Polarization dependent second-harmonic generation in cascaded optically poled fibers

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The fortuitous discovery of effective second-harmonic generation (SHG) by Österberg and Margulis in 1986 has laid the pavement for optical poling [1]. They observed that when a Ge-doped fiber was exposed to an intense laser beam for several hours, the SH power grew exponentially before saturating after 10 hrs. This was an astounding observation, as they demonstrated an effective $\chi^{(2)} \approx 10^{-3}\, pm/V$ and a peak SHG conversion efficiency of 5%. This experimental work also paved the way for the discovery of optical poling using an external SH-seed [2] and extensive search for the physical mechanism responsible for efficient SHG in commercial optical fibers [3, 4]. Batdorf *et al.* [5] and the authors [6] demonstrated that the $\chi^{(2)}$ nonlinear grating length never exceeds 60 cm, and the onset length, where strong SH growth is observed, depends on the SH power used during seeding. Here we report, to the best of our knowledge, a novel experiment where an efficient SHG device was constructed from spliced short fiber segments poled using both linearly and circularly polarized pumps.

We conducted the SHG experiment employing a microchip Nd:YAG laser operating at 1064 nm, generating 800 ps fundamental (FF) pulses at a repetition rate of 30 kHz. A FF pump, either linearly or circularly polarized, with an average power of 36 mW, was coupled to the Corning HI980 Ge-doped fiber using an aspheric lens with 8 mm of focal length with a coupling efficiency exceeding 70%. After 15 min exposure of the fiber to both FF and type-II SH signal from a KTP crystal, the KTP was withdrawn, and the fiber continued to be poled exclusively with the FF beam. Once the SHG saturated, FF and SH powers were recorded at the exit facet of the poled fiber. We experimentally found a strong Raman spectral broadening for FF output power above 10 mW when poling a 1 m long fiber and, in order to avoid any Raman spectral broadening at the maximum pump power, we decided to pole segments as short as 20 cm. Fig.1a shows the average SH output power ($P_{SH_{avg}}$) measured as a function of the average FF output power ($P_{FF_{avg}}$); the SH power growth measured at the output of the 20 cm segment, that was poled by a linearly polarized pump (red curve), exhibits a quadratic dependence and is fitted with $P_{SH_{avg}} = 0.94 \times P_{FF_{avg}}^2$ (violet). In contrast, for segments poled by a circularly polarized pump (green), the SH power growth deviates from the theoretical parabola, and the almost linear increment is well approximated by $P_{SH_{avg}} = 0.06 \times P_{FF_{avg}}^2 + 7.09 \times 10^{-3} \times P_{FF_{avg}}$ (blue). The average SH conversion efficiency ($\eta_{avg} = P_{SH_{avg}}/P_{FF_{avg}}$) at $P_{FF_{avg}} = 11.2$ mW was about 1.2% and 0.8% for fibers poled by a linear and circular polarization, respectively.

In order to achieve a nonlinear quadratic grating longer than the onset length and to boost SH conversion efficiency, we poled several 20 cm long fibers and spliced them together. Moreover, to gain an insight into the role of polarization, we carried out the poling process utilizing either a linearly polarized (Fig.1b) or circularly polarized (Fig.1c) pump. Once the poling process was completed, before splicing, we measured the SH power at the output of each segment, verifying that all the pieces had comparable conversion efficiencies (an example is reported for two fiber segments in Fig.1b and Fig.1c: black and green graphs). Then, the segments were spliced with negligible insertion loss and the total spliced fiber length was limited to 60 cm to mitigate the detrimental effect of Raman-

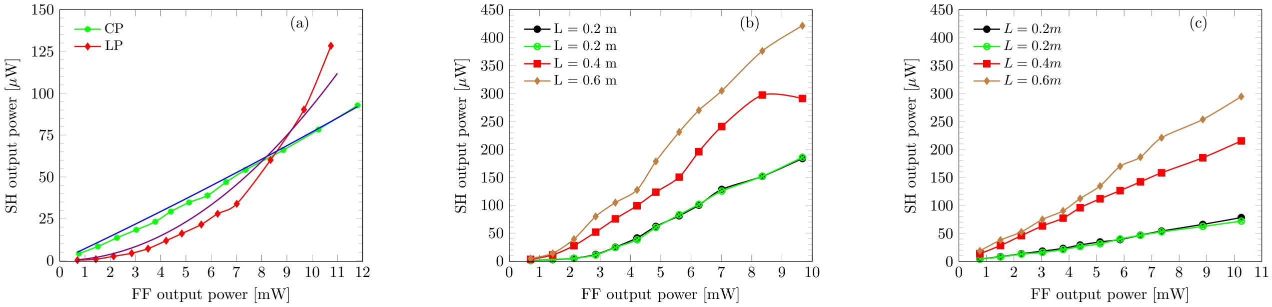

Figure 1: (a) SH output power growth as a function of the FF output power for fiber poled by a linearly (red) and circularly (green) polarized pump. Output SH (P_{SHavg}) versus FF power (P_{FFavg}) for different lengths of spliced fibers corresponding to 1,2,3 segments, each having a length of 0.2 m, poled using (b) a linearly polarized and (c) a circularly polarized pump.

induced pump depletion. We marked the fibers before removing them from the poling stage to be able to approximately preserve, during splicing, the orientation between each segment and the initial FF beam used for poling. In this regard we observed that when poling a 20 cm fiber by using a linearly polarized pump the FF output was still linearly polarized whereas the SH was elliptically polarized. Fig. 1b and Fig.1c show the SH power obtained from a single 20 cm long poled fiber and subsequently joined 2 and 3 poled segments. The conversion efficiency value obtained from 3 spliced segments (brown) poled by the linearly polarized pump is $\eta_{avg} = 4.35\%$ at $P_{FF_{avg}} = 9.67$ mW, about 2.3 times that of a single segment (green). Note that this value is less than the theoretically expected increment of 9 under ideal conditions. Similarly, for segments poled using a circularly polarized pump, the conversion efficiency is 2.87%, which is about 3.8 times that of a single 20 cm segment. We also observed that the conversion efficiency of 60 cm long poled fibers is similar to that of 20 cm poled fibers, and in some tests was even smaller. For instance, in the case of a linearly polarized pump, we measured for 60 cm long fibers $P_{SH_{avg}}$ in the range $120 - 190$ μW for $P_{FF_{avg}}$ around 10 mW, to be compared with $P_{SH_{avg}} = 190$ μW shown in Fig. 1b for $P_{FF_{avg}} = 10$ mW.

In conclusion, we have reported an efficient SHG device constructed via splicing of 20 cm segments poled using both linearly and circularly polarized pump with a corresponding average conversion efficiency of 4.35% and 2.87%, respectively. We expect further improvement with polarization control between successive segments and by utilizing polarization-maintaining fibers.

References

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