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Broadband supercontinuum generation spanning 1.5–13 μm in $Ge_{11.5}As_{24}Se_{64.5}$ based chalcogenide glass step index optical fiber

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ABSTRACT

We have reported a design of a step index optical fiber in $Ge_{11.5}As_{24}Se_{64.5}$ chalcogenide glass. The proposed design of optical fiber is analyzed using full vectorial finite element method. The structure offers a high nonlinear coefficient of 1431 W^{-1} km^{-1}. Due to this high nonlinearity of the optical fiber a supercontinuum spectrum ranging from 1.5–13 μm is generated in only 10 mm long fiber by applying 50 fs laser secant pulses of 4000 W peak power at the pump wavelength of 3.1 μm. The use of femtosecond pulse laser results in the supercontinuum with high shot-to-shot coherence. Broadband mid-infrared supercontinuum generation has many applications such as in medical diagnosis, food quality control, gas sensing, telecommunication, and optical metrology etc.

1. Introduction

Supercontinuum has various potential applications in different diverse fields such as spectroscopy [1], early cancer diagnosis [2], food quality control [3], and optical coherence tomography [4]. Supercontinuum generation (SCG) is basically the broadening of spectrum of light when a very high intense laser pulse is passed through a highly nonlinear medium which is a result of several nonlinear things such as self-phase modulation, stimulated Raman scattering, self-steepening, four wave mixing, cross phase modulation, and soliton fission taking place inside that material. SCG was first observed around 1970 in solid and gaseous nonlinear systems [5–7].

During the last two decades, Supercontinuum generation has become a very attractive and emerging research field due to the development of the various techniques used to obtain desirable supercontinuum sources. In most studies, supercontinuum generation has been achieved in silica fiber. But it has high material losses when used beyond 2 μm wavelength making it difficult to generate supercontinuum in mid-infrared region (MIR). MIR, also known as molecular fingerprint region, is very significant because the fundamental vibration absorption bands of most of the bio-molecules are stronger than overtones and combinational vibration absorption bands present in this region [8]. Molecular microscopy can be used to understand the structure of matter thoroughly and to perform the non-intrusive diagnostics of various systems composed of the physical, chemical and biological interest.

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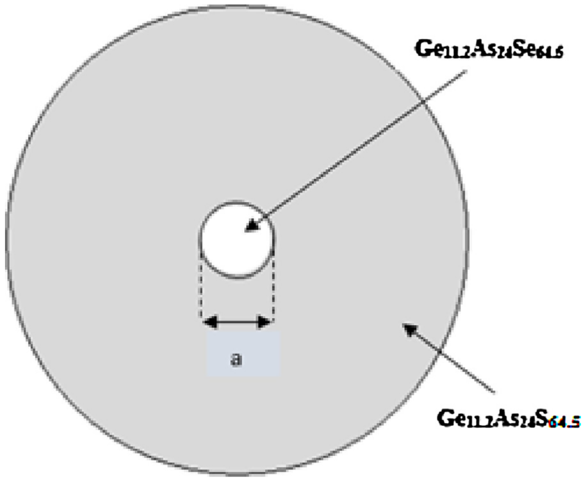

Fig. 1. Cross-section of the step index fiber structure.

Research on the other non-silica glasses have been enhanced which have transparency in mid-infrared region and are able to generate supercontinuum in this region. Numerous non-silica glasses, for example tellurite, ZBLAN, bismuth, fluoride and chalcogenide have been reported for SCG in the mid-infrared domain [9–15]. Among all these non-silica glasses, chalcogenide glasses are preferred for supercontinuum generation in MIR due to their higher optical transparency, high linear and non-linear refractive indices as compared to the silica. Sulfides based chalcogenide glasses can provide MIR transparency beyond 8.5 μm, while the selenides and tellurite based chalcogenide glasses possesses MIR transparency upto 14 μm and around 20 μm respectively [16]. A few of these chalcogenide materials such as As_2S_3, As_2Se_3, $Ge_{11.5}As_{24}Se_{64.5}$ and $Ge_{11.5}As_{24}S_{64.5}$ are used to make active and passive devices in MIR. As_2Se_3 chalcogenide PCF with airholes filled by As_2S_3 rods can be used for the SCG in the mid-infrared range of 2.6–6.5 μm [17]. SC spectrum spanning 1.2–15 μm was generated using an 8 mm long equiangular spiral PCF structure pumped with 50 fs laser pulses of peak power of 500 W [18]. SC covering the range 1.4–13.3 μm was observed in 85 mm long As_2S_3step index fiber with a 16 μm core [19]. Recently interest has grown in designing and optimizing planar waveguides made from $Ge_{11.5}As_{24}Se_{64.5}$ chalcogenide glasses for broadband mid-infrared SCG with appropriately tailored group velocity dispersion (GVD), including a zero dispersion wavelength (ZDW) close to the central wavelength of the pump [20,21].

In the present paper, we numerically demonstrate MIR supercontinuum generation spanning 1.5–13 μm in a step index fiber having $Ge_{11.5}As_{24}Se_{64.5}$ as core material and $Ge_{11.5}As_{24}S_{64.5}$taking as cladding material. Amongst all chalcogenide glasses, $Ge_{11.5}As_{24}Se_{64.5}$ possesses high thermal and optical stability under intense illumination [22]. The variations in the optical properties of fiber such as dispersion profile, effective mode area, nonlinearity of material have been studied by varying geometrical properties of fiber and wavelength of the pump source. Diameter of the fiber core has been optimized to keep dispersion in normal regime to get higher stability. SC generation by varying pump power, input pulse duration and length of the fiber has been investigated to obtain a wide supercontinuum spectrum ranging from 1.5–13 μm having a low dispersion of −11.36 ps/nm km at pump wavelength of 3.1 μm. Such broadband SCG has potential applications in various fields such as telecommunication, ultrafast spectroscopy, pulse compression and optical coherence tomography.

2. Fiber design

The cross-sectional interpretation of the proposed step index fiber is shown in the Fig. 1. The diameter of the core is taken as 1.7 μm which is made of $Ge_{11.5}As_{24}Se_{64.5}$ chalcogenide glass material, while $Ge_{11.5}As_{24}S_{64.5}$ chalcogenide glass is taken as the cladding material.

In this paper, the chalcogenide materials are chosen to design the fiber for getting mid-infrared supercontinuum generation due to their high nonlinearity and transparency in mid-infrared domain. Fig. 2 shows the transverse electric field distribution of fundamental mode in the fiber at pump wavelength of 3.1 μm. The fundamental mode with effective mode area of 6.09 μm^2 has been obtained.

3. Numerical method analysis

In this work, a full vectorial finite element method based commercially available software 'COMSOL Multiphysics' has been used to simulate the effective indices of the fundamental mode propagating in the core of the reported fiber. For the calculation of wavelength dependent linear refractive index, n(λ) of the chalcogenide materials, following sellmeier equations are used [22].