



A METHOD FOR FINE BONDING WIRE DETECTION USING LIGHT DIFFRACTION

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Abstract- In manufacturing industry, bonding wires are used to interconnect the pads of a semiconductor chip to terminals of a package containing the chip [1]. With increasing demand of fine wires, current detection apparatus encounters some limitations. In this paper, a method to detect breakage of fine bonding wires using diffraction of light is proposed, where a laser head generates the light beam, and a slot introduced in the path of light source generates diffraction pattern. Then, irradiance loss of the corresponding diffraction pattern at the receiver could be observed, due to the presence of a wire. Simulation and experimental results show that the proposed method with a slot design renders satisfactory performance of wire detection.

Index terms: Bonding wire, diffraction, slot, and irradiance.

I. INTRODUCTION

In modern semiconductor industry, bonding wires used to interconnect the pads of a semiconductor chip to terminals of a package containing the chip are generally made of aluminum, copper or gold, and have a small diameter of about 50 μm or less [1, 2]. Each interconnecting wire must be bonded to the upper surface of a small, typically rectangular-shaped, integrated circuit pad a few mils wide at one end of the wire to form a first bond site, and to a similarly shaped, larger package terminal comprising a second bond site. A problem which can occur using automatic bonding is accidental breakage of a length of bonding wire rearward of the bonding tool [3, 4]. Such breakage can be caused by imperfections in the wire supply from the reel, causing the wire to be weakened, excessive tension being exerted on the wire by the supply reel, or other such causes.

Recently, a number of schemes for detecting broken or missing wires have been proposed. Missing wire detector discloses a method and apparatus for monitoring the presence of a bonding wire in a bonding machine in which the AC ultrasonic drive signal for the ultrasonic transducer of an ultrasonic bonding tool is coupled [5]. Zuta presents a system for wire detection comprising a transmitter for transmitting multi-polarity waves, means for receiving waves reflected off target and means for analyzing the polarization of the reflected waves to detect linearly polarized echoes characteristic of wires and to issue a warning indicative of the presence of a wire [6]. One limitation of this method is that the wavelength of the transmitted waves is larger than the diameter of the wires to be detected. Other detection of bonding or similarly small wires using a diffusive fiber optic sensor can also be found in the product catalog provided by photoelectric sensor makers, such as Pepperl-Fuchs, Omron, etc. The disadvantage of this principle is easy to imagine and will determine the minimum detectable wire thickness. A conventional thru beam sensor will not make matters better, as the thin wire will not block much light.

It is well known that diffractive optics has been successfully applied to real industries, such as in the areas of optics communications [7] and laser technology [8], etc. As well, intelligent sensors play key role in modern automation factories, and a lot of research activities have been involved to achieve higher effectiveness and efficiency [9-12]. Therefore, there exists a demand of

implementation of diffractive optics to smart systems, and instead of using the ray properties of the light only use should be made of the wave properties [13]. In particular, a fine wire or the like will diffract the emitted light, which will cause pattern change of received signal rather than when the light beam is only blocked. This paper investigates a method with combination of both wave and ray properties, and introduces a slot design in the path of light beam, so that the bonding wire will block the particular diffraction pattern and irradiance loss is resulted if the wire is missing. The remaining of this paper is organized as follow. Section II describes the basic knowledge of diffractive optics. Section III discusses optical principle with a slot for wire detection. In Section IV and V, simulation and experimental results are demonstrated. Finally, conclusions are given in Section VI.

II. PRINCIPLE OF DIFFRACTION

When light passing through an opaque obstruction is allowed to illuminate a screen, bright and dark regions appear [14]. The intensity of the illumination of each point on the screen, bright or dark, is proportional to the square of the amplitude of the light wave incident at that point, and not just the amplitude. Diffraction occurs whenever a wave front travels past boundary of an obstruction in its path. As the wave front passes the boundary, secondary spherical waves emerge from the small region near the boundary. In Figure 1 (a), plane waves are incident upon single boundary of an obstruction. The parallel lines represent crests on the wave front. The distance between each crest is a wavelength. Figure 1 (b) shows a plane wave front incident on a small obstruction whose width is of the order of the wavelength of the incident wave front. Notice that the crests and troughs from the two sets of spherical waves overlap at every point beyond the screen. The amplitudes of the two secondary spherical waves add algebraically at each point to give new amplitude at each point. Also, the amplitudes of the two waves add up but not the intensities. This is called the superposition principle. The intensity of light at any point is the square of this new amplitude at that point. The two spherical waves are now said to interfere with each other because the intensity depends on how the amplitudes add up at that point.

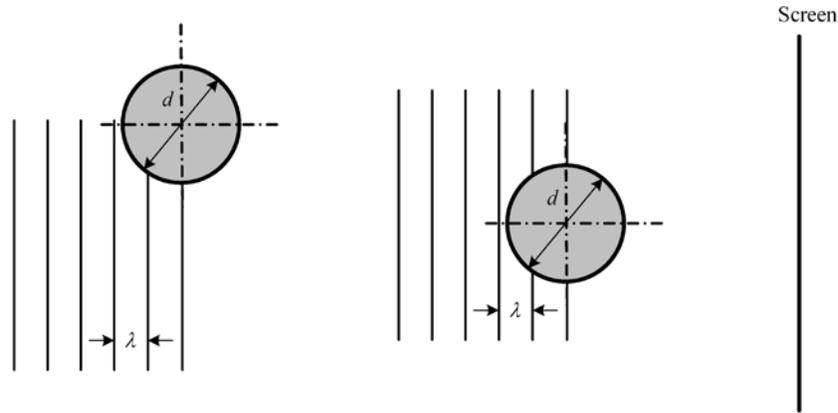


Figure 1. Plane wave incident (a) on single boundary, (b) on small obstruction

Two extreme ways are also noticed in which the waves interfere. At certain points, a crest adds to another crest (or a trough adds to another trough) resulting in a larger amplitude (positive or negative). The light intensity is high at these points since the intensity is the square of the amplitude. This is called constructive interference. At certain other points, a crest adds to a trough resulting in a smaller (and sometimes nearly zero) amplitude. The light intensity at these points is almost zero. This is called destructive interference. All other interference effects are between these two extremes. A direct consequence of the superposition principle is that the observed intensity of diffracted light falling on a screen has bright (constructive interference) and dark (destructive interference) regions or bands.

In an actual diffraction experiment, the angular positions of the bright and dark fringes will be somewhat different from what may be expected. The actual interference pattern arises due to the superposition of spherical waves from all points out of the obstruction, and not just the boundary. The relative position and distribution of these bright and dark regions are predictable and depends upon the wavelength of the light used, the dimension of the obstruction and the distance of the screen from the diffracting obstruction.

III. WIRE DETECTION ALGORITHM

Figure 2 depicts the schematic of a typical wire detection system with laser optics, photosensitive element, signal amplifier, and control unit.

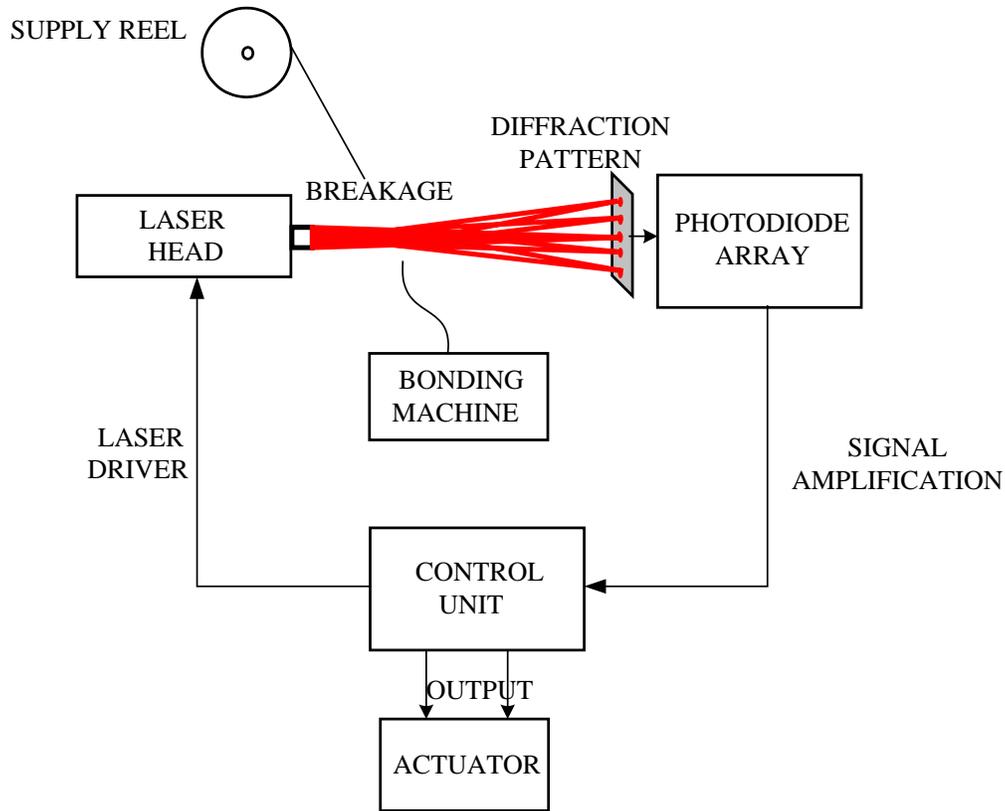


Figure 2. Schematic of diffraction-based wire detection system

The amplified signal will be processed in the control unit, and outputs to the external actuator are then generated for proper action, such as providing an alarm signal of the absence to thereby alert an operator that the wire or the like must be re-threaded into the tool to enable operation to be continued, and/or providing a halt signal to halt operation of the machine until re-threading has been effected.

The principle of the proposed design with a slot is illustrated in Figure 3, where b is the width of the slot, R_0 is the distance from the slot to receiving screen, d is the diameter of the bonding wire, and (x_w, z_w) represents the location of the bonding wire.

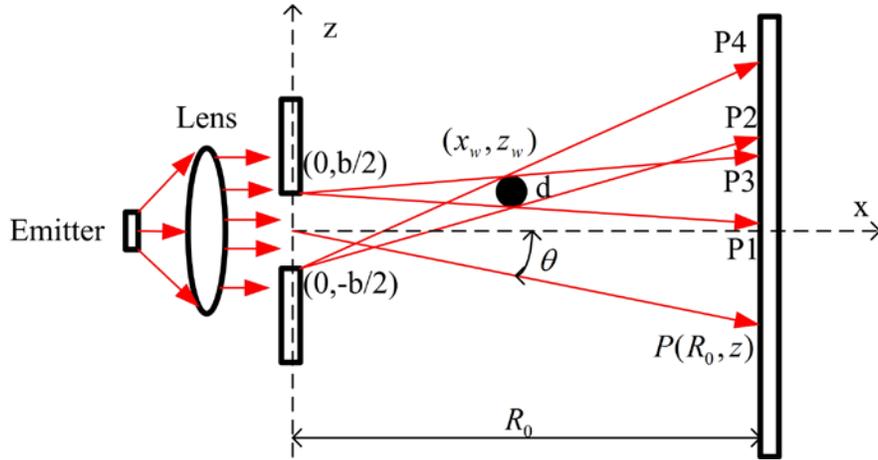


Figure 3. Optical principle of bonding wire detection with a slot

Assume that the center of the slot is coordinate origin. Then, the following boundary coordinates

at the screen could be obtained, $P_1 \left(R_0, \frac{z_w - \frac{b+d}{2}}{x_w} R_0 + \frac{b}{2} \right)$, $P_2 \left(R_0, \frac{z_w + \frac{b-d}{2}}{x_w} R_0 - \frac{b}{2} \right)$,

$$P_3 \left(R_0, \frac{z_w - \frac{b-d}{2}}{x_w} R_0 + \frac{b}{2} \right), P_4 \left(R_0, \frac{z_w + \frac{b+d}{2}}{x_w} R_0 - \frac{b}{2} \right).$$

For simplicity, denote $\tau = \frac{z - \frac{z_w}{x_w} R_0 + \frac{dR_0}{2x_w}}{1 - \frac{R_0}{x_w}}$ and $\gamma = \frac{z - \frac{z_w}{x_w} R_0 - \frac{dR_0}{2x_w}}{1 - \frac{R_0}{x_w}}$. Then, according to the

principle of diffraction, the irradiance equation at the screen becomes:

$$I(z) = I_0 \frac{\sin^2 \beta}{\beta^2}, \text{ for } z \in (-\infty, P_1) \text{ and } z \in (P_4, \infty) \quad (1)$$

$$I(z) = I_0 \frac{\sin^2 \left[\left(\frac{\tau}{b} + \frac{1}{2} \right) \beta \right]}{\beta^2}, \text{ for } z \in (P_1, P_3) \quad (2)$$

$$I(z) = \frac{I_0}{\beta^2} \left[\sin^2 \beta + \sin^2 \left(\frac{\tau - \gamma}{b} \beta \right) + 2 \sin \beta \sin \left(\frac{\tau - \gamma}{b} \beta \right) \cos \left(\frac{\tau + \gamma}{b} \beta \right) \right], \text{ for } z \in (P_3, P_2) \quad (3)$$

$$I(z) = I_0 \frac{\sin^2 \left[\left(-\frac{\gamma}{b} + \frac{1}{2} \right) \beta \right]}{\beta^2}, \text{ for } z \in (P_2, P_4) \quad (4)$$

where I_0 is the maximum irradiance intensity of central diffraction pattern, $\beta = kb \sin \theta / 2$, $k = 2\pi / \lambda$ and $\theta = \arctan(z / R_0)$..

Take note that equation (1) is independent of the status of a wire, which means that the photosensitive element should be placed in area from P1 to P4, so that maximum sensitivity of detection could be achieved. Hence, light loss of diffraction pattern at the receiver due to presence of a wire can be evaluated by integrating equations (2) – (4) over the slot, respectively.

IV. SIMULATION STUDY

In this section, simulation of irradiance intensity at receiving screen has been carried out with Mathematica 5. Given that $\lambda = 650 \mu\text{m}$, $b = 150 \mu\text{m}$, and $R_0 = 40\text{mm}$. When a wire is missing or broken, the irradiance equations (1)-(4) become

$$I(z) = I_0 \frac{\sin^2 \beta}{\beta^2}, \text{ for } z \in (-\infty, \infty). \quad (5)$$

Irradiance of the diffraction pattern is shown in Figure 4, which is assumed to be the baseline of the simulation study.

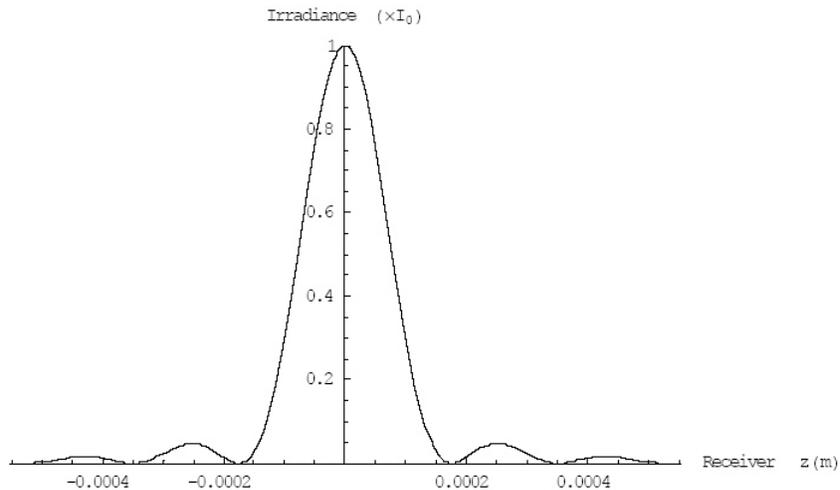


Figure 4. Diffraction pattern for single-slot design without a wire

Now consider a bonding wire with diameter $d = 25\mu m$, and study irradiance intensity on the central diffraction pattern. Figure 5 shows the irradiance loss corresponding to the baseline in Figure 4 while the wire is moving in both directions of x and z .

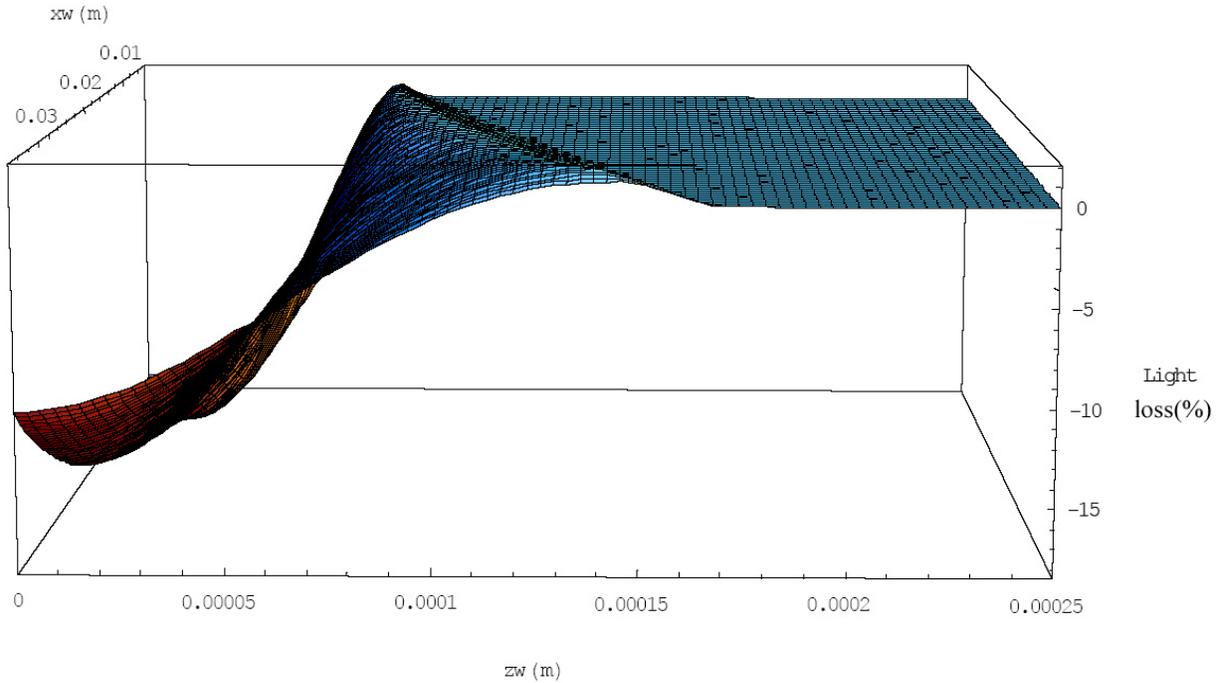


Figure 5. Irradiance loss of central diffraction pattern

Clearly, the following observations can be summarized.

- (1) Maximum light loss at certain locations is about 15%. Then, breakage of the wire could be detected if a threshold of 10% is set. However, if narrow width of photosensitive element were available, the detection effectiveness would be improved.
- (2) The detection method is very sensitive to the position of the wire in direction z_w , which means that the wire should be aligned as close to x -axis ($z_w = 0$) as possible, so that consistent irradiance loss can be obtained.
- (3) Moreover, irradiance intensity for $z_w > 100\mu m$ in Figure 5 remains unchanged; this is because the irradiance loss concentrates on the side pattern rather than the central one.

Figures 6 and 7 show the irradiance variation at the receiver while the bonding wire is fixed at $x_w = 0.66R_0$. It can prove that with thicker diameter of the wire, irradiance of the diffraction pattern will lose more, and higher sensitivity of wire detection could be achieved.

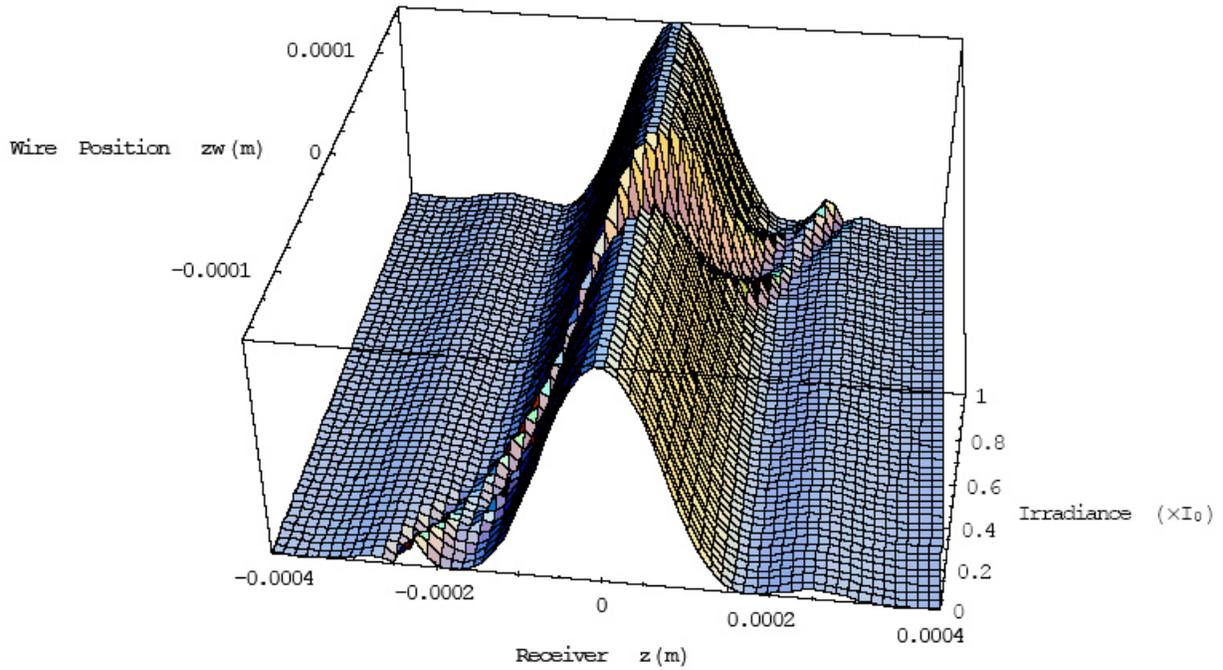


Figure 6. Irradiance variation when $x_w = 0.66R_0$

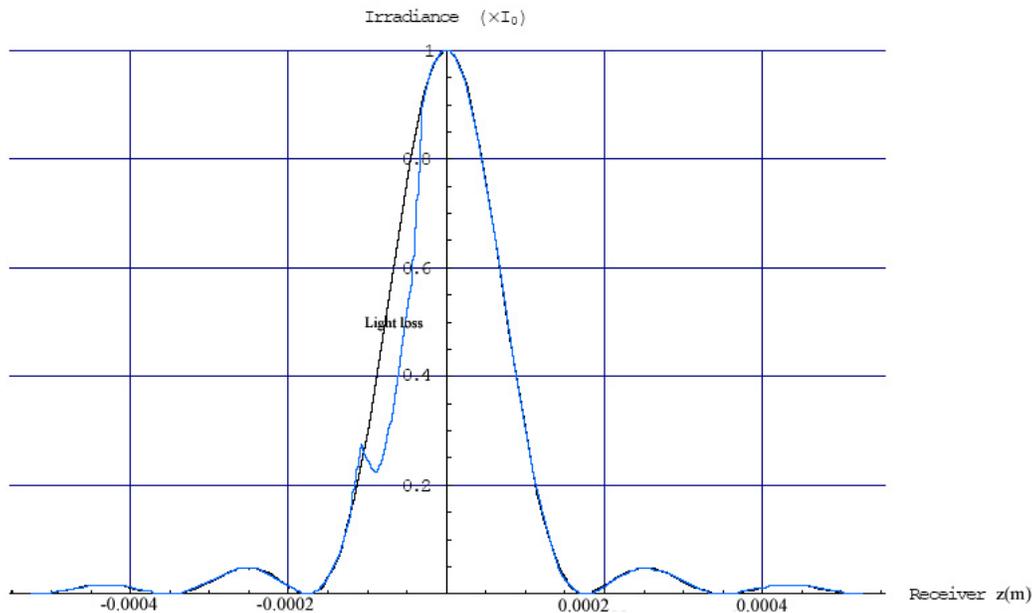


Figure 7. Irradiance variation when $x_w = 0.66R_0$ and $z_w = 0.05mm$

V. EXPERIMENTAL RESULTS

To verify the effectiveness of the proposed method, an optical configuration of the experiment has been developed, as shown in Figure 8 [15, 16]. Pepperl-Fuchs thru-beam sensor, VS18-M-LAS/76a/118, works as the laser emitter, which comes with M18 housing, metal design, pulsed red light, beam diameter $< 1.5 \text{ mm}$ at 1.5m , wavelength 650nm . Hamamatsu S8865-256 photodiode array (PDA) combined with a signal processing IC chip is chosen as the receiver of the diffraction pattern. The number of the elements of the PDA is 256, with element width 0.1mm , pitch 0.2mm , and height 0.3mm . The IC chip is formed by CMOS process and incorporates a timing generator, shift register, charge amplifier array, clamp circuit and hold circuit, making the external circuit configuration simple.

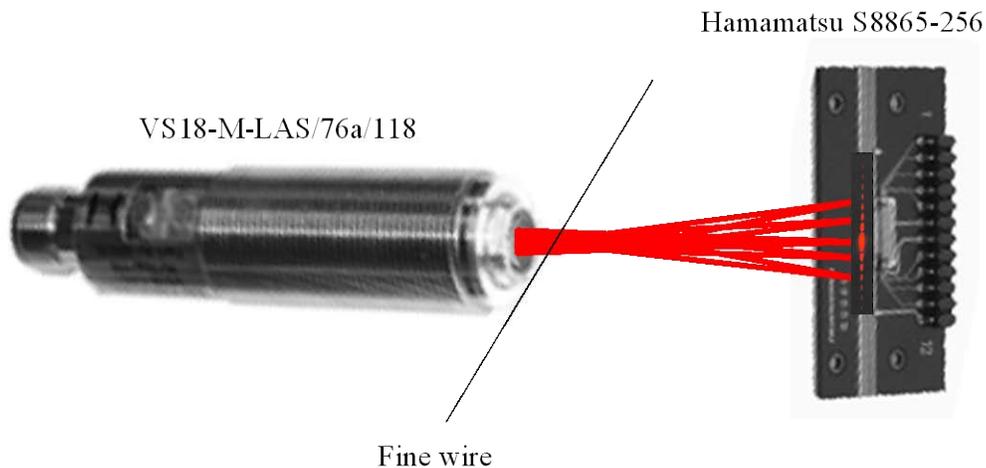


Figure 8. Optical configuration of experimental setup

A slot $b = 150\mu\text{m}$ is equipped with the emitter to generate the diffraction pattern. When a bonding wire is present in the light beam, the corresponding diffraction spot becomes dim and irradiance loss can be recorded by the PDA. Figure 9 shows the received signal swing when $z_w = 0$ and $R_0 = 40\text{mm}$ are set, while wire position and diameter are varying. Take note that diameter $0\mu\text{m}$ denotes the absence of a wire.

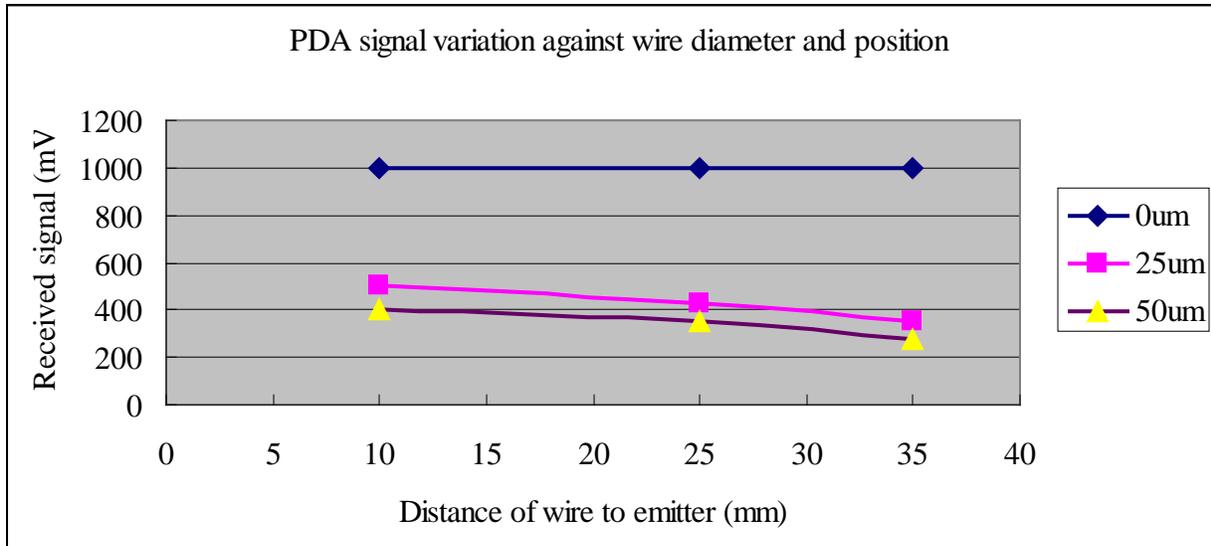


Figure 9. PDA signal for variant wire diameter and position

It can be seen that the irradiance loss on the specific PDA element is sufficient to trigger an event of wire breakage if a threshold of $800mV$ is set. Also, thicker wires would render better detection accuracy, as more diffraction light would be blocked. Moreover, due to narrower PDA elements than width of the central pattern ($400\mu m$), higher signal-to-noise ratio (SNR) than that in simulation study can be obtained.

VI. CONCLUSIONS

In this paper, an extended method of fine bonding wire detection using principle of diffraction has been proposed, where a dedicated optical design with a slot is used to project diffraction pattern to the receiving PDA. Upon removal of the wire due to inadvertent breakage or misfeeding, light loss of diffraction pattern can be observed. Simulation and experimental results on typical bonding wires have demonstrated the effectiveness of the proposed scheme. However, the future concerns might include proper alignment of the wire, design of the slot, and signal processing of the PDA, so that detection sensitivity could be further improved.

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