An improved design of atomic-beam fluorescence collector

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Fluorescence detection technique plays an important role in precision spectral analysis. This technique typically uses a specially-designed structure for photon collection, in which the signal intensity is proportional to the collection efficiency[1].

Here, we designed an improved atomic beam fluorescence collection structure that combines an ellipsoid surface with a spherical surface. In this combined structure, the center of the fluorescent emitter is designed as the first focal point of the ellipsoid and the center of the spherical surface. A low noise photodetector (PD) is placed near the second focal point. We show that for the chosen sphere and PD, the photons emitted from the central position can reach the detector definitely when the following condition is satisfied: $\frac{2R^2}{2R+\Phi} < |F1F2| < \frac{2R^2}{2R-\Phi}$, where $|F1F2|$ denotes the distance between the ellipsoid's focal points, R is the sphere's radius, and Φ is the photodetector's diameter, as depicted in Figure 1.

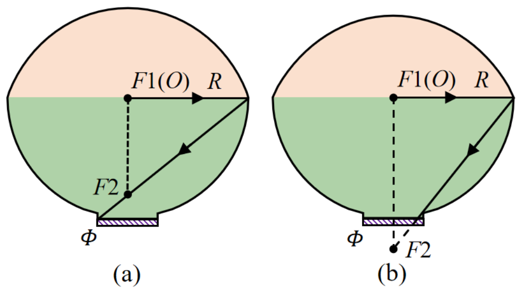

Fig. 1: Fluorescence collection structure.

Taking cesium beam atomic clocks as an example, a 3mm × 1mm cesium beam interacts with a 3mm diameter resonant laser, and their intersection region defines the dimensions of the fluorescent emitter. We simulated the relationships between fluorescence collection efficiency ρ and ellipsoidal parameters, as well as between fluorescence losses and ellipsoidal parameters when $R = 20$mm and $\Phi = 10$mm, as illustrated in Figure 2. It shows that for an optimal major axes $2a$, the fluorescence collection efficiency ρ can reach over 98% when the minor axis $2b$ lies within the range of 41.72mm to 43.52mm. Within this specified range, the primary source of fluorescence losses is attributed to hole losses.

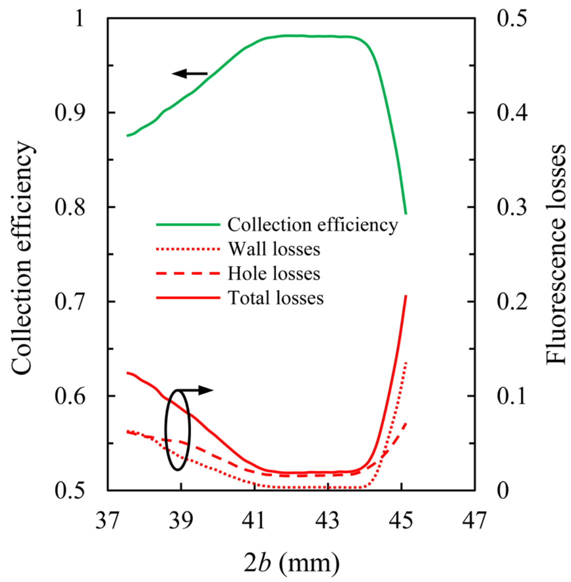

Fig. 2: Parameters optimization.

In summary, we present a design method for atomic-beam fluorescence collectors that capture photons with a near 4π solid angle coverage. This collector can achieve a higher collection efficiency by increasing the radius of the sphere and coating it with a highly reflective film, and it can also be miniaturized according to the demand.

[1] Cérez P, et al., "Accurate measurement of the fluorescence collection efficiency in a light-atom interaction experiment", Meas. Sci. Technol., vol. 1, p. 1106-1109, 1990.