In this paper, we give two very simple schemes to produce two kinds of W states, one kind is path W state with one photon and the other is multiphoton photon polarization W state. These schemes just need a common commercial multiport fiber coupler and single photon sources, they are feasible by current technologies.

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Entanglement is the key physical resource in most quantum information process, e. g., quantum teleporation [1], quantum key distribution [2], quantum computation [3] and so on. In multiparticle case, it was shown that there exists two inequivalent classes of entangled states, namely Greenberger-Horne-Zeilinger (GHZ) [4] state and W state [5], where, for example in three-particle case, \(|\text{GHZ}\rangle = \sqrt{\frac{1}{2}}(|000\rangle + |111\rangle)\) and \(|W\rangle = \frac{1}{\sqrt{3}}(|001\rangle + |010\rangle + |100\rangle)\), they can not been converted to each other even under stochastic local operations and classical communication. Recently, Cabello considered a set of Bell inequality to show some differences between the violation of local realism exhibited by GHZ state and W state [6]. One obvious application of general W state is telecloning [7, 8]. If we choose the particular W state \(|\Psi_{\text{clone}}\rangle = \sqrt{\frac{3}{8}}|100\rangle - \sqrt{\frac{1}{8}}|010\rangle - \sqrt{\frac{1}{8}}|001\rangle\), then we can get precisely a Buzek-Hillery cloning [9] from the sender to two receivers, provided that the results are averaged over the four possible measurement outcomes of Bell state by sender. In Ref. [10], we give a scheme by which W state can be used to realize the teleportation of an unknown state probabilisticly. The teleportation of the entangled state and dense coding by W state are discussed in Ref. [11]. In this paper, we consider how to produce a W state. The GHZ state has been produced in laboratory recently using Spontaneous-Parametric-Downconversion. [12] How about W state? In Ref. [13], authors present a quantum electrodynamics scheme, by which, a multiatom W state can be produced. The Heisenberg model was used to produce three-atom or four-atom W state in Ref. [14]. Very recently, Zou et. al [15] present a scheme by which a four-photon or a three-photon W state can be generated by linear optical elements. In their scheme, besides many linear optical elements, a maximal entangled state source and single photon source are needed. The setup seems complicated. In this paper, we give two very simple schemes, by which, two kinds of W state can be produced very easily. The first kind is the path W state, the character of the first kind W state is that the total number of particle is just one. The successful probability is 100%. The second is the multiphoton polarization W state, we can get it probabilistically with postselection. In these two schemes, just a common commercial multiport fiber coupler and single photon source are needed. Contrast to the scheme [15], no maximal entangled source and other linear optic elements are needed. So, they are very simple and easy to do in practice. Furthermore, by these schemes, not only a three-mode or a four mode W state (first kind) and a three-photon or a four-photon W state (second kind), but also an arbitrary multimode (first kind) and multiphoton (second kind) W state can be produced in principle, so our schemes are more general than the scheme in Ref. [15]. In the follow, we give these schemes to produce two kinds of different W states respectively. Firstly, we discuss how to generate the first kind of W state.

We take how to produce the state \(|W\rangle = \sqrt{\frac{2}{3}}(|001\rangle + |010\rangle + |100\rangle)_{123}\), as an example, where, subscripts 1, 2, 3 refer to the different three space modes, and |0\rangle means vacuum state, |1\rangle means one photon state. In order to do it, what we need is just a 3×3 symmetric fiber coupler (tritter) if we do it in fiber system. A symmetric 3×3 fiber can be described by a unimodulat matrix. A standard form of the tritter matrix \(T\), in which the first column and the first row are real, is given by [16]

\[
T = \sqrt{\frac{1}{3}} \begin{bmatrix}
1 & 1 & 1 \\
1 & \exp(i\frac{2\pi}{3}) & \exp(i\frac{4\pi}{3}) \\
1 & \exp(i\frac{4\pi}{3}) & \exp(i\frac{2\pi}{3})
\end{bmatrix}.
\]  

(1)

If the input state to the tritter is \(|\Psi_{\text{in}}\rangle = (1,0,0)_{123}\), where, 1, 2, 3 refer to three input ports of tritter, one photon is in input 1, the inputs to 2 and 3 are vacuum state, then the output state \(|\Psi_{\text{out}}\rangle = T|\Psi_{\text{in}}\rangle = \sqrt{\frac{2}{3}}(|001\rangle + |010\rangle + |001\rangle)_{1'2'3'}\), where, 1', 2', 3' refer to three output ports of tritter. This is the W state which we want to produce. The probability of success is 100%. Obviously, besides one single-photon source and one common tritter, no other element is needed, so this scheme is very simple.

We can generalize this method to produce an arbitrary path W state of one photon. What we need is just a \(N\times N\) lossless multiport fiber beam splitter. This multiport fiber coupler can be described by a unitary \(N\times N\) matrix, where the matrix elements are the probability...
the three-photon W state, we need three single photon sources, they are very easy to realize in practice. We can use this scheme to get the path W state with 100% probability without further requirements like post-selection. Combining with post-selection, we can get multi-photon polarization W state probabilistically. Of course, we can produce the more modes W state from less modes W state or more photons W state from less photons W state by using the same procedure as entanglement swapping [20], the disadvantage is that the Bell state measurement is needed, which makes this scheme difficult in practice.

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[1] C. H. Bennett, et. al., Phys. Rev. Lett., 70, (1993) 1895
[2] A. K. Ekert, Phys. Rev. Lett., 67, (1996) 661
[3] L. K. Grover, Phys. Rev. Lett., 79, (1999) 325
[4] D. M. Greenberger, et. al., Am. J. Phys., 58, (1990) 1131
[5] W. Dur, et. al. Phys. Rev. A., 62, (2000) 062314
[6] A. K. Ekert, Phys. Rev. A., 86, (2001) 1502
[7] M. Murao, et. al., Phys. Rev. A., 59, (1999) 156
[8] D. Bruß, et. al., Phys. Rev. A., 57, (1998) 2368
[9] V. Bužek and M. Hillery, Phys. Rev. A., 54, (1996) 1844
[10] B. S. Shi and A. Tomita, Phys. Lett. A, 296, (2002, 191
[11] V. N. Gorbachev, et. al., quant-ph/0203028
[12] D. Bouwmeester, et. al., Phys. Rev. Lett., 82, (1999) 1345
[13] G. P. Guo, et. al., quant-ph/0105123
[14] X. Wang, Phys. Rev. A., 64, (2001) 012313
[15] X. Zou, et. al., quant-ph/0202090
[16] K. Mattle, et. al., Appl. Phys. B., 60, (1995) S111
[17] C. Bruzel, et. al., Phys. Rev. Lett., 83, (1999) 2722
[18] C. Santori, et. al., Phys. Rev. Lett., 86, (2001) 1502
[19] P. Michler, et. al., Science, 290, (2000) 2282
[20] S. Bose, V. Vedral and P. L. Knight, Phys. Rev. A, 57, (1998) 822