ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Forecasting Of Advanced Electronic Packaging Technologies Using Bibliometric Analysis and Fisher-Pry Diffusion Model

Course Title: Technology Forecasting
Course Number: ETM 532/632
Instructor: Dr. Tugrul Daim
Term: Winter
Year: 2011
Author(s): Nasir Sheikh, Fredy Gomez, Joseph Cho, and Jayanth Siddappa

ETM OFFICE USE ONLY

Report No.:
Type: Student Project
Note:

1 Contents

Forecasting of Advanced Electronic Packaging Technologies Using Bibliometric Analysis and Fisher-Pry Diffusion Model

Nasir Sheikh, Fredy Gomez, Joseph Cho, Jayanth Siddappa

Abstract

Forecasting advanced or emerging technologies by determining their technology diffusion rates is a science and an art because of lack of experiential data. One method to assist in forecasting is data mining and analysis of bibliometric data from a variety of sources such as patents, journal citations, and science awards. This information can then be used in well-known technology diffusion models such as Fisher-Pry where emerging technologies substitute older ones. This paper uses global bibliometric analysis to forecast the growth of advanced or next-generation electronic packaging technologies relying on analogous technology growths.

1 Introduction

Electronic Packaging (EP) is a critical aspect of electronic circuits and components and its functions include circuit support and protection, heat dissipation, and power and signal distribution. In the latest years, EP technologies have taking off substantially compared with previous years; according to BCC Research [21] the global market for advanced electronic packaging will grow from $39.5 billion in 2006 to $57.6 billion in 2011. The organization International Technology Roadmap for Semiconductors (ITRS) has also stated that design concepts, packaging architectures, materials, manufacturing processes and systems integration technologies are all changing rapidly in the EP industry [10]. The result of these changes has been a set of new EP technologies like System-in-Package (SiP), Three Dimensional Integrated Circuit (3DIC), and Wafer Level Package (WLP) and significant improvements in older EP technologies such as Ball Grid Array (BGA) and Microelectromechanical Systems (MEMS).

One driver of this development process is Moore's law, since traditional Moore's law scaling is becoming more difficult to implement or manufacture, EP innovation enables functional diversification and enables scaling in the third dimension to compensate for the limitations [10]. Gagnard and Mourier [19] also point out that the 3DIC technology is answering the needs of reducing the cost of the final product by optimizing the package and by improving the performance, contributing to the “More than Moore’s law” (i.e. integrate more functionality on devices). INEMI [12] also states that EP technologies have become the limiting factors in system cost and performance as traditional Moore’s law scaling becomes increasingly more difficult.

Another evidence regard to the increasing importance of EP technologies includes the different Technology Roadmap programs developed by consortia (INEMI, ITRS, and JJTRC) and the recent increase in cooperative development by universities in areas such as materials and manufacturing equipment [10].

This study seeks to select the most prominent EP technologies—SiP, 3DIC, WLP, BGA, and MEMS and build forecasting model to represent their market diffusion or growth curves using existing bibliometric data (data mining). This study uses multiple types of bibliometrics such as patents, science research awards, and scholarly journal citations. [Note: An initial attempt to include conference proceedings for the purpose of forecasting EP technologies was abandoned due to lack of available data in the university accessible databases.]

2 Electronic Packaging Trends

One of the key variables for the proliferation of microelectronics is the advancement in Integrated Circuit (IC) and packaging technologies [16]. Bogatin [20] uses the next phrase to refer to the general trends to guide the EP Technology Industry: “faster, smaller, cheaper”, along with portability (lighter), lower power consumption, more environmental compatibility, and more functionalities [16]. Although old EP technologies have the advantage of long learning curve, emerging technologies will take over the market as cost, and size decrease, and performance and system complexity increase [15].

ITRS [10] elaborates the main issues for the leading package technologies such as speed, heat dissipation, reliability and cost. Due to the rise of the mobile market, the market has brought up a different set of technology challenges like weight, functional diversification (RF and video), system integration, reliability, time to market, and cost. The packaging community has responded with wafer level packaging, new generations of flip chip CSPs, various forms of 3D stacked die and stacked packages, fine pitch surface mount and 3D IC. VTI[16] also confirm that Wafer Level Packaging (WLP) and 3DIC packaging are the major trends in electronic packaging.

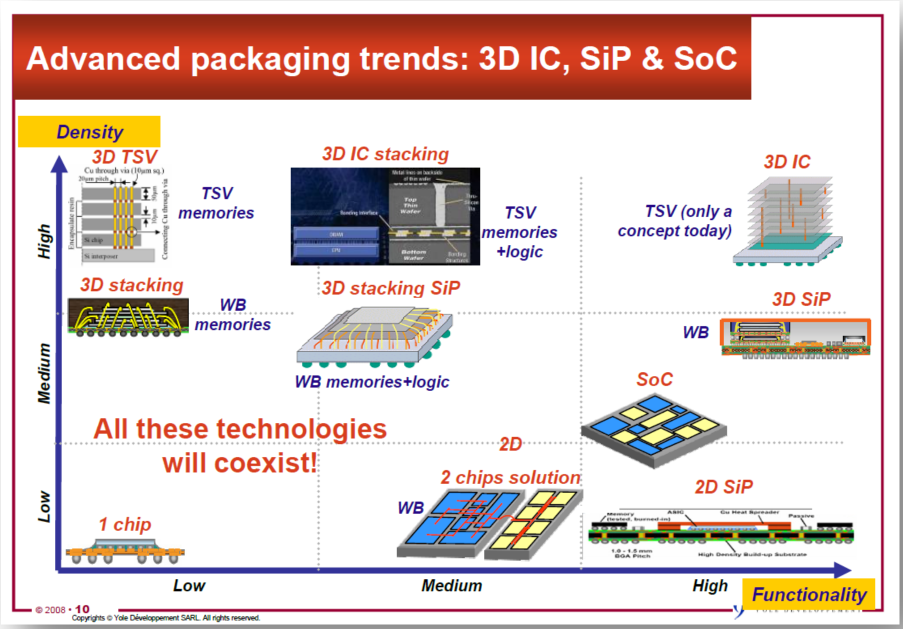


Figure 1. 3D IC Packaging Evolution [17]

2.1 MEMS

Micro-electro Mechanical Systems (MEMS) have developed in the past decades, especially in the last fifteen years when Government agencies started large MEMS support programs [12]. MEMS are chips incorporating mechanical devices and are widely used in many electronics applications/systems however their fabrication and packaging are mainly customized processes. These processes include device simulation, design, and testing and manufacturing [11, 17]

2.2 BGA

Ball Grid Array (BGA) has evolved from Pin Grid Array (PGA) starting from a jointly of Motorola and Citizen in 1989. PGA, as the name implies, is a package with one face covered with pins in a grid pattern. The pins provide the electrical signal and power connection from the IC to the printed circuit board (PCB). In BGA the pins are replaced by balls of solder and provide a more manufacturing-friendly approach [11, 17].

2.3 3D IC

3DIC packaging involves stacking and interconnecting of ICs for better performance by improving interconnects delay and package size management. This is typically done using a technique called "Through Silicon Vias (TSV)" [11, 17]. According to Experts in package technology and some of the results found in our study, 3DIC is one of the most promising technologies that will lead the package industry in the medium term. Figure XX show a roadmap of the technology presented by Fermilab (2009).

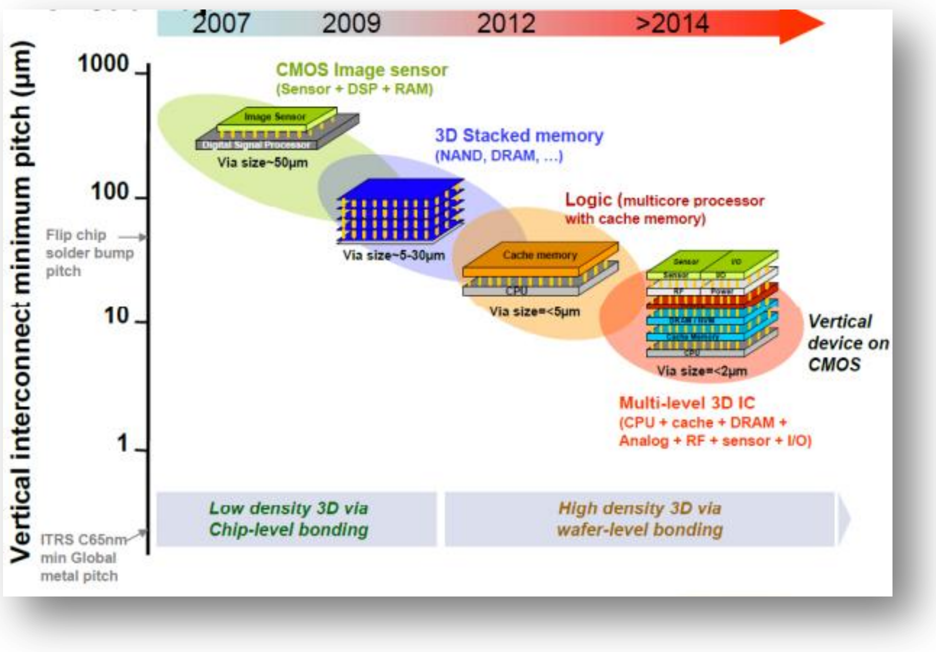


Figure 2. 3D IC Technology Roadmap. Source : [3]

2.4 WLP

Wafer-Level Packaging (WLP) is a type of chip scale package (CSP) technology for integrated circuit at wafer level so the result is the die. WLP streamlines the manufacturing process to enable integration of fab wafer, packaging, testing, and burn-in –all at the wafer level. Non-WLP packaging involves wafer dicing prior to packaging and solder bumps. A variety of proprietary methods are being used for WLP [11, 17].

2.5 SiP

System-in- Package (SiP) is evolving as an alternative to System-on- Chip (SoC) and includes packaging considerations more prominently. SiP is positioned to provide a path to system-level improvements in power, cost , and size beyond Moore's Law (CMOS) scaling. SiP is becoming popular in mobile/cellular phone manufacturing since it enables stacking of memory or logic devices or modules to integrate mixed signal and passive devices. SiP is also used in high volume consumer electronics and 3D-SiP is emerging for use in portable electronic products. SiP provides integration flexibility and lower R&D and product costs. For certain applications SiP may include SoC components. SiP is still a developing area and improvements are being made in cost reductions, thermal dissipation, higher density substrates, and high-speed design and simulation tools [11, 17].

3 Methodology

3.1 Forecasting Model: Fisher-Pry Diffusion Model, and Bibliometric Analysis

The pioneering work by Fisher and Pry [4] has set the stage for the study of forecasting technologies where "technological advances can be considered as competitive substitution of one method of satisfying the need for another." Fisher–Pry model forecasting is similar to biological system growth. It is also referred to as the "substitution model" because of its application in forecasting the rate of the replacement technology. The Fisher Pry model expresses the fractional rate of fractional substitution of the old technology by the new in terms of what is left to be substituted. The Fisher-Pry model—with its transformation to linear form for ease in regression analysis—can be represented by the equation [8].

$$\frac{Y}{L-Y} = 10^{A-Bt}$$

L: Normalized Upper Growth Limit (100), t: Year

Use of data mining and bibliometrics such as patents, journal citations, and national science awards is gaining popularity due to the availability of data and the application of "fitting" growth curves (such as Fisher-Pry) to this data [2]. Figure 3 represent one of the patterns and relationship between the different types of S-Curves, either it represents the R&D awards, Conferences, Journal or Patents.

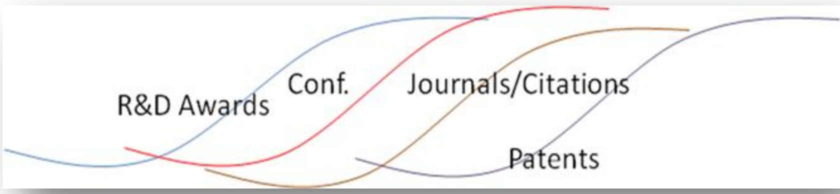


Figure 3. Patterns of different S-Curves.

3.2 Key words and Sources of Data

Experts in Electronic Package Technology provide the keywords to search in the different Databases sources. These technologies represent an important set of both old and emerging EP technologies are illustrated in Table 1 along with the acronyms.

Keywords	Acronym
"MEMS Packaging" and "Microelectromechanical Systems Packaging"	MEMS
"Ball Grid Array Packaging"	BGA
"3-D Integrated Circuit Packaging"	3D IC
"Wafer Level Packaging"	WLP
"System-in-package"	SiP

Table 1. Keywords from Experts

Data mining for issued patents globally was performed using web-based tool Boliven (http://www.boliven.com/), which includes the following national and international patent data bases: United States (USPTO), International (PCT), Europe (EPO), Japan (JPO), Korea (KIPO) and INPADOC (INPADOC). A period from 1990 to 2009 was used for the search (2010 is considered incomplete). Due to the inconsistency and difficulty in using patent classifications (both U.S. and International), this method was not used for this broad patent survey.

In the case of Journals Citation Analysis, Science Citation Index (SCI) was used to find the keywords defined. This database cover over 3,700 of the world's leading scientific and technical journals across 100 disciplines. Finally, Data mining for research award funded by government in each nation was performed using the following each national data bases:

- United States : NSF research funding data
- England : BIS (Department for Business Innovation and Skills) and EPSRC (Engineering and Physical Sciences Research Council) research funding data
- Japan : ReaD[1] (Directory Database of Research and Development Activities)
- South Korea : NTIS[2] (National Science and Technology Information Service)

4 Results

4.1 Awards

According to the cumulative number of research awards of advanced EP technologies may be ranked from high to low in terms of relative technology maturity as MEMS, 3DIC, SiP, BGA and WLP.

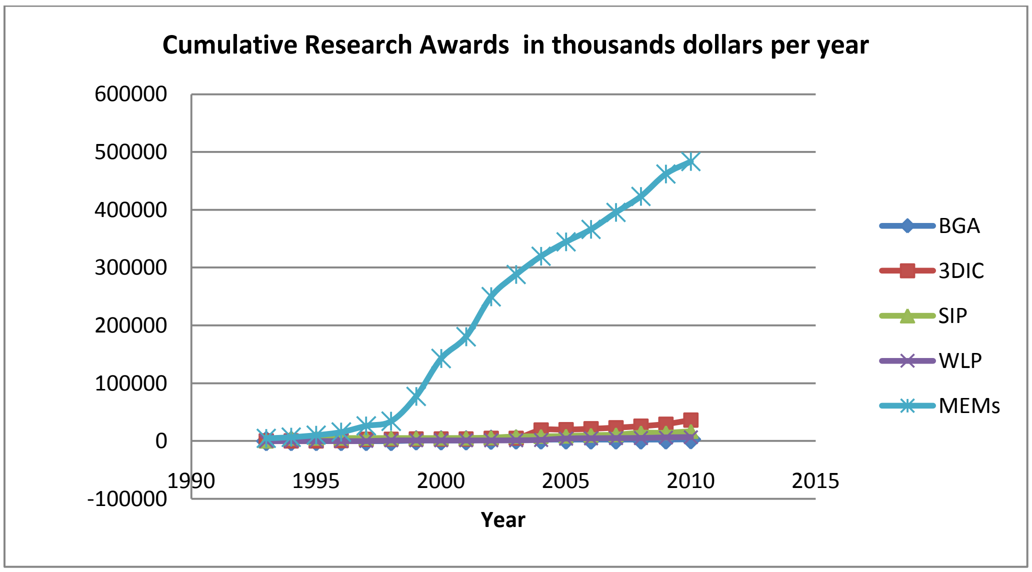


Figure 4. Advanced Packaging Technologies – Annual Research Awards Granted in Thousands dollars

[1] ReaD is the web site that collects and provides scientific information on research institutes, researchers, research subjects and research resources in Japan. It developed by JST (Japan Science and Technology Agency)

[2] It provides government-funded R&D information on topics such as program, projects, human resources, equipment/facilities, and outcomes (about 560,000) in real time.

Therefore, MEMS appears to have the highest maturity and WLP the lowest. The remarkable technology trend is 3D IC. The number of awards of 3D IC is continuously growing. It could be the next generation technology. Also, BGA is quite a bit old technology so there could be a little interest in basic research area, because it was initially developed by company more focused on the applied commercialized technology. Historically, Motorola and Citizen jointly developed the plastic BGA (PBGA) in 1989, following a very similar approach used by Motorola and IBM for a number of years with the ceramic BGA (CBGA).

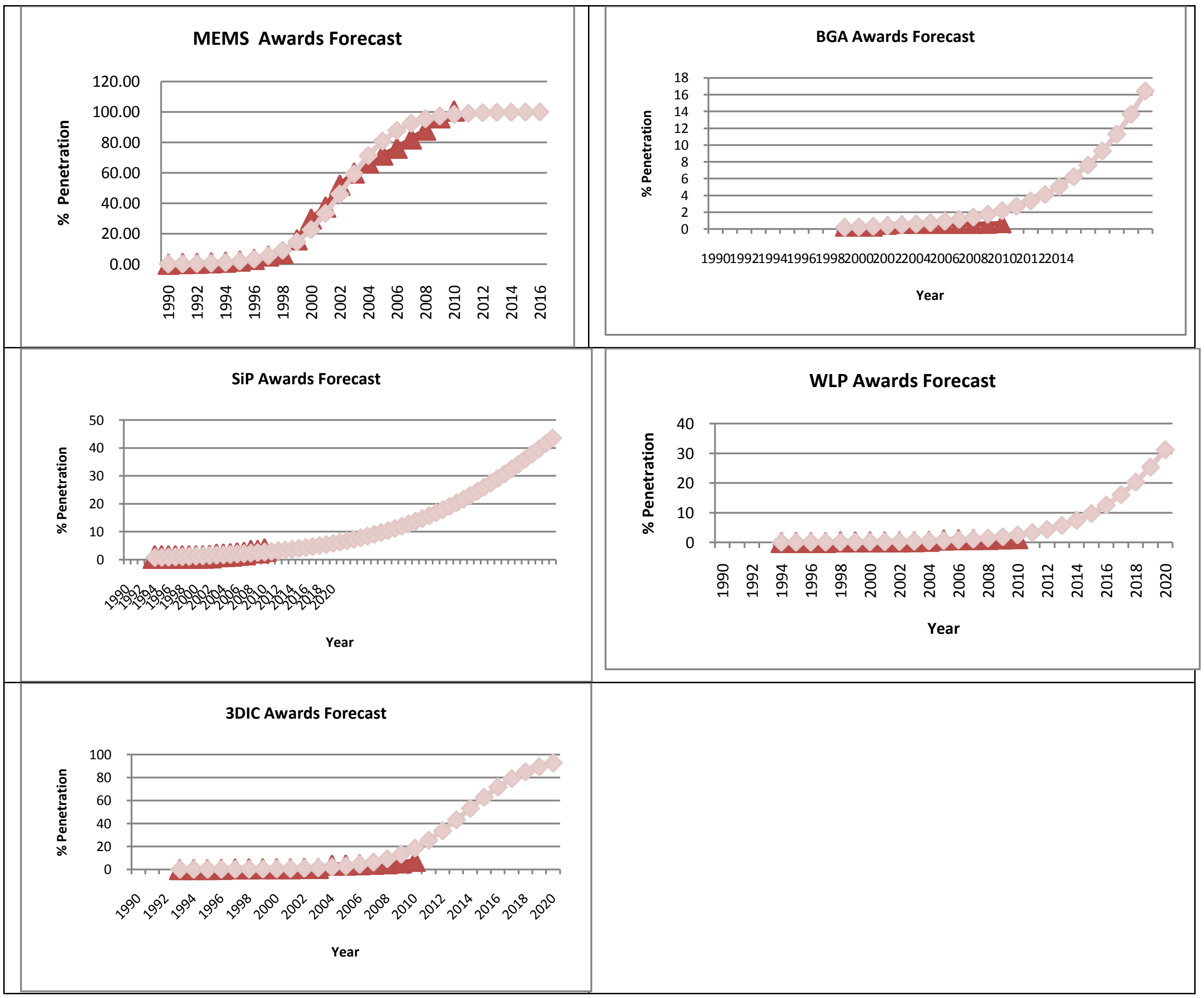


Figure 5-9: Growth Curves for Research Awards

4.2 Journal Citations

The cumulative number of papers found for each year is shown in Figure 10 for all the EP technologies. As it was found in the Award analysis, MEMS are the ones that lead the introduction of the package technology, in this case, for research activities. As expected, BGA also shows an aggressive growth, showing a very strong research activity in this area not only in the past, but also in the present. The rest of the technologies (SiP, WLP and 3DIC) present a clear behavior of emerging technologies fighting to have the lead in the future EP technology market.

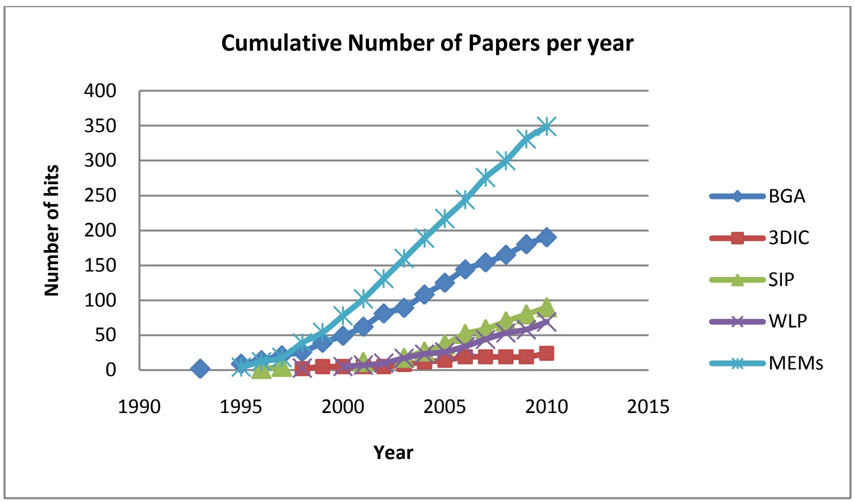


Figure 10. Cumulative curves for Journal

As it was defined in the methodology, this study assume that the most mature technology (MEMS) will be used as the saturation point to drawn the growth curves of all the EP technologies of this study. Figure 11-15 illustrate the growth curves for all the EP technologies using Fisher Pry model.

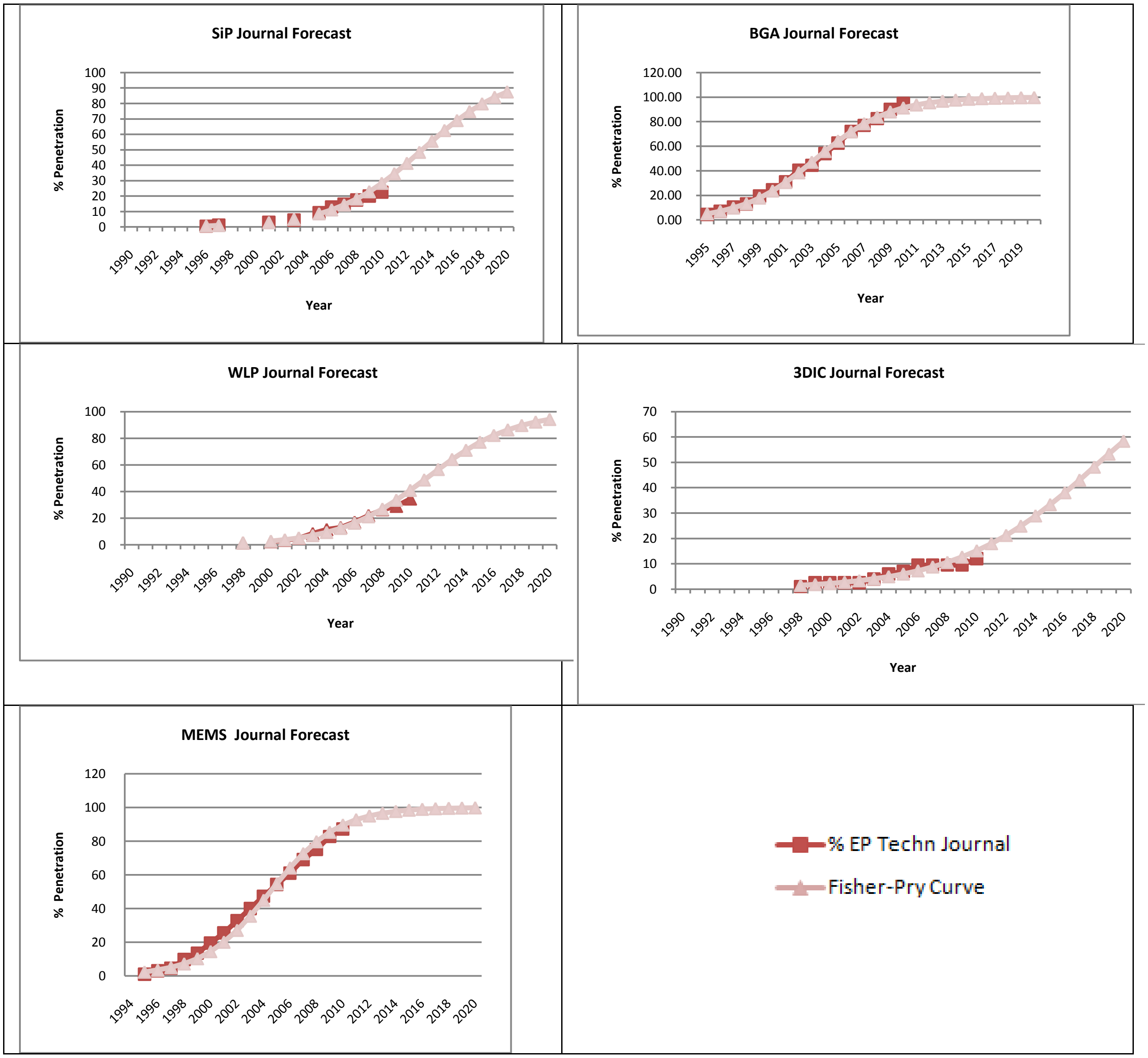


Figure 11-15. Growth Curves for Journal

4.3 Patents

Finally, the patent growth curves (i.e. overall patents per year and Fisher-Pry curves) for the main advanced EP technologies (MEMS, BGA, 3DIC, WLP, and SiP) are shown in Figure 16. For the Fisher-Pry technology diffusion model the MEMS Packaging cumulative patent count was used to normalize the five advanced EP technologies. In this way it was inherently assumed that all the five EP technologies would be analogous to the cumulative MEMS count at maturity. MEMS was selected because it is already a similar technology and had reached a level of maturity where the patent count had peaked in 2007 and was now decreasing. Future research may lead to other choices of analogous technologies.

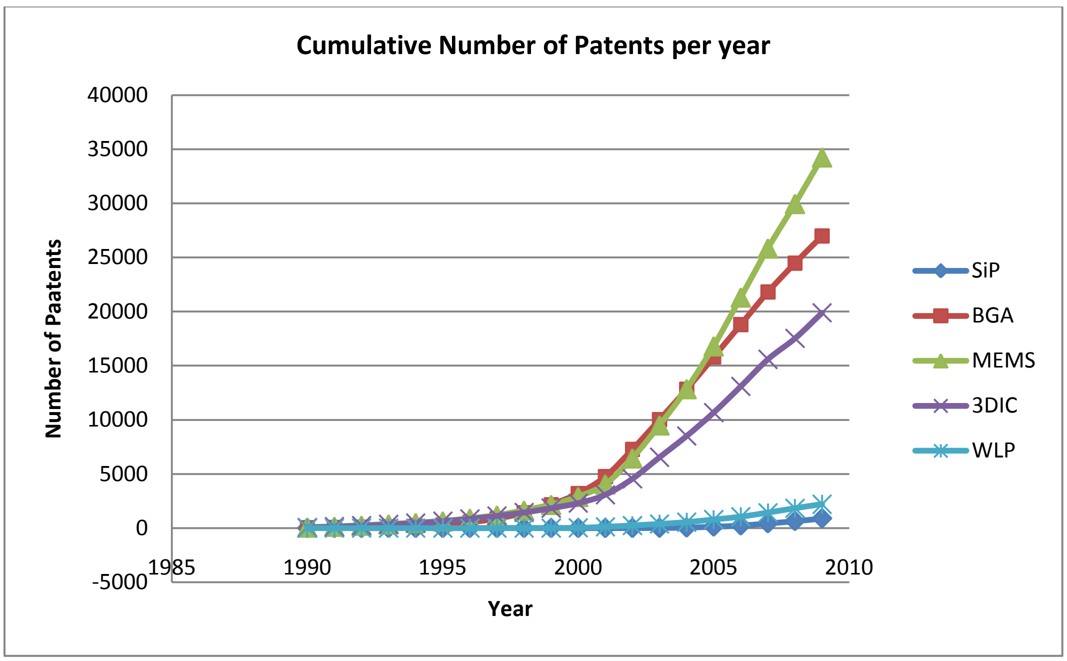


Figure 16: Cumulative Patents for EP Technologies

Figure 16 shows a very similar growth behavior compared with Journal analysis (at least for MEMS and BGA). It's interesting though the growth showed by 3DIC, leading among the group considered "New EP technologies". Figures 17-21 illustrate the patent growth curves for all the EP Technologies.

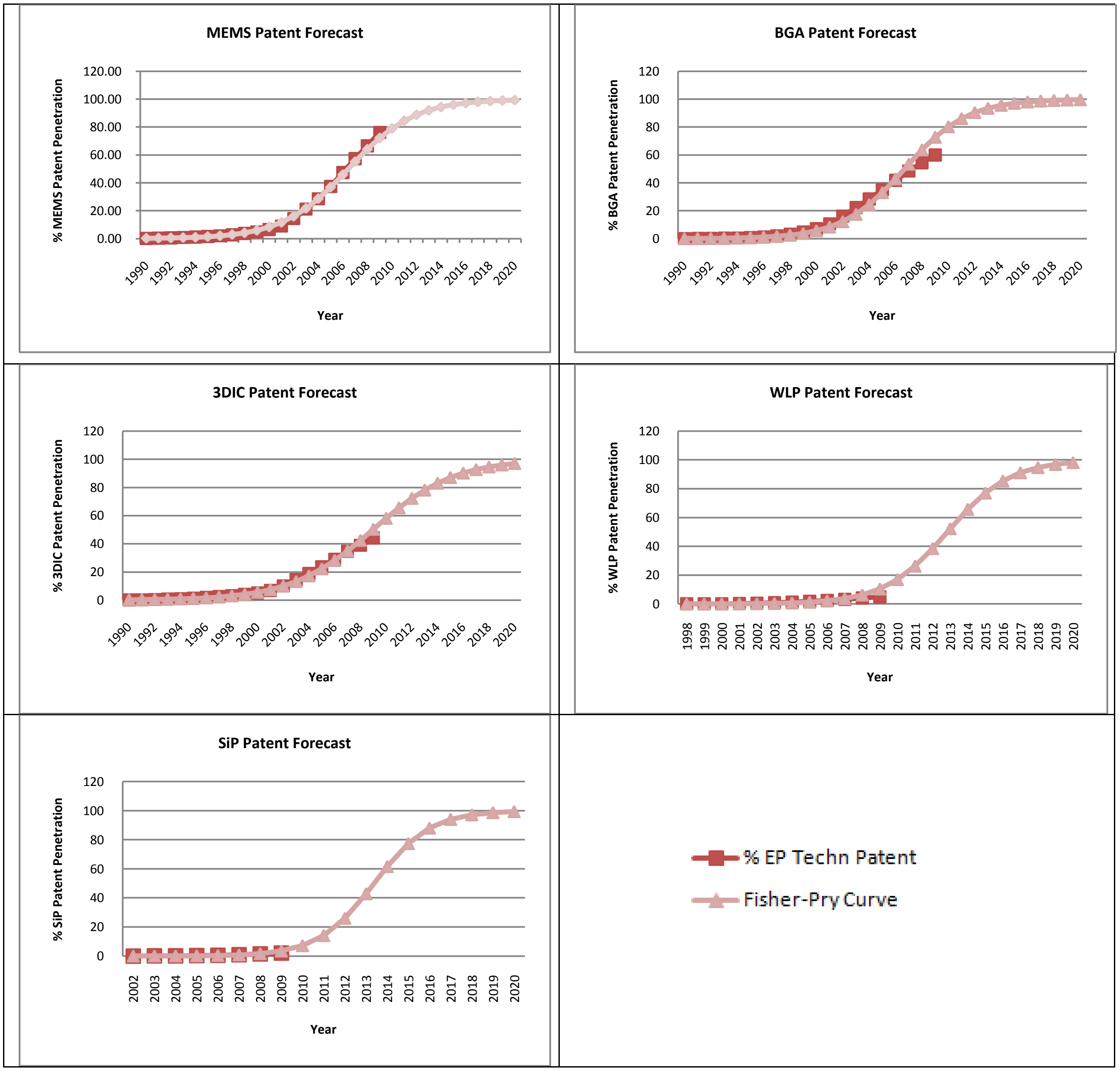


Figure17-21: Percent WLP Patent Forecast

According to global patent information advanced EP technologies may be ranked from high to low in terms of relative technology maturity as follow: MEMS, BGA, 3DIC, WLP and SiP. Hence, MEMS appears to have the highest maturity and SiP the lowest. This implies that SiP and WLP are still in its early stages of maturity. 3DIC is around its inflexion point of the growth curve. The Appendix gives details for the computations and growth curve formulations for patents.

4.4 Compilation of Growth Curves

After the analysis of the different sources separately, this chapter focuses in putting together all the growth curves for each technology. Figures 22-26 represent the compiled growth curves for MEMS, SiP, BGA, WLP and 3D IC respectively.

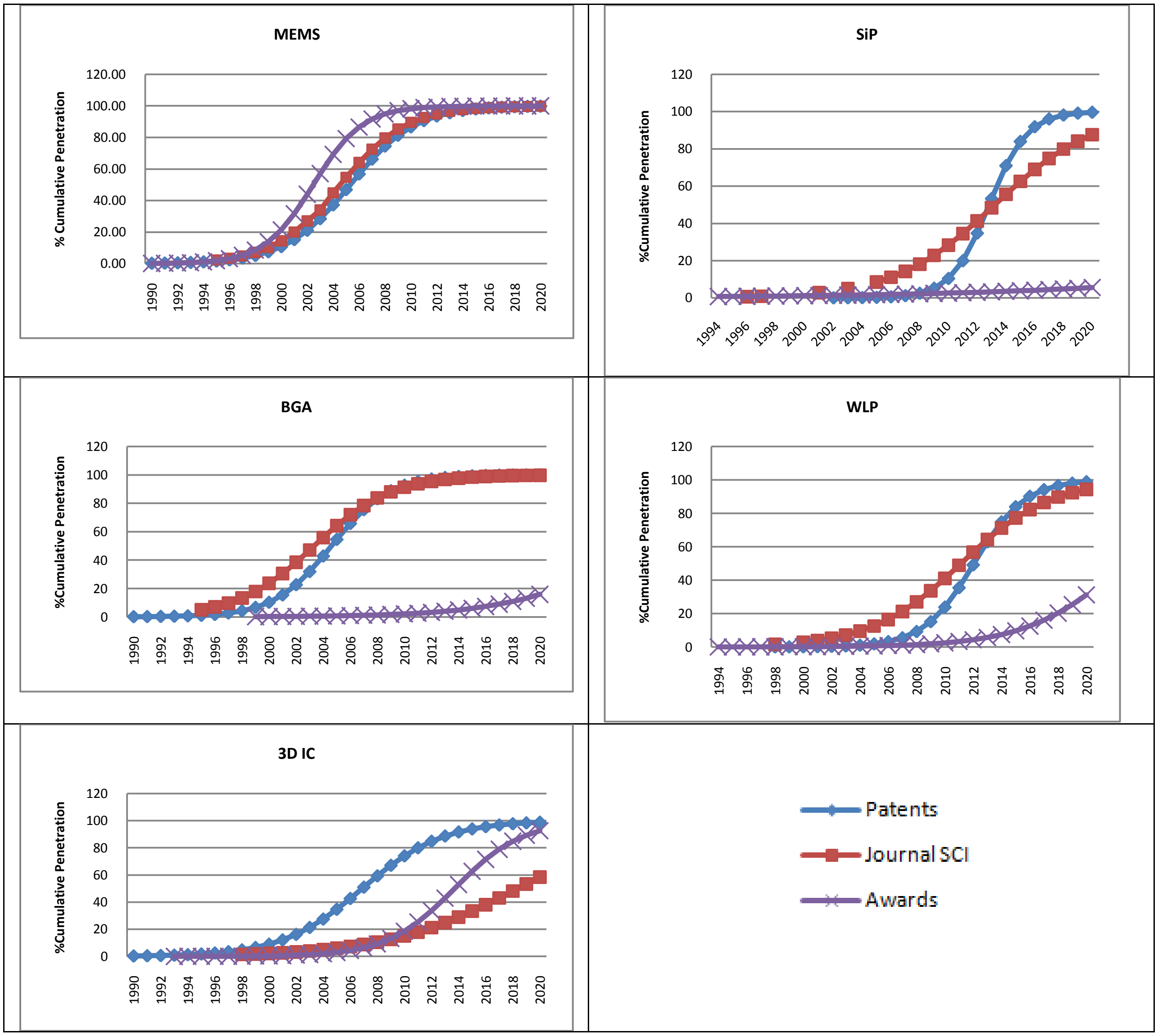


Figure 22-26. Compilation of Growth Curves for Each EP Technology

According to the graphs, MEMS Research Awards lead Journal Citations and Patents closely. MEMS is the only technology that follows an expected trend—where the process of research and patent is preceded by research funding (MEMS received considerable governmental research awards). The narrow gap between Journals and Patents explain not only the intensive research effort made by universities, but also the high interest of the industry to develop and apply this technology.

3DIC Patents lead Journal and the respective Research Awards lag significantly. This behavior can be explained by a high interest of the industry to implement this technology without the need of award or research. Many experts consider this technology as the most promising for the future for EP. Hence, this interest from companies to develop and exploit it commercially is high.

BGA Journals lead Patens by a small margin and the Awards lag significantly. As for most of the technology, journal and patents are developed almost at the same time (2-3 years of lag-difference). WLP Journals lead initially followed by Patents and lead after 50% growth (2013) until maturity level is reached. Research Awards lag significantly for most of the technologies. In the case of SiP, Journal Citations lead initially until 40% growth (2012) and then Patents lead until maturity level. Research Awards lag significantly.

5 Conclusions

Except for MEMS, Fisher-Pry growth curves for Research Awards, Journal Citations, and Patents did not follow the expected sequence. Specially, Research Awards show an unusual behavior since it usually never precedes the process of research and patent. For advanced EP technologies, research awards are not reliable leading indicators.

Journal papers and patents growth curves are close for mature technologies like MEMS and BGA implying strong industry adoption. There is a drastic reduction of patents related with these two technologies.

Strong industry adoption for WLP, SiP and 3DIC was found. Hence government research awards are nominal. SiP, 3DIC and WLP are in earlier stages of their growth curves. High levels of maturity are expected by 2020*.

For advanced technologies that are closely tied to industrial applications such as electronic/semiconductor chip manufacturing it may be better to use more industry oriented data mining such as patents, trade shows, number of companies or startups, etc. Another step for forecasting could include using industry experts and a delphi model for forecasting (and further validation).

6 References

[1] Bolanos, Mario A, Texas Instrument, “Electronics Market and Packaging Technology Trends: Applied Research Opportunities”, 2007.

[2] T.U. Daim, G. Rueda, H. Martin, and P. Gerdsri, “Forecasting emerging technologies : Use of bibliometrics and patent analysis,” *Technological Forecasting and Social ChangeSocial Change*, vol. 73, 2006, pp. 981 - 1012.

[3] G. Deptuch, J. Hoff, F. Khalid, M. Trimpl, A. Shenai, and T. Zimmerman, “3D-IC technology for future detectors,” 2009, pp. 1-32. http://www-ppd.fnal.gov/EEDOffice-W/ASIC_Development/Assets/Presentations/3D_fnal_gd.pdf

[4] J. C. Fisher and R.H. Pry, “A Simple Substitution Model of Technological Change *,” *Technological Forecasting and Social Change*, vol. 88, 1971, pp. 75-88.

[5] X. Gagnard and T. Mourier, “Microelectronic Engineering Through silicon via: From the CMOS imager sensor wafer level package to the 3D integration,” *Microelectronic Engineering*, vol. 87, 2010, pp. 470-476.

[6] P. Leduc, “What is 3D IC integration and what metrology is needed ? Outline Challenges of advanced interconnects 3D integration for Integrated Circuits (3D ICs) Applications for 3D ICs 3D IC technologies: Integration approaches and main players Metrology needs,” *conference on Frontiers of Characterization and Metrology for Nanoelectronics*, 2007, pp. 1-28.

[7] L. Porter and J. Detampel, “Technology Opportunities Analysis,” *Science and Engineering Indicators*, vol. 10010, 1995, pp. 237-255.

[8] L. Porter, A.T. Roper, T.W. Mason, F.A. Rossini and J. Banks, “Forecasting and Management of Technology”, Wiley, New York (1991).

[9] International IOR Rectifier, “Wafer Level Package Technology”, pp. 0-4.

[10] ITRS, International Technology Roadmap for Semiconductors, “Assembly and Packaging”, 2009

[11] ITRS, Assembly and Packaging Technical Working Group. “The Next Step in Assembly and Packaging”, 2008.

[12] iNEMI, International Electronic Manufacturing Initiative, “Packaging Roadmap Overview”, 2005

[13] Freescale Semiconductor, “Manufacturing with the Land Grid,” 2008.

[14] VTI. Technologies, “Business review 2005,” 2005.

[15] VTI. Technologies, “WHAT IS AHEAD IN THE PACKAGING ROADMAP OF MEMS?”, 2006, pp. 1-3.

[16] Ho-Ming Tong, “Microelectronics packaging: present and future,” *Materials Chemistry and Physics*, 1995.

[17] Yole-Developpemente, 3DIC & TSV Report: Cost, Technologies & Markets, 2007

[18] http://www.inems.com/MEMS_course_AREA/01_introduction/MEMS_History.htm

[19] Gagnard, Xavier and Mourier, Thierry., 2010. Through silicon via: From the CMOS imager sensor wafer level package to the 3D integration. *Microelectronic Engineering,* 87, 470–476.

[20] Bogatin, E., 1991. High Performance packaging solutions. *Integrated Circuit Engineering Corporation,* Scottsdale, AZ.

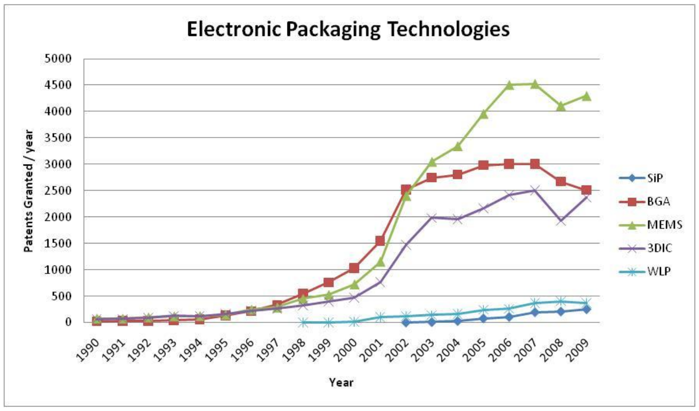
[21] BCC Research. Online. http://www.bccresearch.com/report/SMC066A.html. May 2007.

7 Appendices

Appendix A: Patents: Computations & Growth Curves

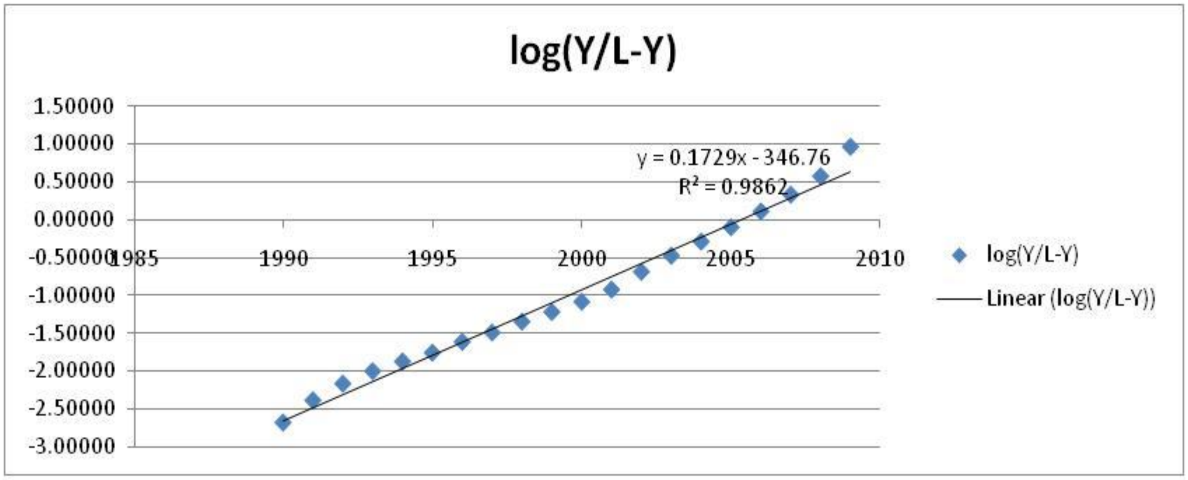
EP Technologies: Patents Granted Per Year

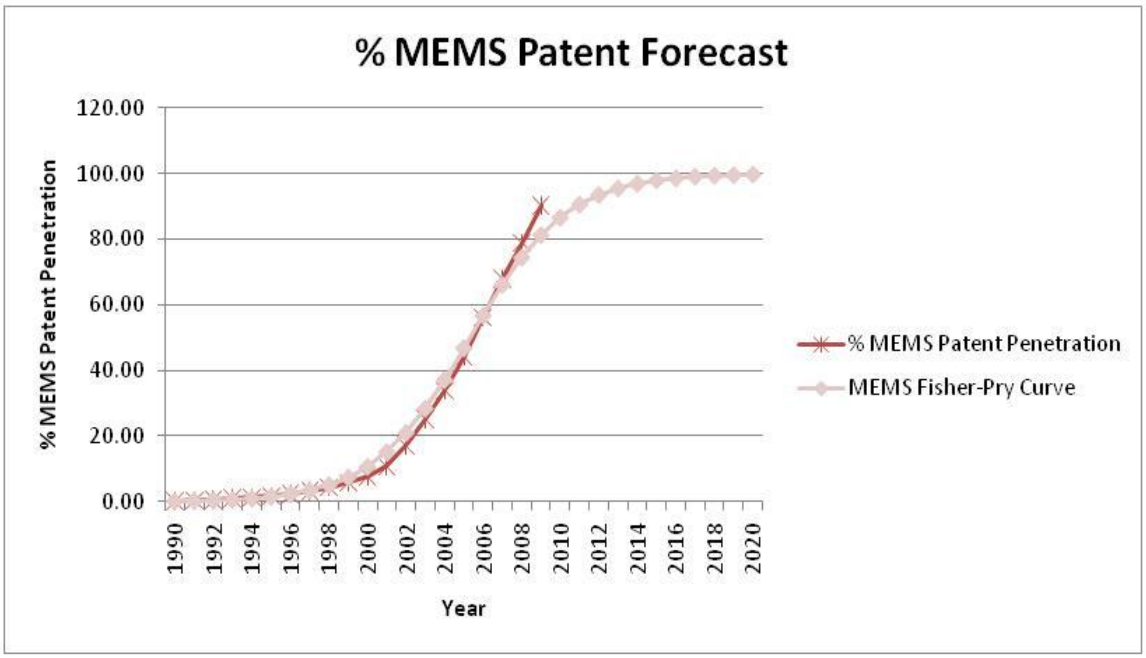
Electronic Packaging Technologies					
Year	Patents Granted Per Year				
	SiP	BGA	MEMS	3DIC	WLP
1990		23	80	66	
1991		32	77	68	
1992		31	102	86	
1993		39	119	127	
1994		62	126	125	
1995		130	153	163	
1996		215	248	225	
1997		334	289	268	
1998		547	451	321	5
1999		761	528	397	3
2000		1028	728	469	16
2001		1550	1157	769	102
2002	4	2517	2402	1477	118
2003	12	2747	3048	1982	142
2004	33	2806	3345	1962	165
2005	82	2981	3955	2170	244
2006	109	3004	4503	2416	259
2007	197	3002	4526	2500	374
2008	210	2672	4110	1927	406
2009	253	2510	4296	2369	371
2010					
2011					
2012					
2013					
2014					
2015					
2016					
2017					
2018					
2019					
2020					
Totals	900	26,991	34,243	19,887	2,205



MEMS: Fisher-Pry Modeling – Computations and Forecasting

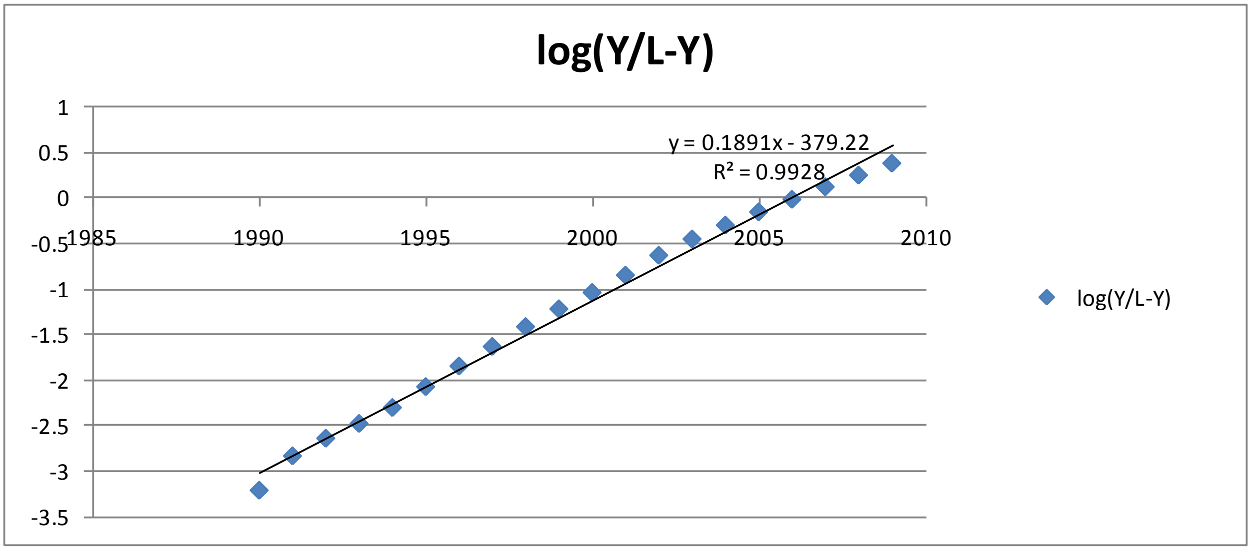
MEMS Cumulutive Max	**37,667**						
L	**100**						
100% Penetration	**38,000**						
Assumption: L=100% is represented by 38,000 patents (MEMS Analogy)							
	Year	**MEMS - Patents**		**Predicted % Pen.**			
		Pat/Yr	**% Pen.**	**Fisher-Pry Curve (FP)**			
	t		**Y**	**{L*10^(A-Bt)}/{1+10^(A-Bt)}**	**log(Y/L-Y)**	**FP-Error**	Intercept=A
	1990	80	0.21	0.22434	-2.67578	-0.01381	-346.7588
	1991	77	0.41	0.33369	-2.38209	0.07947	
	1992	102	0.68	0.49608	-2.16351	0.18550	Slope=-B
	1993	119	0.99	0.73692	-1.99795	0.25781	0.1729
	1994	126	1.33	1.09340	-1.87155	0.23292	
	1995	153	1.73	1.61951	-1.75464	0.10944	**Error Stats**
	1996	248	2.38	2.39263	-1.61267	-0.01106	SUMSQ
	1997	289	3.14	3.52163	-1.48891	-0.37952	182.53
	1998	451	4.33	5.15522	-1.34440	-0.82627	
	1999	528	5.72	7.48777	-1.21715	-1.76935	Mean Sq Err
	2000	728	7.63	10.75604	-1.08275	-3.12183	9.61
	2001	1157	10.68	15.21620	-0.92243	-4.53726	
	2002	2402	17.00	21.08881	-0.68863	-4.08881	
	2003	3048	25.02	28.46691	-0.47663	-3.44586	
	2004	3345	33.82	37.20914	-0.29148	-3.38546	
	2005	3955	44.23	46.87677	-0.10066	-2.64519	
	2006	4503	56.08	56.78466	0.10617	-0.70308	
	2007	4526	67.99	66.17793	0.32720	1.81417	
	2008	4110	78.81	74.44821	0.57040	4.35968	
	2009	4296	90.11	81.26861	0.95973	8.84454	
	2010			86.59625			
	2011			90.58415			
	2012			93.47497			
	2013			95.52213			
	2014			96.94799			
	2015			97.92966			
	2016			98.60014			
	2017			99.05558			
	2018			99.36380			
	2019			99.57186			
	2020			99.71208			
	Cumulative	34,243					

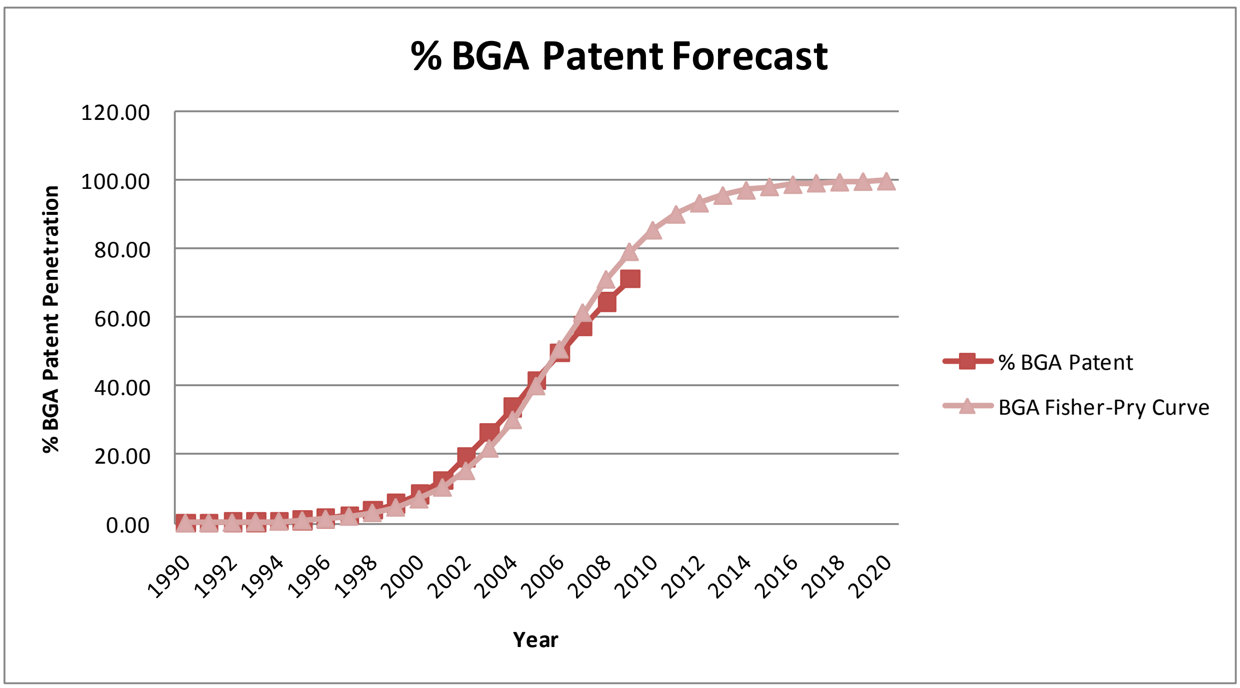

log(Y/L-Y)
1.50000
1.00000
0.50000
0.00000
-0.50000
-1.00000
-1.50000
-2.00000
-2.50000
-3.00000
1985
1990
1995
2000
2005
2010
y = 0.1729x - 346.76
R² = 0.9862
log(Y/L-Y)
Linear (log(Y/L-Y))


% MEMS Patent Forecast
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% MEMS Patent Penetration
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year
% MEMS Patent Penetration
MEMS Fisher-Pry Curve

BGA: Fisher-Pry Modeling – Computations and Forecasting

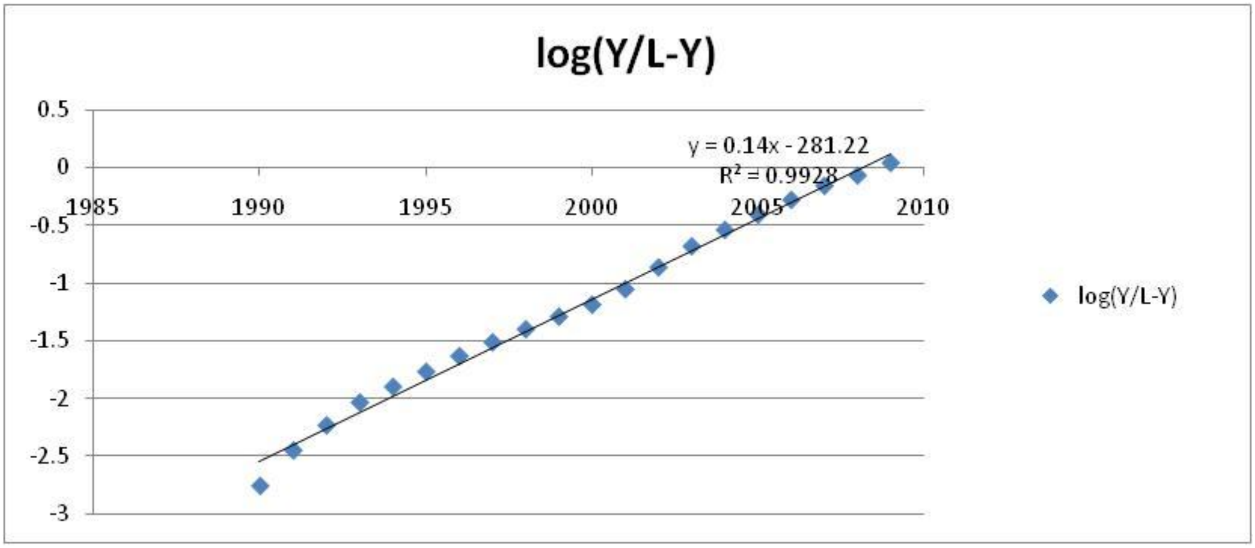
L	**100**						
100% Penetration	**38,000**						
Assumption: L=100% is represented by 38,000 patents (MEMS Analogy)							
	Year	**BGA Patents**		**Predicted %Pen.**			
		Pat./Yr	**%Pen.**	**Fisher-Pry Curve (FP)**			
	t		**Y**	**{L*10^(A-Bt)}/{1+10^(A-Bt)}**	**log(Y/L-Y)**	**FP-Error**	Intercept=A
	1990	23	0.06	0.097416131	-3.2177928	-0.0368898	-379.2206
	1991	32	0.14	0.150470111	-2.8387919	-0.0057333	
	1992	31	0.23	0.232350716	-2.6443012	-0.0060349	Slope=-B
	1993	39	0.33	0.358627867	-2.4814426	-0.0296805	0.1891
	1994	62	0.49	0.553153176	-2.3057995	-0.0610479	
	1995	130	0.83	0.852289507	-2.0750862	-0.018079	**Error Stats**
	1996	215	1.40	1.311061274	-1.8477489	0.0889387	SUMSQ
	1997	334	2.28	2.011770703	-1.6322538	0.2671767	187.89
	1998	547	3.72	3.075311021	-1.4131846	0.64311	
	1999	761	5.72	4.67428059	-1.2169388	1.046772	Mean Sq Err
	2000	1028	8.43	7.044193382	-1.036133	1.3821224	9.89
	2001	1550	12.51	10.48353455	-0.8448891	2.0217286	
	2002	2517	19.13	15.32528643	-0.626102	3.8036609	
	2003	2747	26.36	21.85717504	-0.4462155	4.5007197	
	2004	2806	33.74	30.18075646	-0.2930655	3.5613488	
	2005	2981	41.59	40.04954155	-0.1475547	1.5373006	
	2006	3004	49.49	50.79749599	-0.0088233	-1.3053907	
	2007	3002	57.39	61.47223342	0.1293621	-4.0801282	
	2008	2672	64.42	71.14650844	0.2578846	-6.7228242	
	2009	2510	71.03	79.21302391	0.3894711	-8.1840765	
	2010			85.48449883			
	2011			90.10032445			
	2012			93.36232184			
	2013			95.60193957			
	2014			97.10928558			
	2015			98.11023122			
	2016			98.76898064			
	2017			99.19997087			
	2018			99.48086091			
	2019			99.66346509			
	2020			99.78198007			
	Cumulative	26,991					


log(Y/L-Y)
y = 0.1891x - 379.22
R² = 0.9928
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
1985
1990
1995
2000
2005
2010
log(Y/L-Y)

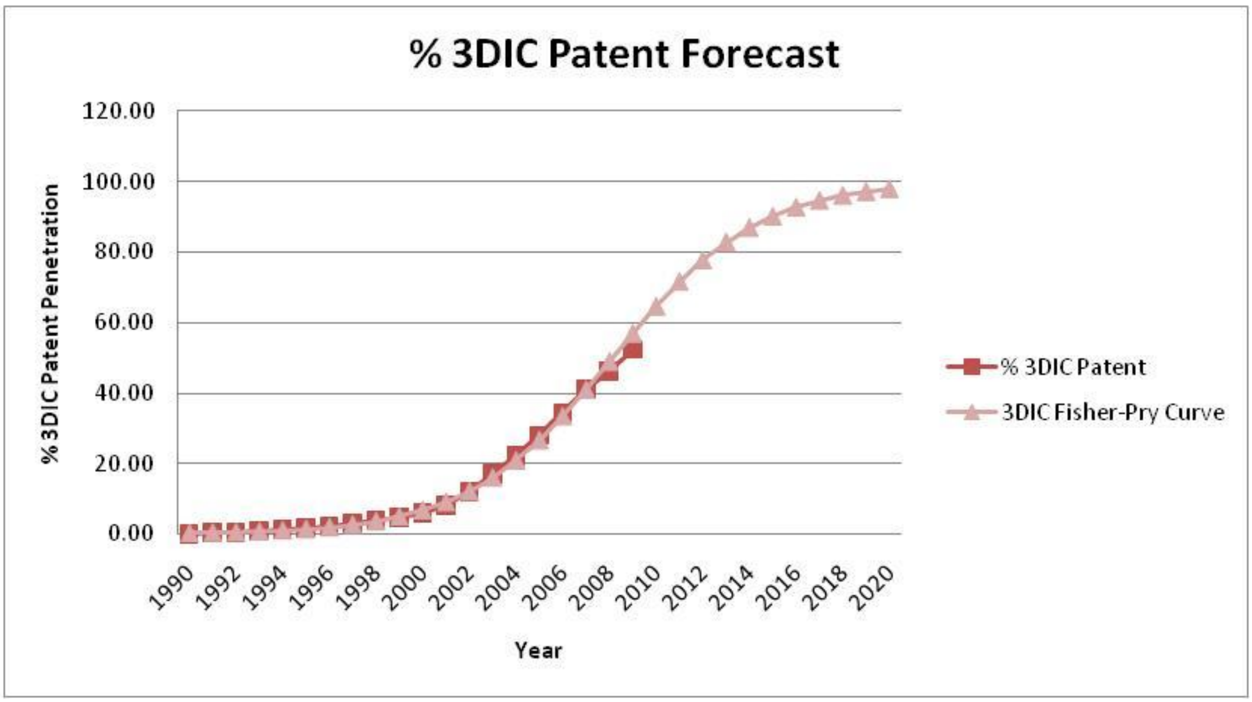

% BGA Patent Forecast
% BGA Patent Penetration
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year
% BGA Patent
BGA Fisher-Pry Curve

3DIC: Fisher-Pry Modeling – Computations and Forecasting

L	**100**						
100% Penetration	**38,000**						
Assumption: L=100% is represented by 38,000 patents (MEMS Analogy)							
	Year	**3DIC Patents**		**Predicted %Pen.**			
		Pat./Yr	**%Pen.**	**Fisher-Pry Curve (FP)**			
	t		**Y**	**{L*10^(A-Bt)}/{1+10^(A-Bt)}**	**log(Y/L-Y)**	**FP-Error**	Intercept=A
	1990	66	0.17	0.28745258	-2.7594847	-0.1137684	-281.2204
	1991	68	0.35	0.39639826	-2.4511446	-0.0437667	
	1992	86	0.58	0.546408521	-2.2348393	0.03253885	Slope=-B
	1993	127	0.91	0.752758612	-2.0354701	0.16039928	0.1400
	1994	125	1.24	1.036224463	-1.9004134	0.2058808	
	1995	163	1.67	1.424902333	-1.7696913	0.2461503	**Error Stats**
	1996	225	2.26	1.956487334	-1.6353434	0.30667056	SUMSQ
	1997	268	2.97	2.680995784	-1.5143876	0.28742527	37.31
	1998	321	3.81	3.663771751	-1.4018309	0.14938614	
	1999	397	4.86	4.988339197	-1.2919247	-0.1304445	Mean Sq Err
	2000	469	6.09	6.758185092	-1.1879347	-0.6660798	1.96
	2001	769	8.12	9.095851536	-1.0539101	-0.9800621	
	2002	1477	12.00	12.1368682	-0.8651932	-0.1342366	
	2003	1982	17.22	16.01546569	-0.6819404	1.20295536	
	2004	1962	22.38	20.83956774	-0.5400741	1.54201121	
	2005	2170	28.09	26.65557044	-0.4081923	1.43653482	
	2006	2416	34.45	33.40967632	-0.2793835	1.04032368	
	2007	2500	41.03	40.92035072	-0.1575485	0.10859665	
	2008	1927	46.10	48.88007958	-0.0678878	-2.7800796	
	2009	2369	52.33	56.89700915	0.04057889	-4.5627986	
	2010			64.56803482			
	2011			71.55633926			
	2012			77.64356518			
	2013			82.74225211			
	2014			86.87468515			
	2015			90.13556173			
	2016			92.65479701			
	2017			94.56941874			
	2018			96.00648014			
	2019			97.07502267			
	2020			97.86401722			
	Cumulative	19,887					



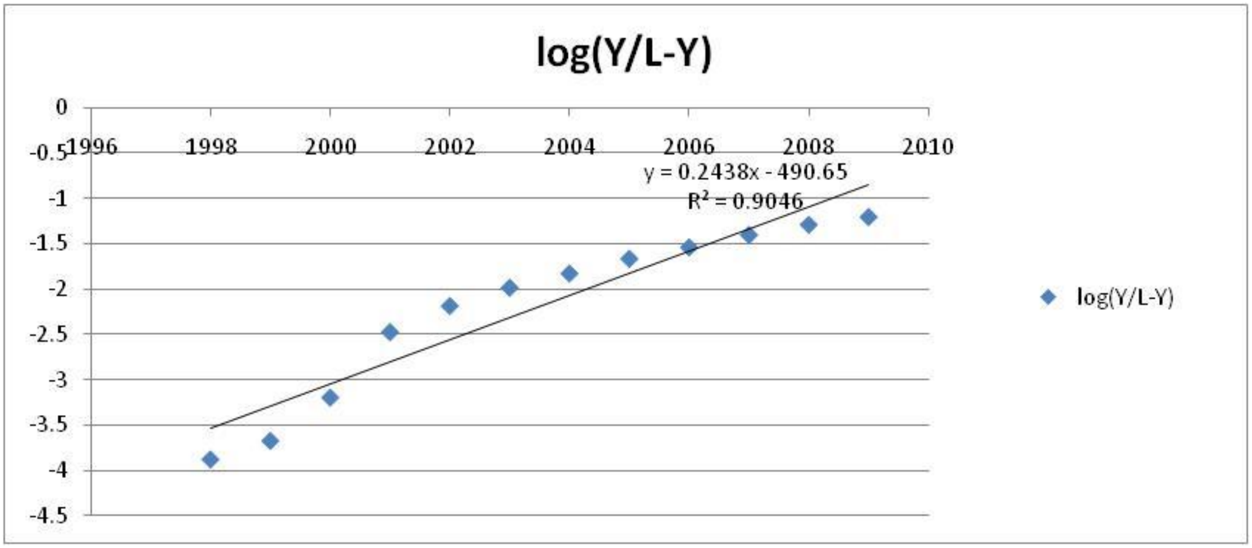
log(Y/L-Y)
y = 0.14x - 281.22
R^2 = 0.9928
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
1985
1990
1995
2000
2005
2010
log(Y/L-Y)



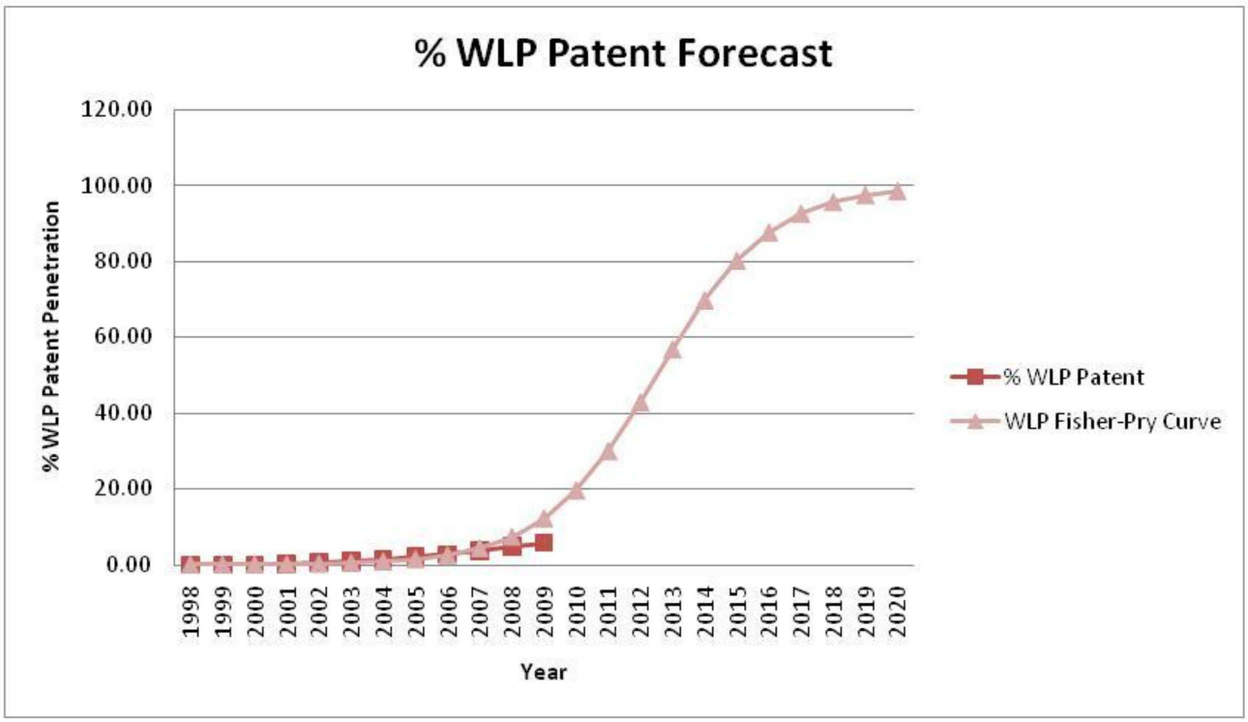
% 3DIC Patent Forecast
% 3DIC Patent Penetration
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year
% 3DIC Patent
3DIC Fisher-Pry Curve

WLP: Fisher-Pry Modeling – Computations and Forecasting

L	**100**						
100% Penetration	**38,000**						
Assumption: L=100% is represented by 38,000 patents (MEMS Analogy)							
	Year	**WLP Patents**		**Predicted %Pen.**			
		Pat./Yr	**%Pen.**	**Fisher-Pry Curve (FP)**			
	t		**Y**	**{L*10^(A-Bt)}/{1+10^(A-Bt)}**	**log(Y/L-Y)**	**FP-Error**	Intercept=A
	1990						-490.6455
	1991						
	1992						Slope=-B
	1993						0.2438
	1994						
	1995						**Error Stats**
	1996						SUMSQ
	1997						48.98
	1998	5	0.01	0.028917377	-3.8807564	-0.0157595	
	1999	3	0.02	0.05068291	-3.6766022	-0.0296303	Mean Sq Err
	2000	16	0.06	0.088816369	-3.199298	-0.0256585	4.45
	2001	102	0.33	0.155596505	-2.4779706	0.17598244	
	2002	118	0.64	0.272451032	-2.1895962	0.36965423	
	2003	142	1.02	0.476645524	-1.9887622	0.53914395	
	2004	165	1.45	0.832600446	-1.8322886	0.61739955	
	2005	244	2.09	1.450505291	-1.6702342	0.64159997	
	2006	259	2.77	2.515349602	-1.5447268	0.25833461	
	2007	374	3.76	4.327589265	-1.4084205	-0.5696945	
	2008	406	4.83	7.347093488	-1.2949011	-2.5207777	
	2009	371	5.80	12.20464764	-1.2104138	-6.4020161	
	2010			19.59459038			
	2011			29.93355048			
	2012			42.82241357			
	2013			56.76484993			
	2014			69.71213508			
	2015			80.13878443			
	2016			87.61379244			
	2017			92.53746675			
	2018			95.60216241			
	2019			97.44303334			
	2020			98.52522922			
	Cumulative	2,205					



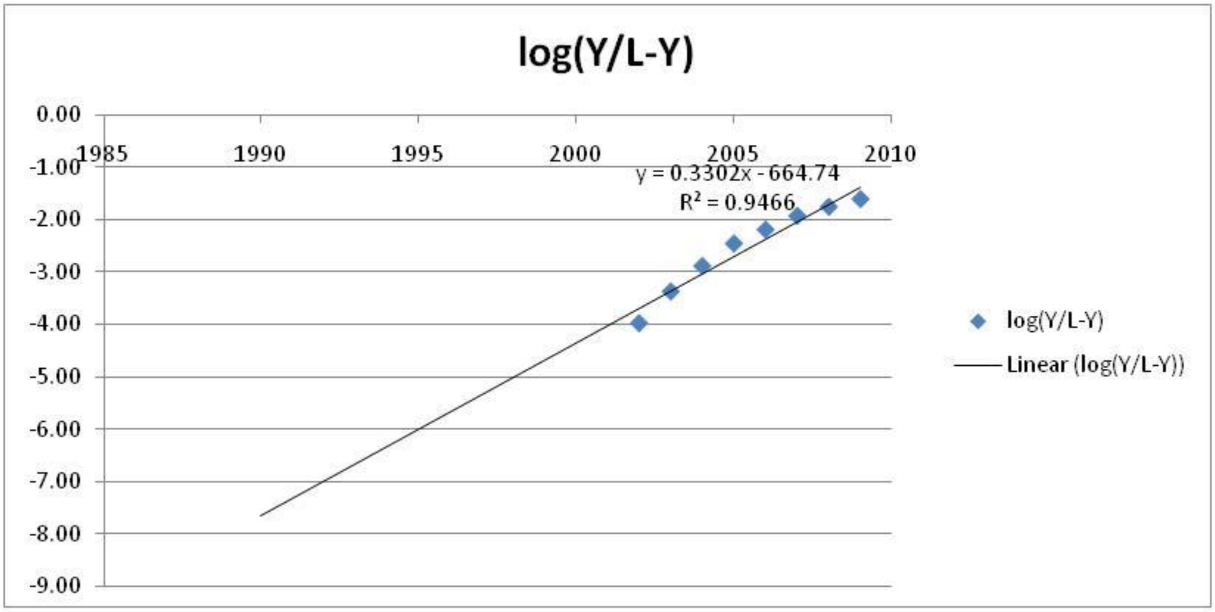
log(Y/L-Y)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
1996
1998
2000
2002
2004
2006
2008
2010
y = 0.2438x - 490.65
R² = 0.9046
log(Y/L-Y)

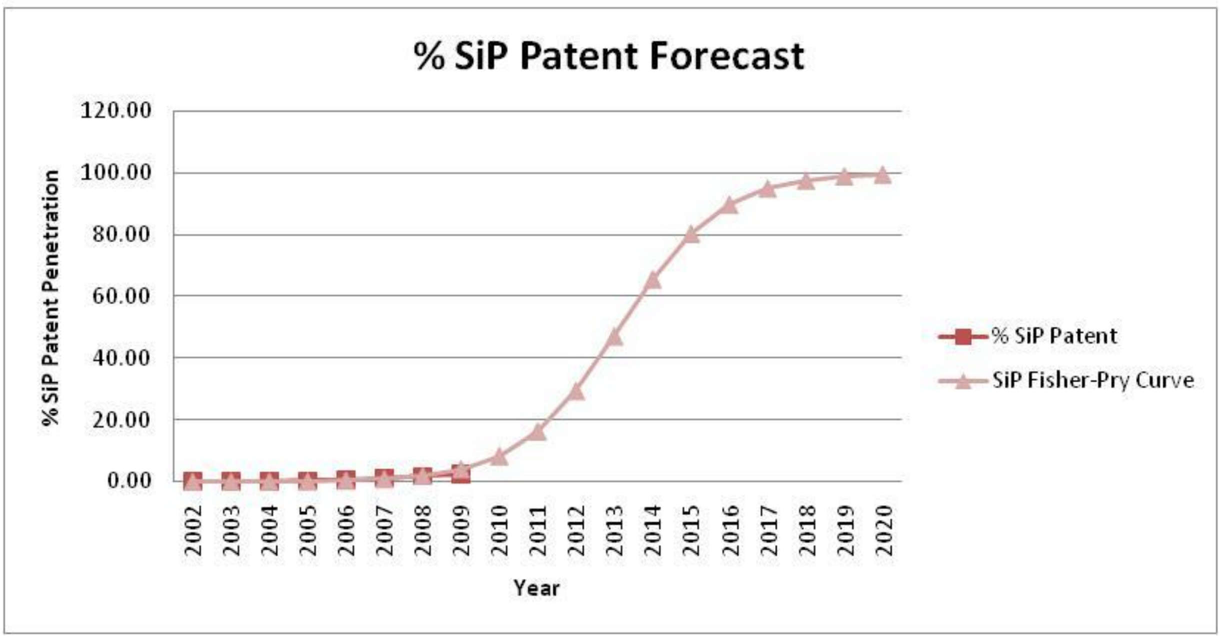


% WLP Patent Forecast
% WLP Patent Penetration
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year
% WLP Patent
WLP Fisher-Pry Curve

SiP: Fisher-Pry Modeling – Computations and Forecasting

L	**100**						
100% Penetration	**38,000**						
Assumption: L=100% is represented by 38,000 patents (MEMS Analogy)							
	Year	**SiP Patents**		**Predicted % Pen.**			
		Pat/Yr	**% Pen.**	**Fisher-Pry Curve (FP)**			
	t		**Y**	**{L*10^(A-Bt)}/{1+10^(A-Bt)}**	**log(Y/L-Y)**	**FP-Error**	Intercept=A
	1990						-664.74
	1991						
	1992						Slope=-B
	1993						0.33
	1994						
	1995						**Error Stats**
	1996						SUMSQ
	1997						3.12
	1998						
	1999						Mean Sq Err
	2000						0.45
	2001						
	2002	4	0.01	0.02	-3.98	-0.01	
	2003	12	0.04	0.04	-3.38	0.00	
	2004	33	0.13	0.10	-2.89	0.03	
	2005	82	0.34	0.20	-2.46	0.14	
	2006	109	0.63	0.43	-2.20	0.20	
	2007	197	1.15	0.92	-1.93	0.23	
	2008	210	1.70	1.95	-1.76	-0.25	
	2009	253	2.37	4.09	-1.62	-1.72	
	2010			8.35			
	2011			16.31			
	2012			29.42			
	2013			47.13			
	2014			65.60			
	2015			80.31			
	2016			89.72			
	2017			94.91			
	2018			97.56			
	2019			98.84			
	2020			99.46			
	Cumulative	900					


log(Y/L-Y)
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-8.00
-9.00
1985
1990
1995
2000
2005
2010
y = 0.3302x - 664.74
R^2 = 0.9466
log(Y/L-Y)
Linear (log(Y/L-Y))


% SiP Patent Forecast
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% SiP Patent Penetration
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year
% SiP Patent
SiP Fisher-Pry Curve