive for experiments generating high-peak-power few-cycle vortex beams and will help with obtaining isolated attosecond light vortices, opening an alternative perspective in ultrafast science.

DOI: 10.1103/PhysRevA.106.053516

I. INTRODUCTION

Vortex beams have been widely studied in the last few decades for both the intriguing physics involved and potential applications [1]. The orbital angular momentum (OAM) induced by the helical phase wave front connects the classical and quantum physics, offering a convenient tool to study quantum information and quantum computation [2]. It also provides a new freedom to influence light-matter interactions, facilitating atom trapping and guiding [3]. When the OAM is introduced to ultrashort pulses, more fascinating phenomena arise in the nonlinear propagation, such as spatiotemporal vortices [4], vortex algebra [5], and orbital-to-spin angular momentum conversion [6]. One of the most attractive topics concerning femtosecond vortex beams is high-harmonic generation (HHG), which is an effective tool to generate extreme-ultraviolet vortex beams [7–10] and trains of attosecond light vortices [11]. The attosecond light vortices can provide unique light sources for the fundamental study of and diagnostic tools for ultrafast science [12]. For example, attosecond light vortices can trigger transitions forbidden by selection rules [13,14] and facilitate probing molecular chirality on a subfemtosecond timescale [15]. For reliable generation of isolated attosecond light vortices, high-power few-cycle vortex beams are necessary [16], which may also be useful for the generation of vortex beams in the terahertz regime [17]. However, to the best of our knowledge, only few-cycle vortex beams with gigawatt-level peak power have been generated via optical parametric amplification [18]. Although obtaining an intense midinfrared (MIR) few-cycle vortex beam via a plasma-based photon decelerator driven by a vortex beam in underdense plasma has been proposed theoretically [19], the energy-conversion efficiency is relatively low, and the experiment conditions may not be commonly available.

Actually, it is intuitive to obtain few-cycle vortex beams by postcompression of supercontinuum vortices, which have been realized using the four-wave frequency-mixing approach [5] and the thin-plate scheme [20]. However, the postcompression of these supercontinuum vortices will cause inevitable energy loss [21]. As an alternative method, self-compression is of particular interest because of its convenience for generating few-cycle pulses with high conversion efficiency [22,23]. Although it is well known that self-compression may occur when intense MIR femtosecond pulses propagate in media with anomalous dispersion, self-compression of femtosecond vortex beams has not been studied. This is because the strong nonlinear effects and initial noise usually lead to multiple filamentation, which will destroy the vortex characteristics of the initial beam [24]. The study of MIR few-cycle vortex beams will be helpful for the generation of isolated and shorter attosecond vortices with higher photon energy [25,26]. To generate high-power few-cycle MIR vortex beams, the thin-plate scheme is a promising candidate for performing pulse self-compression of the MIR femtosecond vortex beam while avoiding multiple filamentation [27,28]. With the thin-plate setup, a femtosecond pulse with a central wavelength of 4 μm was self-compressed to 29.4 fs with a high efficiency [29]. Moreover, this scheme was applied to obtain powerful supercontinuum vortices in the near-infrared regime [20]. However, it is unknown whether the MIR femtosecond vortex beam can be self-compressed to a few-cycle vortex beam with high

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